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Field Evaluation of Black Soldier Fly (BSF) Frass as an Organic Fertilizer for Tomato

Jeffrey A. Cortez[1], Artemio A. Martin Jr, PhD[2]
[1]Graduate Student, Master of Science in Crop Science, Isabela State University, Echague Campus, Echague, Isabela, Philippines
[2]Profesor VI, Isabela State University, Echague Campus, Echague, Isabela, Philippines

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Email of Corresponding Author: jeffreyacortez90@gmail.com

Abstract

This study aimed to evaluate the effectiveness of Black Soldier Fly (BSF) frass as an alternative organic fertilizer for tomato production, focusing on its effects on plant growth, yield, fruit quality, and economic performance under field conditions. Grounded in the principles of sustainable agriculture, organic nutrient management, and circular bioeconomy, the research employed a Randomized Complete Block Design (RCBD) with treatments consisting of BSF frass applied alone and in combination with recommended inorganic fertilizers (120-60-60 kg NPK ha^{-1}). The experiment was conducted in a field setting using tomato plants (D-max F1), with data collected on growth parameters, yield components, fruit quality attributes, and economic indicators. Results showed that the combined application of BSF frass and inorganic fertilizers significantly improved plant height, branching, biomass, and yield compared to sole applications and the control. The highest yield (35.88 t ha^{-1}) and return on investment (804.03%) were obtained from the treatment combining inorganic fertilizer with 4.5 t ha^{-1} BSF frass, indicating enhanced nutrient efficiency and profitability. However, higher rates of BSF frass reduced fruit quality parameters such as total soluble solids and vitamin C content, highlighting a trade-off between yield and quality. The study concludes that BSF frass is most effective when used as a complementary input rather than a sole fertilizer source, with recommended rates of 3.0–4.5 t ha^{-1} combined with inorganic fertilizers to optimize productivity and economic returns. The findings support Sustainable Development Goals including Zero Hunger (SDG 2), Responsible Consumption and Production (SDG 12), Climate Action (SDG 13), and Life on Land (SDG 15), as the study promotes sustainable nutrient management, waste valorization, and improved soil health. The sustainability impact lies in enhancing environmentally sustainable agricultural practices, improving soil fertility, reducing reliance on synthetic fertilizers, and supporting economically viable and resource-efficient farming systems.

Keywords: Black Soldier Fly Frass, Circular Agriculture, Economic Performance, Fruit Quality, Integrated Nutrient Management, Sustainable Agriculture, Tomato Yield

1. Introduction

The increasing demand for sustainable agricultural production has intensified concerns over the environmental and agronomic impacts of synthetic fertilizer use. This study examines Black Soldier Fly (BSF) frass as an alternative organic fertilizer for tomato production, focusing on its effects on plant growth, yield, fruit quality, and economic performance under field conditions. By integrating waste valorization and nutrient management, the study positions BSF frass as a potential contributor to sustainable and resilient agricultural systems.

1.1 Background of BSF Frass Application in Tomato Growth, Yield, Fruit Quality, and Economic Performance

The global demand for healthy and sustainable food production continues to rise, placing pressure on conventional agricultural systems that depend heavily on synthetic fertilizers. While these inputs have improved crop yields, their prolonged and excessive use has led to environmental pollution, soil acidification, nutrient imbalance, and potential health risks due to toxic residues. In the Philippines, such practices have contributed to declining soil fertility, particularly in intensively cultivated vegetable-growing areas, resulting in reduced productivity. This situation underscores the need for sustainable soil fertility management strategies to ensure long-term food security. Black Soldier Fly (BSF) frass has emerged as a promising organic fertilizer derived from the bioconversion of organic waste by BSF larvae. It contains essential macronutrients, micronutrients, and organic matter that support plant growth. Additionally, it improves soil structure, enhances water retention, and stimulates beneficial microbial activity, contributing to a more resilient soil ecosystem. Its use reduces reliance on synthetic fertilizers while promoting circular agriculture. For economically important crops such as tomato (Solanum lycopersicum L.), BSF frass offers a sustainable approach to improving yield and fruit quality while maintaining soil health.

1.2 Themes and Insights on BSF Frass and Fertilizer Effects on Tomato Growth, Yield, and Quality

Existing literature highlights the adverse effects of prolonged synthetic fertilizer use, including soil degradation, reduced microbial diversity, and declining productivity. In contrast, organic amendments such as BSF frass provide multiple agronomic benefits, including improved nutrient availability, enhanced soil structure, and increased biological activity. These benefits support healthier plant growth and sustainable crop production systems. Moreover, the integration of organic waste into fertilizer production aligns with circular economy principles, reducing environmental impact while improving agricultural efficiency. Studies also emphasize the importance of evaluating both agronomic and economic performance when introducing alternative fertilizers. Assessing growth parameters, yield components, fruit quality, and profitability provides a comprehensive understanding of the viability of organic inputs like BSF frass in comparison with conventional fertilization practices.

1.3 Local, National, and Global Context of Sustainable Fertilization in Tomato Production

Globally, the transition toward sustainable agriculture is driven by the need to address environmental degradation and ensure food security. In developing countries such as the Philippines, challenges associated with soil degradation and excessive fertilizer use are particularly pronounced in vegetable production systems. Locally, declining soil fertility in intensively cultivated areas highlights the urgency of adopting sustainable nutrient management practices. At the national and global levels, the promotion of organic fertilizers and circular agriculture is increasingly recognized as a strategy to reduce environmental impacts, improve soil health, and enhance agricultural resilience. The utilization of BSF frass represents a localized solution with global relevance, linking waste management with sustainable crop production.

1.4 Theoretical Basis of BSF Frass Use in Tomato Growth, Yield, Quality, and Economic Outcomes

This study is grounded in the principles of sustainable agriculture, organic nutrient management, and circular bioeconomy. Sustainable agriculture emphasizes the efficient use of resources to maintain productivity while minimizing environmental harm. Organic nutrient management focuses on improving soil fertility through natural inputs that enhance biological processes and nutrient cycling. The concept of circular agriculture underpins the use of BSF frass, where organic waste is converted into valuable fertilizer inputs through biological processes. This framework supports resource efficiency, waste reduction, and environmental sustainability while maintaining agricultural productivity.

1.5 Research Gaps in BSF Frass Effects on Tomato Growth, Yield, Fruit Quality, and Economic Performance

Despite the recognized benefits of BSF frass, there is limited field-based evidence evaluating its effectiveness on tomato production, particularly in terms of growth performance, yield, fruit quality, and economic viability under specific local conditions. Furthermore, comparisons between BSF frass, inorganic fertilizers, and their combined applications remain insufficient. This study addresses these gaps by systematically evaluating the effects of varying BSF frass application rates, both alone and in combination with inorganic fertilizers, on key agronomic and economic parameters. The findings aim to provide empirical evidence to support the adoption of sustainable fertilizer alternatives in tomato production.

1.6 Alignment of BSF Frass–Based Tomato Production with Sustainable Development Goals (SDGs)

This study contributes to several Sustainable Development Goals (SDGs). It supports Zero Hunger (SDG 2) by promoting sustainable agricultural practices that enhance productivity and soil health. It aligns with Decent Work and Economic Growth (SDG 8) through the development of waste-to-fertilizer industries that create economic opportunities. The study advances Responsible Consumption and Production (SDG 12) by utilizing organic waste in a circular bioeconomy framework. Additionally, it contributes to Climate Action (SDG 13) by reducing the carbon footprint associated with synthetic fertilizer production, and to Life on Land (SDG 15) by improving soil biodiversity and fertility. These alignments highlight the role of BSF frass in promoting environmentally sustainable and resource-efficient agricultural systems.

1.7 Importance of BSF Frass Application in Tomato Production to Multidisciplinary Sustainability

The study holds significance across multiple dimensions of sustainability. In terms of environmental sustainability, it promotes reduced chemical inputs, improved soil health, and enhanced ecosystem resilience. From a socio-economic perspective, it supports farmers by providing cost-effective and sustainable fertilizer alternatives, potentially improving income and productivity. In the context of agricultural and food sustainability, the study contributes to the production of safer and higher-quality food while maintaining long-term soil fertility. It also supports technological and innovation sustainability through the application of BSF bioconversion processes in agriculture. Furthermore, the study informs policy and institutional sustainability by providing evidence that can guide integrated nutrient management strategies and sustainable farming practices.

2. Material and methods

2.1 Research Design

The study employed a Randomized Complete Block Design (RCBD) to assess the effects of BSF frass applied alone and in combination with inorganic fertilizers on tomato production. The treatments consisted of a control with no fertilizer, a recommended rate of inorganic fertilizer (120-60-60 kg NPK ha^{-1}), combinations of this recommended rate with BSF frass at varying levels, and BSF frass applied alone. The inorganic fertilizers used were 16-20-0, 14-14-14, and urea (46-0-0), which supplied the required nutrients.

2.2 Locale of the Study
The experiment was conducted in an upland area, which was prepared through clearing, plowing, and harrowing. The field was left idle for two weeks to allow weed decomposition before final soil preparation. The experimental area was divided into three blocks with designated alleyways and further subdivided into plots for treatment application.

2.3 Respondents of the Study
This study did not involve human respondents, as it focused on tomato plants (D-max F1 variety) grown under field conditions to evaluate the effects of BSF frass and inorganic fertilizers on plant performance.

2.4 Sample and Sampling Procedure
Soil samples were randomly collected from the experimental area prior to the study, processed through air drying, pulverizing, and screening, and a composite sample was submitted for laboratory analysis of pH and nutrient content. Seedlings were produced using a 1:1 mixture of BSF frass and garden soil, with one seed sown per cell and maintained under partial shade until transplanting. The experimental field was divided into three blocks, each containing six plots measuring 4 m × 4 m. Planting was done at a spacing of 75 cm between rows and 50 cm between hills, with one seedling per hill. Replanting was conducted after five days to ensure uniform plant population. Ten representative sample plants per plot were randomly selected for data collection.

2.5 Research Instrument
The study utilized standard agricultural tools and laboratory procedures for data collection. Plant height was measured using standard measuring techniques, while fruit weight was determined using a digital weighing scale. Soil analysis was conducted by the Bureau of Soils and Water Management to determine pH and nutrient levels. Fruit quality parameters such as firmness, total soluble solids, and vitamin C content were analyzed using standard laboratory procedures.

2.6 Data Gathering Procedure
BSF frass was procured from Saint Joseph Cooperative in Echague, Isabela and ensured to be fully decomposed prior to application. The land was prepared through plowing and harrowing, followed by plot construction and fertilizer application based on treatment specifications. Inorganic fertilizers were applied with one-third of nitrogen as basal and the remaining portion side-dressed 30 days after planting, while BSF frass was applied during planting within the furrows. Crop management practices included cultivation for aeration, manual weeding, irrigation as needed, and pest and disease control using chemical pesticides. Harvesting was conducted when fruits reached marketable size, and samples from representative plants were collected and properly labeled. Data collected included plant height, number of branches, biomass, number of fruits, fruit weight, number of marketable and non-marketable fruits, total yield per plot, and computed yield per hectare. Fruit quality parameters such as firmness, total soluble solids, and vitamin C content were also measured. Economic data were gathered to determine production cost, gross income, net income, and return on investment.

2.7 Data Analysis Techniques
The collected data were analyzed using analysis of variance (ANOVA) appropriate for a Randomized Complete Block Design with the Statistical Tool for Agricultural Research (STAR) software. Differences among treatment means were further compared using Tukey's Honestly Significant Difference (HSD) test.

3. Results and Discussion

3.1 Effects of BSF Frass and Inorganic Fertilizer on Tomato Growth and Yield

3.1.1 Plant Height
Plant height at 30 days after transplanting ranged from 42.77 to 58.73 cm, with the highest values observed in treatments combining inorganic fertilizer and BSF frass, particularly at 3.0 and 4.5 t ha^{-1}. At 50 days after transplanting, plant height ranged from 81.87 to 93.30 cm, with all treatments receiving inorganic fertilizer showing significantly greater height than the control, while differences among combined treatments were not significant. The increased plant height is attributed to improved nutrient availability, particularly nitrogen, which supports cell division and elongation (Singleton, 2006). The results indicate that while BSF frass enhances early growth, its combination with inorganic fertilizer sustains vegetative development. The comparable performance among combined treatments suggests that nutrient sufficiency was achieved, aligning with integrated nutrient management principles (Havlin et al., 2014; Marschner, 2012; Beesigamukama et al., 2020).

3.1.2 Number of Branches

The number of branches ranged from 1.33 to 4.23, with the highest values observed in treatments combining inorganic fertilizer and BSF frass at 1.5 to 4.5 t ha^{-1}. The control and sole BSF frass application produced the lowest number of branches, while inorganic fertilizer alone resulted in moderate branching. The enhanced branching is linked to improved nutrient availability and soil conditions. Nitrogen promotes vegetative growth, while phosphorus and potassium support plant vigor (Marschner, 2012). The synergistic effect of combining organic and inorganic fertilizers ensures sustained nutrient supply and improved nutrient use efficiency, consistent with integrated nutrient management (Havlin et al., 2014; Beesigamukama et al., 2020).

3.1.3 Biomass Production

Biomass ranged from 0.56 to 1.73 kg per plant, with the highest value observed in the treatment combining inorganic fertilizer with 4.5 t ha^{-1} BSF frass. Intermediate values were recorded in treatments with lower BSF frass rates and inorganic fertilizer, while the control produced the lowest biomass. The increase in biomass is due to improved nutrient availability and uptake efficiency. Nitrogen enhances vegetative growth, while phosphorus and potassium support energy transfer and plant development (Marschner, 2012). The organic matter in BSF frass improves soil structure and microbial activity, enhancing nutrient retention and availability, as supported by Beesigamukama et al. (2020).

3.1.4 Yield per Plant

The number of fruits ranged from 14 to 35 per plant, while fruit weight ranged from 0.51 to 1.53 kg. The highest values were observed in treatments combining inorganic fertilizer and BSF frass, particularly at 4.5 t ha^{-1}, while the control produced the lowest yield. The improved yield is attributed to the combined effects of nitrogen, phosphorus, and potassium on plant growth and fruit development (Marschner, 2012). BSF frass enhances soil properties and nutrient retention, leading to better nutrient uptake and higher productivity. Similar results were reported by Beesigamukama et al. (2020), confirming the effectiveness of BSF frass in increasing crop yield.

3.1.5 Yield per Plot

Marketable fruit yield per plot ranged from 549 to 1289 fruits, with the highest values observed in treatments combining inorganic fertilizer and higher BSF frass rates. Non-marketable fruits were also higher in fertilized treatments compared to the control. The increase in marketable yield is due to improved nutrient availability and soil conditions, which enhance fruit formation and development (Marschner, 2012). The higher number of non-marketable fruits is associated with increased total production and environmental factors. Despite this, the overall yield advantage remains significant, supporting the use of BSF frass in integrated nutrient management (Beesigamukama et al., 2020).

3.1.6 Yield per Sampling Area

Marketable yield ranged from 20.24 to 57.41 kg per plot, with the highest value observed in the treatment combining inorganic fertilizer and 4.5 t ha^{-1} BSF frass. The control recorded the lowest yield, while sole BSF frass application produced moderate results. The enhanced yield is due to improved nutrient availability, soil structure, and microbial activity. BSF frass contributes organic matter that enhances nutrient retention and uptake, complementing the immediate nutrient supply from inorganic fertilizers (Marschner, 2012; Beesigamukama et al., 2020).

3.1.7 Computed Yield per Hectare

Computed yield ranged from 12.65 to 35.88 t ha^{-1}, with the highest yield obtained from the combined application of inorganic fertilizer and 4.5 t ha^{-1} BSF frass. The control had the lowest yield, while sole BSF frass application resulted in moderate productivity. The substantial yield increase reflects improved nutrient use efficiency and soil conditions. The combination of organic and inorganic fertilizers enhances nutrient availability and supports sustained plant growth, as reported by Beesigamukama et al. (2020) and Marschner (2012).

3.2 Effects of BSF Frass on Fruit Quality

3.2.1 Fruit Firmness

Fruit firmness ranged from 1.49 to 1.99 kg/cm², with the highest values observed in treatments with inorganic fertilizer alone and in combination with low BSF frass rates. Higher BSF frass rates resulted in lower firmness values. The variation in firmness is influenced by nutrient balance, particularly potassium, which strengthens cell walls and regulates water balance (Marschner, 2012). Excessive organic inputs may increase water content, leading to softer fruits, consistent with findings of Dorais et al. (2008).

3.2.2 Total Soluble Solids

Total soluble solids ranged from 0.38 to 0.49 °Brix, with the highest value recorded in the control and lower values observed in fertilized treatments. The reduction in TSS is attributed to the dilution effect, where increased fruit size and water content reduce sugar concentration (Dorais et al., 2008). Moderate nutrient levels help maintain better sugar balance, while excessive fertilization may reduce sweetness (Marschner, 2012).

3.2.3 Vitamin C Content

Vitamin C content ranged from 13.80 to 32.30 mg/100 g, with the highest values observed in the control and moderate fertilization treatments, while higher BSF frass rates resulted in lower values. The decline in vitamin C with increased fertilization is associated with the dilution effect and the influence of nitrogen on plant metabolism (Lee and Kader, 2000). Mild nutrient stress may enhance antioxidant accumulation, as noted by Smirnoff (2018), indicating the importance of balanced nutrient supply.

3.3 Economic Performance of BSF Frass Application

The return on investment ranged from 437.84% to 804.03%, with the highest value observed in the treatment combining inorganic fertilizer and 4.5 t ha⁻¹ BSF frass. The control recorded the lowest ROI, while sole BSF frass application produced moderate returns. The higher profitability in combined treatments is attributed to increased yield and improved nutrient efficiency. Inorganic fertilizers provide immediate nutrient availability, while BSF frass enhances soil properties and long-term productivity (Agegnehu et al., 2017; Lehmann & Rondon, 2006). The results support integrated nutrient management as an effective approach to maximizing productivity and profitability (Vanlauwe et al., 2010).

4. Conclusion & Recommendations

The study demonstrated that the application of BSF frass significantly improved the growth and yield of tomato, particularly when combined with inorganic NPK fertilizer, with higher rates (3.0–4.5 t ha^{-1}) enhancing vegetative growth and maximizing yield. The integration of BSF frass with NPK resulted in substantial increases in fruit number, biomass, and total yield, with the highest yield (35.88 t/ha) obtained at 4.5 t ha^{-1} BSF frass combined with recommended NPK, representing a 183.6% increase over the control. Fruit quality showed variable responses, where moderate application maintained desirable firmness, but higher rates reduced total soluble solids and vitamin C content, indicating a trade-off between yield and quality. Economically, all fertilized treatments were viable, with the highest return on investment (804.03%) achieved from the combined application of BSF frass and NPK, confirming that BSF frass is an effective organic amendment that enhances soil fertility, crop productivity, and profitability when used as a complementary input to inorganic fertilizers.

It is recommended to apply 3.0–4.5 t ha^{-1} BSF frass combined with the recommended rate of NPK (120-60-60 kg ha^{-1}) to maximize yield and economic returns, while using BSF frass as a complementary fertilizer rather than a sole nutrient source to ensure adequate nutrient supply and optimal crop performance. For markets prioritizing fruit quality such as sweetness and vitamin C, moderate application rates (1.5–3.0 t ha^{-1}) are advised to balance yield and quality. Further studies should focus on the long-term effects of BSF frass on soil health, optimization of application rates across different crops and soil types, and its integration with reduced inorganic fertilizer rates. Additionally, BSF frass should be promoted as a sustainable and climate-smart fertilizer option within integrated farming systems to reduce dependence on synthetic inputs and improve soil productivity.

The study was limited to specific field conditions, fertilizer rates, and a single crop and location, and therefore the findings may not be directly generalized to other environments, crops, or management systems without further validation.

Compliance with ethical standards

This study was conducted following standard agricultural research procedures under field conditions, ensuring proper handling of materials, accurate data collection, and adherence to established scientific methods throughout the experimental process.

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