PRC-CPD Accredited Provider: PTR-2025-749
National Book Development Board Registration as Book Publisher (Print & Digital): 6312
Global Journal of Agriculture, Forestry, and Food Systems (GLOAFFS)
P - ISSN: 3116-4412; E - ISSN: 3116-4420

Enhanced corn yield through application of Black Soldier Fly (*Hermetia illucens*) Frass and Biostimulants

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Received: 01 March 2026 **Revised**: 04 April 2026 **Accepted**: 07 April 2026

Available Online: 10 April 2026

Volume 1 (2026), Issue 2, P-ISSN – 3116-4412; E-ISSN - 3116-4420

https://doi.org/10.63498/gloaffs2

Abstract
Aim: This study aimed to determine the effects of Black Soldier Fly (*Hermetia illucens*) frass combined with biostimulants and foliar fertilizer on soil properties, growth, yield performance, and economic returns of glutinous corn. Specifically, it examined changes in soil nutrient availability and organic matter content and evaluated the combined influence of Black Soldier Fly frass and biostimulants on crop productivity.
Methodology: A field experiment was conducted using a Randomized Complete Block Design (RCBD) with three replications and seven treatments, including a control treatment with the recommended rate of inorganic fertilizer (140–40–60 kg NPK ha^{-1}). Black Soldier Fly frass was applied alone or in combination with different biostimulants, including humic acid, carrageenan, AMO foliar fertilizer, N-biofertilizer, and *Bacillus subtilis*. Growth parameters, yield components, and economic returns were evaluated. Data were analyzed using the Statistical Tool for Agricultural Research (STAR) and treatment means were compared using the Honestly Significant Difference (HSD) test.
Results: The application of 3 t ha^{-1} Black Soldier Fly frass improved soil organic matter and nutrient availability, indicating enhanced soil fertility. No significant differences were observed in plant height, leaf area, ear length, ear diameter, and kernel row number among treatments. However, treatments combining Black Soldier Fly frass with biostimulants produced competitive yields ranging from 8.02 to 8.42 t ha^{-1}. The highest economic return was recorded in the treatment combining Black Soldier Fly frass with AMO foliar fertilizer, which achieved a return on investment of 82.73%.
Conclusion: The results indicate that the application of Black Soldier Fly frass supplemented with biostimulants, particularly AMO foliar fertilizer, can improve soil organic matter, sustain corn productivity, and serve as a sustainable alternative to conventional inorganic fertilizers in corn production systems.
Keywords: *biostimulants, black soldier fly frass, corn production, organic fertilizer, sustainable agriculture*

INTRODUCTION

The intensification of ecological imbalances, coupled with a growing global population, presents a significant challenge to agricultural sustainability. As the need for annual food resources to meet the demands of the growing global population in a sustainable way (Muhie, 2022), it becomes imperative to adopt sustainable approaches that enhance agricultural productivity while preserving environmental integrity. Likewise, population growth and global warming threaten food security, thereby reducing the amount of arable land available for production. As demand for food outpaces land expansion, solutions such as genetic modification, agrochemicals, and high fertilizer rates are being explored (Guelfi et al., 2022).

A previous report by the Philippine Statistics Authority (PSA) shows that the estimate of corn production in the country for standing crops as of November 2023 had a decrease of 1.1 percent from its record of 1.96 million metric tons as of October 2023 (Buli-e, 2024). Cagayan Valley Region 02 still retained its title as "Top Corn Producer in the Philippines," registering a 1.9 percent from the previous year, with an additional 3.22 metric tons per hectare during October to December 2024 (PSA, 2024).

In the aspect of agriculture, increasing the revenue and productivity of farmers have always been the primary (Mayo and Villarta, 2023). As such, to remain a key player in the nation's corn industry, most farmers use high rates of inorganic fertilizer to achieve higher yields. However, this method, combined with poor land management, often degrades soil quality and reduces agricultural productivity. To address these problems, one possible alternative explored with growing interest

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is to increase the soil microbiome known to play a critical role in soil habitats by influencing soil fertility, crop yields, and biotic and abiotic stress tolerance (Iqbal et al., 2025).

Nowadays, many alternative nutrient sources improve soil quality and promote crop growth and yield, such as organic fertilizers and biostimulants for their multiple advantages, such the protection of natural resources, support of crops to cope with stress from pests and environmental factors, and the considerable reduction of production cost-all without harming crop yields (Van et al., 2022). According to previous studies, these include seaweed extract, humic acid (HA), *Bacillus subtilis* applied as a foliar spray or by drenching, and black soldier fly frass. Black soldier fly frass contains macro- and micronutrients that enhance nutrient cycling. In contrast, other soil amendments enhance soil properties, significantly promote root development, and improve overall crop growth and yield, as cited by Aslam and Ahmad (2020). In as much as these nutrient sources offer a promising opportunity to enhance crop production, they are expected to significantly affect crop yields, leading to food security and uplifting farmer livelihoods.

More importantly, this approach not only boosts crop productivity but also promotes long-term soil fertility and environmental sustainability, aligning with the Sustainable Development Goals (SDGs). It supports SDG 13 (Climate Action) by enabling soil to sequester carbon, which helps mitigate emissions, SDG 15 (Life on Land), maintaining a healthy ecosystem for plant and animal life, SDG 6 (Clean Water and Sanitation) providing healthy soil, filters water and most importantly, SDG 2 by improving soil health and food production and minimizing environmental impact. However, it remains unclear whether the co-application of the three soil amendments has a synergistic effect on alleviating soil quality deterioration and creating favorable growing conditions for glutinous corn, highlighting the need for this study.

Review of Related Literature and Studies

Larval Black Soldier Fly (*Hermetia illucens*) Frass (BSFF) as Organic Fertilizer

One of the most promising insect species for bioconversion is *Hermetia illucens* (Diptera: Stratiomyidae), also known as the Black Soldier Fly (BSF), which can be used as an organic fertilizer. In addition to macro- and micronutrients and microorganisms, black soldier fly frass (BSFF) can also affect soil microorganisms. Research has shown that larval BSFF fertilizers can be used as soil amendments to boost yields of maize (Gärttling et al., 2020). According to Setti et al. (2019), plants grew more when black soldier fly larvae (BSFL) frass was applied appropriately (10%–20%), but when it was used in excess, the plants' growth was stunted.

Previous researchers suggest that BSFF can be converted into compost (Song et al., 2021). If frass were to be used as fertilizer or compost, it could recycle nitrogen and phosphorus from the existing food chain and reduce demand for synthetic (i.e., chemical) fertilizers (Schmitt and de Vries, 2020). The findings of Anyega et al. (2021) provide clear evidence that soil fertilization with composted BSFF can improve plant growth across several species (French beans, tomatoes, and kale). They further claimed that the chemical composition of organic fertilizers affects the balance between plant nutrient uptake and soil nutrient retention and is therefore essential for plant growth. In the case of BSFF, reports by Debode et al. (2016) and Quilliam et al. (2020) indicate that its high chitin content can confer beneficial effects on plant growth and yield.

BSFF contains 41.2 % N, 32.4 % P, and 77.1 % K of NPK content, and is recognized for maintaining the availability of N in the soil for crop growth, such as corn. The use of insect frass fertilizers, such as from BSFL, also offers additional benefits for crop production, including drought and salt tolerance, improved soil health, and disease suppression. Mahmood et al. (2017) demonstrated that the combined use of chicken manure and inorganic fertilizers at a rate of 150–85-50 kg ha^{-1} of NPK significantly increased corn grain yield compared to the individual use of organic or inorganic fertilizers. The application of BSFF fertilizers at 7.5 t ha^{-1} mixed with N at 30, 60, and 100 kg ha^{-1} led to an increase in grain yields of 71–96% during the short rainy season and 49–101 % during the long rainy season compared to the control (only BSF). This indicates that fertilizer application may be influenced by the growing season.

Effect of Humic Acid, Seaweed Extracts, Carrageenan, *Bacillus subtilis*, and AMO as Biostimulants

Biostimulants enhance plant growth and crop yields by affecting the plant's natural processes (Jat et al., 2025). They promote the development of roots and shoots, increase organic carbon levels, improve nutrient exchange and nitrogen use, stimulate beneficial soil microbes, boost the plant's antioxidant defenses, and help plants retain water more effectively (Arslan et al., 2021).

Humic acid-based fertilizers increase crop yield, stimulate plant enzymes/hormones, and improve soil fertility in an ecologically and environmentally sustainable way. According to Mauromicale et al. (2011), humic acid plays a well-known role in controlling soil-borne diseases, improving soil health and plant nutrient uptake, increasing mineral availability, and enhancing fruit quality.

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Han et al. (2020) also found that the combined effect of biochar and humic acid was more pronounced in reducing soil pH and conductivity and in increasing soil nutrient levels. The nutrient content of HA is relatively high, and it can promote the activity of soil microorganisms and increase the number of beneficial organisms. Still, its microbial species and abundance are limited. Humic acid is known to stimulate the formation of soil aggregates, inhibit soil evaporation, and accelerate the leaching and irrigation of soil surface salts and alkali.

In dry and semi-dry areas, using seaweed extract, in combination with humic and fulvic acids, chitosan, and plant growth-promoting rhizobacteria (PGPR) was proven to improve crop yields by 8.5% during moderate water stress and by 11.4% under severe water stress (Mullany, 2024).

Seaweed extracts (SEs) are another kind of biostimulant extracted from seaweed (especially brown algae) that can promote crop growth, improve crop quality, and enhance crop stress resistance. SE mainly contains natural hormones, such as auxin, cytokinin, gibberellin, abscisic acid, and other active substances, such as seaweed polysaccharides, sugar alcohols, betaine, and phenolic compounds (Battacharyya et al., 2015), which have been used in agriculture for many years (Mukherjee and Patel, 2020).

Tarakhovskaya (2007) claimed that seaweeds are suitable for use as biofertilizers, not only because they have biological effects, but also because of their biocompatibility, as they share common biological compounds with plants. This major advantage has put seaweeds at the top of the plant biostimulant list and facilitated many plant treatment processes, mainly for serving and promoting organic and sustainable agriculture.

On a similar note, Layek et al. (2015) reported that seaweed extracts, derived from seaweeds, hold significance as sources of biostimulants. They have been harnessed to effectively demonstrate their ability to promote sustainable growth and increased yields across different crops, with a notable focus on corn.

Algal extracts are often referred to as biostimulants rather than fertilizers because they could stimulate plant growth and defense responses even when applied in small quantities. This agrees with Yaakob et al. (2021), who found that nitrogen is one of the limiting macronutrients for seaweed growth and development and is involved in the synthesis of carbohydrates, proteins, and lipids.

Carrageenans, previously known as a biostimulator for plant defense against insect pest and pathogens (Sangha et al., 2011; Sangha et al., 2015; Mousavi et al., 2017) have also been found to promote the growth of banana plants under normal conditions by improving essential mineral uptake and cellular metabolism (Thye et al., 2022). Foliar application of oligomers of carrageenan enhanced plant growth and photosynthetic under arsenic (As)-stress by reducing the oxidative damage by upregulated antioxidant system in sweet wormwood (*Artemisia annua*) (Naeem et al., 2020). On the other hand, Méndez et al. (2023) reported that oligo κ-carrageenan was also found to effectively increase carbon, nitrogen, sulfur assimilation, photosynthesis, and growth in thale cress (*Arabidopsis thaliana*), while study by Dawood et al. (2025) demonstrated the ability of carrageenan to promote the growth performance of D-, Cr-, and DCr-stressed wheat.

Meanwhile, application of plant growth-promoting bacteria (PGPB) has long been introduced into modern agriculture as a new practice to sustainably enhance crop growth and productivity. Species of bacteria such as *Bacillus spp*., *Pseudomonas spp*., and *Acinetobacter spp*., among others, have been used as plant growth promoters. These bacteria can be mostly found in the rhizosphere as their natural habitat, but also in the aquatic environment and even inside plants as endophytic microorganisms. A recent study on corn found that foliar and/or ground applications of PGPB promoted certain physiological and molecular processes, leading to improved plant growth and productivity, as well as enhanced quality and nutritional characteristics of harvested grains. The results showed that soil application of Priestia megaterium and a mix of Azotobacter chroococcum with *Bacillus subtilis* yielded the highest values. In contrast, *Bacillus subtilis* showed better results for quality characteristics.

Haas and Défago (2005) reported that biostimulants based on *Bacillus spp*. are relatively more active than those based on many other plant growth-promoting bacteria (PGPB) because *Bacillus spp*. are more effective in producing metabolites and form resilient spores, which in turn improve the cell viability in commercially formulated products and promise to be suitable for agricultural applications.

More recently, ammonia mono-oxygenases (AMO), a biostimulant applied as a foliar spray, has gained attention due to its potential in significantly improving crop production. Study by Pasuquin (2024) demonstrated that among all the foliar fertilizers tested, AMO produced the plants with the highest fresh and dry bulb weight, highlighting its ability to maximize profits in garlic cultivation. Notable variation in plant height was also observed on findings presented by Fernandez (2024) in which onions applied with foliar fertilizer alone (3 liters AMO), and those applied in combination of 10 bags of vermicompost per hectare + 3 liters per hectare of AMO foliar fertilizer resulted in the tallest plants. More recently, Arcega II and Rocha (2026) proved that AMO foliar fertilizer added with half of the recommended inorganic fertilizer rate was considerable effective as a biostimulant-based nutrient management strategy to improve eggplant production.

Despite extensive research on individual biostimulant components, limited studies have examined their combined application with different organic fertilizer rates under field conditions, particularly for maize production. Overall, existing

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literature supports the individual and combined potential of various biostimulants to improve crop growth and yield; however, there remains a gap regarding their integrated use with organic fertilizers and their specific physiological effects on glutinous corn which justifies the conduct of the present study.

Theoretical Framework

This study was anchored primarily on Agroecological Nutrient Management Framework.

Agroecological Nutrient Management Theory emphasizes farming systems that work in harmony with natural processes. It mainly supports the use of organic fertilizers and biological inputs to enhance biodiversity, improve nutrient cycling and reduce dependence on synthetic chemicals. In this study, agroecology provides the foundation for using organic fertilizer combined with biostimulants as an environmentally sustainable approach to cultivating glutinous corn.

Conceptual Framework

The conceptual framework illustrates the relationship between **agroecological nutrient management framework** and **glutinous corn growth and yield performance** under field conditions.

The **independent variables** consisted of:

- BSFF organic fertilizer
- Presence/absence of biostimulant

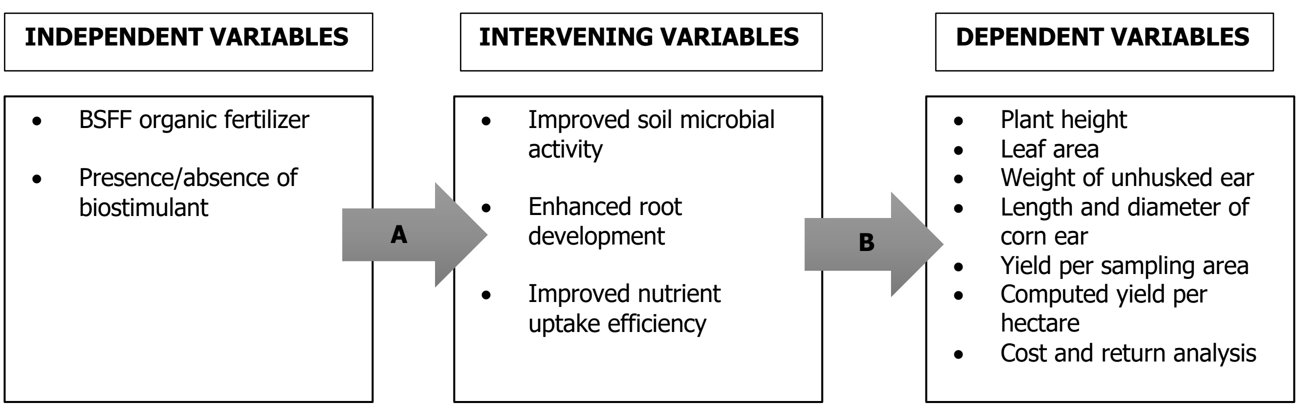
The **intervening variables** included:

- Improved soil microbial activity
- Enhanced root development
- Improved nutrient uptake efficiency

The **dependent variables** were the growth and yield attributes of glutinous corn, namely:

- Plant height
- Leaf area
- Weight of unhusked ear
- Length and diameter of corn ear
- Yield per sampling area
- Computed yield per hectare
- Cost and return analysis

The conceptual framework illustrates the system where organic waste is converted through insect bioconversion into frass-based fertilizer and is enriched with biostimulants to enhance soil health and nutrient availability, which in turn improves the growth and yield of glutinous corn.



NOTE: A – Agroecological nutrient management strategies
B – Physiological and biochemical mechanism

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Statement of the Problem

Corn (*Zea mays* L.) production is strongly influenced by soil fertility, agronomic practices, and climatic conditions. In many corn-producing regions, farmers rely heavily on nitrogen-based inorganic fertilizers to achieve higher yields. However, the continuous use of synthetic fertilizers often results in increasing production costs, soil degradation, and declining soil fertility. These challenges highlight the need for sustainable nutrient management strategies that can improve crop productivity while maintaining soil health and environmental sustainability.

Organic fertilizers and biostimulants have emerged as promising alternatives to conventional fertilizers. Seaweed extracts, humic acid, and beneficial microorganisms have been widely recognized for their ability to enhance plant growth, improve nutrient uptake, and increase stress tolerance. Similarly, Black Soldier Fly (BSF) frass has gained attention as an organic fertilizer due to its rich nutrient composition, microbial activity, and high chitin content, which can stimulate plant growth and improve soil fertility.

Despite the potential benefits of organic fertilizers and biostimulants, limited studies have examined the combined application of Black Soldier Fly frass and biostimulants in corn production systems. In particular, their effects on soil properties, crop productivity, and economic returns remain insufficiently explored. Therefore, this study was conducted to determine the effects of Black Soldier Fly frass combined with biostimulants and foliar fertilizer on soil fertility, growth performance, yield, and economic returns of glutinous corn.

Research Objectives

General Objective

To determine the effects of Black Soldier Fly frass combined with biostimulants and foliar fertilizer on the soil properties, growth performance, yield, and economic returns of glutinous corn.

Specific Objectives

1. To determine the changes in soil properties, including nutrient availability and organic matter content, as influenced by the application of Black Soldier Fly frass and biostimulants.
2. To evaluate the combined effects of Black Soldier Fly frass and biostimulants on the yield performance of glutinous corn.
3. To identify the most effective combination of Black Soldier Fly frass, biostimulants, and foliar fertilizer in enhancing glutinous corn yield and return on investment (ROI).

Research Questions

1. What changes occur in soil properties, including nutrient availability and organic matter content, following the application of Black Soldier Fly frass combined with biostimulants?
2. How does the combined application of Black Soldier Fly frass and biostimulants affect the yield performance of glutinous corn?
3. Which combination of Black Soldier Fly frass, biostimulants, and foliar fertilizer produces the highest yield and return on investment in glutinous corn production?

Hypotheses

Since the study uses **experimental design and statistical testing**, the following hypotheses are appropriate.

Null Hypothesis (H_0)

1. There is no significant difference in soil properties among treatments receiving Black Soldier Fly frass combined with different biostimulants.
2. The combined application of Black Soldier Fly frass and biostimulants does not significantly affect the yield performance of glutinous corn.
3. There is no significant difference among treatments in terms of yield and return on investment.

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METHODS

Study Site, Collection of Soil Samples and Soil Analysis

The experiment was conducted on a well-drained area beside the College of Agriculture, Isabela State University, Echague, Isabela. The soil in the area is clay loam suited for corn production having a moderate rainfall throughout the year. The elevation of the municipality of Echague generally ranges from 20 to 100 meters above sea level. It is situated in the Cagayan Valley region, which is primarily composed of plains and rolling hills near the Cagayan River, rather than high mountainous terrain. Soil samples were collected using a soil auger and core sampler from an undisturbed, flat surface to a depth of 30 cm. The auger was gently pushed into the soil, and the surrounding soil was excavated without disturbing the sample. The intact soil core was carefully removed, excess soil trimmed, and any plants or roots removed. The sample was then placed in a sealed plastic bag, labeled with the date and location. The soil sample was brought to the Bureau of Soils Laboratory for the analysis of soil pH (acidity or alkalinity), nutrient content (NPK and other traced micronutrients) and organic matter percentage.

Table 1. *Organic Matter, Macro and Micronutrients, and pH Analysis Before the Application of Biostimulants.*

Parameters	Results	Description
pH	5.44	moderately acidic
OM (%)	1.81	low
N (%)	0.09	very low
P (%)	5.33	low to moderate
K (%)	0.34	low
Zn ppm	3.19	adequate range
Cu ppm	3.14	adequate range
Mn ppm	82.97	adequate range
Fe ppm	90.50	adequate range

Procurement of Seeds and Biostimulants

The seeds of glutinous corn, humic acid, N-Biofertilizer, AMO foliar fertilizer, and carrageenan were obtained from the Department of Agriculture. In contrast, Black Soldier Fly frass was obtained from an online supplier. *Bacillus subtilis* was acquired from the College of Agriculture, Isabela State University, Echague, Isabela.

Land Preparation, Experimental Layout and Design

An area of 450.50 square meters was cleared before plowing. It was initially plowed with a tractor. The area was left idle for two weeks to allow weeds to decay and allow weed seeds to germinate before the final plowing. Final harrowing was done until the soil was thoroughly pulverized, followed by the planting of seeds. After the final harrowing, the experimental area was divided into three blocks, each block measuring 4 meters by 26.50 meters with an alleyway of one meter between blocks. Each block was further subdivided into seven plots, each plot measuring 5 meters by 4 meters with an alleyway half meter between plots. The treatments were allocated to the plots following the procedure for Randomized Complete Block Design (RCBD) to compare treatment effects of the different biostimulants in combination to black soldier fly frass. RCBD was considered appropriate for this study because it effectively controlled field variability by grouping experimental units into homogeneous blocks, thereby increasing the accuracy and reliability of treatment comparisons under field conditions. Furrows were made at a distance of 75 centimeters between rows and 30 centimeters between hills. Two seeds were planted per hill, spaced 20 centimeters apart. It was covered with fine soil.

Application of Fertilizer

The Black Soldier Fly frass was applied prior to planting by spreading it in the rows and covering it with a thin layer of soil. At the same time, the N-biofertilizer was coated onto the seeds using the slurry method. *Bacillus subtilis*, humic acid, AMO, and seaweed extract as foliar was sprayed onto the leaves of the plants following the recommended rate of three (3) liters per hectare, following the general recommendation. This was dissolved in water and applied as a fine spray to the leaf surface at 15 DAP, 30 DAP, and 45 DAP (100 ml per knapsack spray). Application was done early morning or late in the afternoon. For the treatment applied with inorganic fertilizer, the recommended rate of one-half of the amounts of nitrogen and full amount of the phosphorus and potassium were applied as basal while the remaining one-half of nitrogen was sidedressed during hilling-up at 25 days after planting.

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Soil Incubation per Treatment

The chemical soil properties were determined by using soil incubation method in which one (1) kilogram was placed in polyethylene bags replicated 3 times and applied following the treatment used in the study. Soil moisture was maintained at 60% of field capacity while incubation was carried out at 25–30°C in a controlled environment. The samples were left for about two (2) months. At the end of observation period, 100 grams sample were removed from each treatment for pH determination and soil chemical properties (OM (%), P, K, Zn, Cu, Mn, and Fe)

Experimental Treatments

The treatments used in the study were as follows;
T1 – 140-40-60 kg NPK ha^{-1} RR Inorganic Fertilizer (Control)
T2 – 3 Tons ha^{-1} Black Soldier Fly Frass + 3L ha^{-1} Humic Acid
T3 – 3 Tons ha^{-1} Black Soldier Fly Frass + 3L ha^{-1} Carrageenan
T4 – 3 Tons ha^{-1} Black Soldier Fly Frass + 3L ha^{-1} AMO Foliar Fertilizer
T5 – 3 Tons ha^{-1} Black Soldier Fly Frass + N-Biofertilizer
T6 – 3 Tons ha^{-1} Black Soldier Fly Frass
T7 – 3 Tons ha^{-1} Black Soldier Fly Frass + *Bacillus subtilis*

Care and Management

Cultivation was done to aerate the soil and control weeds. Hilling up was done to prevent the plants from excessive moisture. Insect pests (common cutworms) were immediately controlled with chemical pesticides, while weeds were controlled through hand weeding. The plants were irrigated as the need arises.

Harvesting

The corn was harvested when the plants showed the marketable stage or at the soft dough stage. All samples were tagged to avoid intermixing.

Data Gathered

1. Plant Height at Harvest (cm). The heights of the ten randomly selected representative plants were measured from the base to the first tassel node using a measuring tape.

3. Leaf Area (cm^2). The leaf area of the third leaf from the base of the corn plant was measured and calculated using the formula by Dwyer and Stewart (1986):

$$\text{Leaf Area} = L \times W \times 0.75$$

where: L = Leaf length (cm) (measured from the base to the tip along the midrib)
W = Maximum leaf width (cm) (measured at the widest part of the leaf)
0.75 is a correction factor to estimate the actual leaf area

4. Length and Diameter of Corn Ear. The length of the husked ears from the ten representative plants was measured from end to end using a foot ruler. The same sample ears used to determine ear length were also used to measure ear diameter with a Vernier caliper.

5. Weight of Unhusked Ear per Plant. The ten sample ears, with husk, were weighed immediately after harvest. The total weight was divided by ten to obtain the average weight per ear with husk. This was taken using a digital weighing balance.

6. Yield per Sampling Area. All harvested ears in the sampling area, were weighed and used as the basis for the computation of yield per hectare.

7. Computed Yield per Hectare. The yield per hectare was computed from the yield obtained in the sampling area.

Cost and Return Analysis

The return on investment was computed using the simple economic analysis. The cost of production was based on the prevailing prices of farm inputs and labor in the community. The gross income was determined based on the prevailing corn price. The net income is equal to the gross income minus the cost of production, and the return on investment was computed by dividing the net income by the cost of production multiplied by 100.

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Statistical Analysis

The collected data were analyzed using Analysis of Variance (ANOVA) for a Randomized Complete Block Design (RCBD) and further analyzed using the Statistical Tool for Agricultural Research (STAR) package. The treatments with significant results were compared using the Honestly Significant Difference (HSD).

Ethical Considerations

The study complied with the ethical research standards applicable to agricultural field experiments. No human or animal subjects were involved. Throughout the study, environmentally responsible practices were observed, including proper handling of fertilizers, biostimulants, and pesticides in accordance with recommended agricultural guidelines to prevent environmental harm.

RESULTS and DISCUSSION

This section provides the results and discussion on the macro and micronutrient of soil after application of biostimulants. This also includes the growth and yield parameters of glutinous corn and the cost and return analysis.

1. Soil pH and Nutrient Composition after Two Months of Incubation

The chemical properties of the soil after two months of incubation are shown in Table 2. The soil sampling was conducted separately for each treatment to measure pH, organic matter, phosphorus, potassium, and micronutrients.

Table 2. *Organic matter content of soil, P, K, and micronutrients (ppm) after two months of soil incubation*

Parameters	pH	OM (%)	P	K	Zn (ppm)	Cu (ppm)	Mn (ppm)	Fe (ppm)
T_1 – 140-40-60 kg NPK ha^{-1} (RR)	5.70	6.16	3.52	99.47	1.50	2.48	97.80	70.70
T_2 – 3T ha^{-1} Black Soldier Fly Frass + 3L ha^{-1} Humic Acid	5.57	1.63	0.87	42.58	0.56	0.74	35.60	12.30
T_3 – 3T ha^{-1} Black Soldier Fly Frass + Carrageenan	5.51	1.46	0.96	27.61	0.14	0.40	31.00	8.30
T_4 – 3T ha^{-1} Black Soldier Fly Frass + AMO Foliar Fert	5.94	1.94	1.96	30.61	0.34	0.80	19.60	23.90
T_5 – 3T ha^{-1} Black Soldier Fly Frass + N-Biofertilizer	6.13	1.15	1.56	31.60	0.16	0.22	11.20	8.90
T_6 – 3T ha^{-1} Black Soldier Fly Frass	5.39	4.75	2.01	55.56	0.40	0.44	3.80	47.30
T_7 – 3T ha^{-1} Black Soldier Fly Frass + *Bacillus subtilis*	7.15	2.46	1.39	51.56	0.36	0.66	5.00	10.30

The analysis showed that the pH values ranged from 5.39 to 7.15, indicating a moderate to neutral pH. It was noted that Treatment 6 (3T ha^{-1} Black Soldier Fly Frass) registered the lowest pH value of 5.39, which was described as moderately acidic among all treatments. This can be attributed to the organic nature of BSF frass, which often contains decomposed organic materials that release organic acids during mineralization. Black Soldier Fly frass has compost-like properties, with high macronutrient (NPK) and micronutrient contents, as well as high organic matter content, that are readily available for agricultural use (Bortolini et al. 2020).

The soil analysis presented in Table 2 likewise shows variation in both macro and micronutrient content across treatments (T1–T7). The pH values ranged from slightly acidic (5.39 in T6) to slightly alkaline (7.15 in T7), indicating moderate variability in soil acidity, which can affect nutrient availability. The organic matter content was highest in T6 (4.75%), which means better soil structure, improved nutrient availability, and stronger microbial activity, and can support better plant growth compared with the other plots, especially T5 (1.15%), which has the lowest fertility potential based on its low organic matter content.

Regarding available phosphorus levels, the highest concentration was recorded in the plot treated with sole inorganic fertilizer (T1: 3.52 mg/kg). Notably, inorganic fertilizer provided a readily soluble, immediately available form of phosphorus, resulting in a higher soil concentration than in the other treatments. The effect of a high amount of phosphorus, an essential macronutrient required for root development, energy transfer, and overall plant growth, flowering, and fruiting. On the other hand, the lowest was in T2 (0.87 mg/kg), indicating a potential need for

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phosphorus supplementation. The available potassium (K) was highest in T1 (99.47 mg/kg) and lowest in T3 (27.61 mg/kg), showing substantial differences in soil potassium reserves that could influence crop growth.

The micronutrient analysis showed that, overall, plots treated with full inorganic fertilizer (T1) have the most complete and balanced micronutrient profile, with adequate levels of Zn, Cu, Mn, and Fe compared with plots in T3, T5, and T6. However, these treatments required additional micronutrient fertilizers, organic amendments, or biostimulants to improve nutrient availability further and ensure optimal crop growth and productivity. Notably, the zinc content also differed from 0.14 ppm in T3 to 1.50 ppm in T1, copper (Cu) ranged from 0.22 ppm in T5 to 2.48 ppm in T1, manganese (Mn) was highest in T1 (97.8 ppm) and lowest in T6 (3.8 ppm), and iron (Fe) ranged from 8.3 ppm in T3 to 70.7 ppm in T1. Overall, T1 appears to have the most balanced nutrient profile, while T3, T5, and T6 exhibit deficiencies in key macro- and micronutrients, which may require additional fertilization or soil amendments to optimize crop productivity.

2. Growth Parameters

2.1. Plant Height

The effects of black soldier fly and biostimulants on corn plant height at harvest and leaf area is presented in Table 3. The leaf area of the plants is a reliable indicator of vegetative growth and assesses to determine the effects of black soldier fly frass and biostimulants.

Table 3

Plant height at Harvest (cm) as Affected by Black Soldier Fly and Biostimulants

Treatments	Height (cm)	Leaf Area (cm^2)
T1 – 140-40-60 kg NPK ha^{-1} (RR)	203.83	2990.53
T2 – 3T ha^{-1} Black Soldier Fly Frass + 3L ha^{-1} Humic Acid	201.94	2516.38
T3 – 3T ha^{-1} Black Soldier Fly Frass + Carrageenan	206.95	2760.43
T4 – 3T ha^{-1} Black Soldier Fly Frass + AMO Foliar Fertilizer	206.99	2729.41
T5 – 3T ha^{-1} Black Soldier Fly Frass + N-Biofertilizer	199.34	2581.21
T6 – 3T ha^{-1} Black Soldier Fly Frass	188.45	2552.26
T7 – 3T ha^{-1} Black Soldier Fly Frass + *Bacillus subtilis*	190.07	2355.99
F-RESULT	ns	ns
CV (%)	6.11	10.19

Legend: ns – not significant

Plant height during the vegetative stage reflects the plant's capacity to utilize applied nutrients efficiently. The effect of BSFF in combination with different sources of biostimulants on plant height at harvest shows a non-significant difference among treatments, suggesting that all treatments may have provided adequate nutrients to meet the crop's requirements for height development. Plants treated with 3 tons of Black Soldier Fly Frass (BSFF) combined with various biostimulants showed slightly higher values; however, they did not fully match the performance of plants fertilized with the recommended rate of inorganic fertilizer. The mean heights ranged from 188.45 cm to 206.95 cm, indicating stable growth across treatments and similarity in the effect of BSFF plus biostimulants to the control treatment (T1). The similarity in the impact on the plant growth was attributed to the nutrient content of BSFF plus biostimulant, which provides essential macro- and micronutrients that enhance nutrient uptake, physiological activity, or stress tolerance (Schmitt and de Vries, 2020). This observation was noted in the treatments without added biostimulants (T6 and T7), which showed mean values slightly lower than those in treatments with added biostimulants. Although these improvements did not exceed those achieved with conventional fertilization, the results suggest that BSFF-based amendments may positively influence growth performance under appropriate application conditions.

Moreover, the nonsignificant differences in corn growth between BSFF Frass plus biostimulant and plants applied with the full recommended rate of NPK indicate that the BSF frass fertilizer plus biostimulant can perform as well as commercial mineral fertilizer, as previously reported by Beesigamukama et al. (2020). They further stated that the growth, yield, and agronomic nitrogen use efficiency of corn grown in plots treated with BSF frass fertilizer is due to the high N mineralization and nutrient release rates.

Likewise, there was no significant difference among treatments in corn plant leaf area. This non-significant variation may be attributed to the comparable availability of growth-limiting resources across treatments, leading to similar physiological responses and leaf expansion among the plants. Plants applied with the recommended rate of inorganic fertilizer serving as the control produced the mean value with 2990.53 cm^2 however remains comparable to

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the plants applied with BSF Frass + Carrageenan with 2760.43 cm^2 and T4 - BSF Frass + AMO Foliar Fertilizer with 2729.41 cm^2 while plants applied with BSF Frass + Humic Acid had 2516.38 cm^2, T5 (BSF Frass + N-Biofertilizer, 2581.21 cm^2, T6 (BSF Frass only had 2552.26 cm^2 and T7 (BSF Frass + *Bacillus subtilis* with 2355.99 cm^2). The non-significant difference in leaf area between plants applied with BSF frass combined with biostimulants and those fertilized with inorganic fertilizer indicates that BSF frass, whether used alone or in combination with various biostimulants, is capable of sustaining leaf area development comparable to that achieved with full inorganic fertilization. This result highlights the potential of BSF frass supplemented with biostimulants to partially substitute conventional inorganic fertilizers without compromising leaf area development. However, organic amendments such as BSF frass and biostimulants undergo an initial decomposition phase, during which temporary nitrogen immobilization may occur, thereby limiting immediate nutrient availability to plants (Randrianjafizanaka et. al., 2018).

The result is also similar to the studies of Grover et. al. (2024) on the benefits of insect frass fertilizers in boosting the growth and yield of various crops. The improved performance can be attributed to the superior nutrient content of BSF frass and the faster release of essential nutrients, such as nitrogen and phosphorus, which are critical for physiological processes like chlorophyll formation. The combination of BSF frass and biostimulants often produces results that are appreciable compared to using either alone or conventional fertilizers.

2.2. Ear Length and Diameter (cm)

The data on ear length and diameter of corn under different fertilizer and biostimulant treatments (Table 4) showed variations among treatments.

Table 4
Ear length and diameter (cm) as affected by black soldier fly and biostimulants

Treatments	Length (cm)	Diameter (cm)
T1 – 140-40-60 kg NPK ha^{-1} (RR)	16.45a	4.13
T2 – 3T ha^{-1} Black Soldier Fly Frass + 3L ha^{-1} Humic Acid	15.13ab	3.80
T3 – 3T ha^{-1} Black Soldier Fly Frass + Carrageenan	15.12ab	3.95
T4 – 3T ha^{-1} Black Soldier Fly Frass + AMO Foliar Fertilizer	15.10ab	3.95
T5 – 3T ha^{-1} Black Soldier Fly Frass + N-Biofertilizer	15.07ab	4.01
T6 – 3T ha^{-1} Black Soldier Fly Frass	15.47ab	3.91
T7 – 3T ha^{-1} Black Soldier Fly Frass + *Bacillus subtilis*	13.73b	3.87
F-RESULT	*	ns
CV (%)	5.17	2.14

*Legend: ns – not significant; * - significant at 5% level*

Results showed that the recommended rate of inorganic fertilizer (T1) produced the mean value of 16.45 centimeters. The enhanced growth, productivity, and improved quality traits of the crop plants fertilized with the complete inorganic fertilizer can be attributed to the application of nitrogen and potassium fertilizers. Nitrogen, supplied through inorganic fertilizers, plays a vital role in plant growth as a highly mobile macronutrient that stimulates meristematic activity, leading to increased cell division and elongation. It is also a key component in the synthesis of amino acids such as tryptophan, a precursor of auxin, which regulates cell division and elongation, ultimately resulting in increased plant height (Loddo & Gooding, 2012). In addition, potassium significantly enhances photosynthetic efficiency and activates numerous enzymes involved in metabolic processes, promoting stem elongation and increasing the number of nodes in maize plants (Raza et al., 2021). Potassium further contributes to internode elongation and increased leaves per node by facilitating nutrient synthesis and translocation, thereby supporting overall plant growth and vigor (Ali et al., 2014).

However, ears produced by this treatment were as long as the ears of the plants that were treated with 3 t ha^{-1} BSF frass combined with different biostimulants (T2–T6). This indicates that 3 tons of BSF frass, whether alone or combined with humic acid, Carrageenan, AMO foliar fertilizer, or N-biofertilizer, can statistically match the recommended inorganic fertilizer rate in producing longer ears. Compared with plants treated with BSF frass alone (T6), which recorded a mean ear length of 15.47 cm, the results indicate that BSF frass alone provides adequate soil fertility even without additional supplements; however, smaller ears per plant were produced. This shows that BSF frass can meet the crop's basic nutritional requirements, as evidenced by its ear length being comparable to that of treatments with biostimulants. This supports the claims of Tully et al. (2015) and Wortmann et al. (2019) that the high efficiency of composted BSF frass as a fertilizer may improve crop growth, yield, and nutritional quality.

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In terms of ear diameter, corn fertilized with a constant rate of BSF frass, combined with different biostimulants, and the control treatment showed comparable ear diameter. Ear diameter of corn recorded in T1 (140-40-60 kg NPK ha^{-1} at 4.13 cm, while in T2 (3T ha^{-1} Black Soldier Fly Frass + 3L ha^{-1} Humic Acid) at 3.80 cm. Other treatments supplemented with biostimulants, such as AMO foliar fertilizer (T4), N-biofertilizer (T5), and *Bacillus subtilis* (T7), produced ear diameters ranging from 3.87 cm to 4.01 cm. Although treatments using Black Soldier Fly frass combined with humic acid, Carrageenan, AMO foliar fertilizer, N-biofertilizer, or *Bacillus subtilis* showed slightly smaller ear diameters than T1, the differences were not statistically significant. This implies that these organic or biostimulant-based treatments can produce ear diameters comparable to those achieved with the full NPK rate. Organic fertilizer application exerts substantial physiological effects on corn by improving nutrient availability, root development, and overall metabolic activity throughout the growth cycle. Organic manures also improve soil structure, aggregate stability, and CEC, thereby enhancing root growth, improving nutrient and water uptake, and consequently improving crop performance. The favorable changes in soil microbial activity, diversity, and BSF frass composition ensure better nutrient release and enhanced crop productivity (Olaniyi and Ajibola, 2008).

Organic fertilizer application exerts significant physiological effects on corn by improving nutrient availability, root development, and overall metabolic activity throughout the growth cycle. Organic manures also improve soil structure, aggregate stability, and CEC, thereby enhancing root growth, improving nutrient and water uptake, and consequently improving crop performance. It also brings favorable changes in soil microbial activity, diversity, and composition, thereby improving nutrient release and crop productivity (Olaniyi and Ajibola, 2008).

3. Yield Parameters

3. Weight of Unhusked Ear and Yield per Hectare

The effect of black soldier fly frass and biostimulants on the weight of ear and yield per hectare is shown in Table 5. This parameter is a key indicator of corn yield performance, as it reflects the cumulative influence of nutrient availability, assimilate partitioning, and overall plant vigor during the reproductive stage.

Table 5
Weight of Unhusked Ear (g) as affected by black soldier fly and biostimulants

Treatments	Weight of Unhusked Ear (g)		Yield per Hectare (kg)
	Per Plant	Sampling Area	
T1 – 140-40-60 kg NPK ha^{-1} (RR)	192.17a	3.85a	8555.56
T2 – 3T ha^{-1} Black Soldier Fly Frass + 3L ha^{-1} Humic Acid	180.22a	3.61ab	8022.22
T3 – 3T ha^{-1} Black Soldier Fly Frass + Carrageenan	174.37a	3.49ab	7755.56
T4 – 3T ha^{-1} Black Soldier Fly Frass + AMO Foliar Fertilizer	189.51a	3.79ab	8422.22
T5 – 3T ha^{-1} Black Soldier Fly Frass + N-Biofertilizer	180.81a	3.62ab	8044.44
T6 – 3T ha^{-1} Black Soldier Fly Frass	142.78b	3.22b	7155.56
T7 – 3T ha^{-1} Black Soldier Fly Frass + *Bacillus subtilis*	177.54a	3.55ab	7888.89
F-RESULT	**	**	
CV (%)	3.56	4.51	

*Legend: ** - significant at 1% level*

The weight of unhusked corn ears per plant differed significantly across treatments. The BSFF plus biostimulant combination, achieved yields comparable to the full recommended rate of inorganic fertilizer. The results indicate that the full recommended rate (RR) of inorganic fertilizer (T1), and that different combinations of Black Soldier Fly (BSF) frass with biostimulants (T2–T7) are not significantly different from each other. The recommended rate of inorganic fertilizer (T1) produced the highest mean value, as expected, because full fertilization with inorganic fertilizer provides optimal nutrient availability for crop growth and supplies immediate macro- and micronutrients (Ahmed et al., 2022).

On the other hand, the comparable weight of unhusked ears per plant relative to those treated with inorganic fertilizer may be attributed to the unique properties of BSF frass. When combined with carrageenan, BSF frass enhances stress tolerance and stimulates growth. Humic acid supports nutrient uptake, root growth, and soil health, while N-Biofertilizer and AMO foliar fertilizer enhance fruit quality and yield. When used as fertilizers, these

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amendments can recycle nitrogen and phosphorus from the existing food chain and reduce the demand for synthetic fertilizers (Schmitt and de Vries, 2020). Moreover, BSF Frass is a nutrient-dense organic fertilizer enriched with nitrogen, phosphorus, potassium, and chitin, a biopolymer that promotes beneficial soil microbial activity. These nutrients, being partly in mineralized form, are more accessible to plants, leading to increased biomass and grain yield (Yadav et al, 2021).

Likewise, weight of unhusked corn ears per sampling area varied significantly, with the control plots yielding 3.85 kg. However, the rest of the treatments yielded comparably to the plants applied with the full recommended rate of inorganic fertilizer. This implies that BSF frass, when combined with biostimulants, can sustain yields comparable to those of conventional inorganic fertilizers. Notably, plants receiving sole BSF frass without biostimulant had the lowest unhusked ear weight, averaging 3.22 kg, suggesting the potential for yield enhancement through integrated nutrient management and serving as a viable alternative or supplement to organic fertilizers. Combining organic materials not only helps plants use nutrients efficiently but also improves plant growth and yield. These findings suggest that integrating organic fertilizer and a biostimulant to provide a quick nutrient supply and improve soil health and plant vigor is a beneficial strategy.

The results support the findings of Geng et al. (2019) that the combined application of 3 tons per hectare BSF Frass and biostimulant was as effective as the full rate of NPK in terms of corn yield. This improvement is likely due to the synergistic effects of both organic fertilizers and biostimulants, which enhance nutrient availability, soil health, and overall growing conditions. More importantly, organic fertilizers offer the advantage of binding nutrients to the organic matrix, limiting their leaching while also reducing their water solubility and plant availability. This happens by retaining nutrients in complex organic forms; these fertilizers promote a more gradual and sustained release of essential elements into the soil solution. However, their availability largely depends on microbial activity and soil biological processes that decompose organic matter and convert nutrients into plant-available forms (Halpern et al. 2015).

The computed unhusked ear yield per hectare (kg, tons) across the different treatments shows the following trend: Plants on the control treatment (T1 – RR Inorganic Fertilizer) produced 8.56 t/ha, T4 – 3T ha^{-1} Black Soldier Fly Frass + AMO Foliar Fertilizer (8.42 t/ha), slightly lower than the control. Other treatments (T2, T5, T6, T7) yielded between 8.02 and 8.04 t/ha, while the computed yield in T6 – Black Soldier Fly Frass alone with 7.16 t/ha.

4. Cost and Return Analysis

The cost and return analysis of producing 1 hectare of corn using a combination of BSF frass and biostimulants is shown in Table 6. This evaluates the economic viability of producing corn and compares the expenses incurred with the income generated from the crop.

Table 6
Cost and Return Analysis of Glutinous Corn as Affected by Black Soldier Fly Frass and Biostimulants

TREATMENTS	COST OF PRODUCTION	GROSS INCOME	NET INCOME	ROI (%)
T_1 – 140-40-60 kg NPK ha^{-1} (RR)	45,900.00	85555.60	34,756.00	75.72
T_2 – 3T ha^{-1} BSFF + 3L ha^{-1} Humic Acid	43,700.00	80222.20	32,152.00	73.57
T_3 – 3T ha^{-1} BSFF + Carrageenan	43,700.00	77555.60	29,486.00	67.47
T_4 – 3T ha^{-1} BSFF + AMO Foliar Fertilizer	43,700.00	84222.20	36,152.00	82.73
T_5 – 3T ha^{-1} BSFF + N-Biofertilizer	43,700.00	80444.40	32,374.00	74.08
T_6 – 3T ha^{-1} BSFF	42,200.00	71555.60	24,986.00	59.21
T_7 – 3T ha^{-1} BSFF + *Bacillus subtilis*	41,700.00	78888.90	32,819.00	78.70

It shows that the highest return was obtained with Treatment 4 (3T ha^{-1} Black Soldier Fly Frass + AMO Foliar Fertilizer), at 82.73%. It was followed by T7 (3T ha^{-1} Black Soldier Fly Frass + *Bacillus subtilis*) with 79.70 percent, T1 (RR Inorganic Fertilizer (Control) with 75.72, T5 (3T ha^{-1} Black Soldier Fly Frass + N-Biofertilizer) with 74.08 percent T3 (3T ha^{-1} Black Soldier Fly Frass + Carrageenan) with 73.57 percent, T2 (3T ha^{-1} Black Soldier Fly Frass + 3L ha^{-1} Humic Acid) with 73.57 percent. At the same time, the lowest return was recorded in Treatment 3 (3T ha^{-1} Black Soldier Fly Frass + Carrageenan), at 67.47%.

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Conclusions

The results of the study demonstrate that the application of Black Soldier Fly (BSF) frass combined with biostimulants can positively influence soil fertility and corn productivity. The application of 3 t ha^{-1} BSF frass improved soil organic matter and contributed to enhanced nutrient availability, which supports favorable crop growth conditions. Although several growth parameters such as plant height and leaf area showed no significant differences among treatments, the combined application of BSF frass with biostimulants produced yields comparable to those obtained from the recommended rate of inorganic fertilizer.

Among the treatments evaluated, the combination of BSF frass and AMO foliar fertilizer generated the highest return on investment, indicating strong economic potential for farmers. These findings suggest that BSF frass, when supplemented with appropriate biostimulants, can serve as a sustainable nutrient management strategy that improves soil health while maintaining crop productivity. The integration of organic fertilizers such as BSF frass into corn production systems may contribute to more sustainable agricultural practices and reduced dependence on synthetic fertilizers.

Recommendations

Based on the results of the study, the use of Black Soldier Fly (BSF) frass combined with appropriate biostimulants may be considered as an alternative nutrient management strategy in glutinous corn production. In particular, the combination of BSF frass and AMO foliar fertilizer may be adopted by farmers to enhance soil organic matter and improve economic returns while reducing reliance on conventional inorganic fertilizers.

Agricultural extension workers and policymakers may also promote the use of organic fertilizers such as BSF frass as part of sustainable soil fertility management programs. The adoption of these practices may contribute to improved soil health, increased agricultural productivity, and more environmentally sustainable farming systems.

Further studies may be conducted to determine the most effective combinations of biostimulants, optimal application rates, and the long-term effects of BSF frass on soil microbial populations, crop productivity, and environmental sustainability.

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PRC-CPD Accredited Provider: PTR-2025-749
National Book Development Board Registration as Book Publisher (Print & Digital): 6312
Global Journal of Agriculture, Forestry, and Food Systems (GLOAFFS)
P - ISSN: 3116-4412; E - ISSN: 3116-4420

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