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Soil Fertility, Agronomic Performance, and Yield Response of Glutinous Corn to Black Soldier Fly Frass as Organic Fertilizer

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Abstract

This study evaluated the effects of Black Soldier Fly (BSF) frass, applied alone and in combination with inorganic fertilizers, on soil chemical properties, growth, yield, and economic returns of glutinous corn under upland conditions in Maddela, Quirino from February to May 2025. The experiment was organized in a Randomized Complete Block Design (RCBD) with six fertilizer treatments: full recommended NPK, reduced NPK, BSF frass alone, and combined applications of BSF frass with inorganic fertilizer. Agronomic parameters measured included plant height, ear length and diameter, biomass, yield, and cost and return analysis. The initial soil was very strongly acidic (pH 4.61) and deficient in organic matter and essential nutrients. Application of BSF frass improved soil fertility, increasing soil pH to 6.87 - 7.51, organic matter to 3.16 - 6.43 percent, total nitrogen to 0.16–0.32 percent, available phosphorus to 37.27 - 111.14 ppm, and potassium to 478.66 - 1044.70 ppm. Significant improvements in plant growth and yield components were observed across treatments. The tallest plants at harvest were recorded in the reduced NPK plus BSF frass treatment (136.33 cm), while the longest ears were obtained from the full NPK plus BSF frass treatment (15.53 cm). Biomass accumulation was highest in the integrated full NPK plus BSF frass treatment (351.72 g). The highest computed yield was achieved in full NPK plus BSF frass at 13.06 tons, followed by full NPK alone at 10.82 tons, whereas reduced NPK combined with BSF frass produced competitive yields of 10.29 tons. Economic analysis showed that reduced NPK plus BSF frass generated the highest return on investment (305.21%), indicating improved profitability despite lower fertilizer input. Overall, BSF frass enhanced soil fertility, supported sustained crop growth, improved yield performance, and increased economic returns. The integration of BSF frass with reduced inorganic fertilizer rates is therefore recommended as a sustainable and cost-effective nutrient management strategy for glutinous corn production.

Keywords: Black soldier fly, Frass, Organic fertilizer, Soil fertility, Soil productivity

1. Introduction

The increasing global demand for sustainable and safe food production has intensified concerns regarding the environmental and agronomic impacts of conventional agricultural practices that rely heavily on synthetic fertilizers. Although inorganic fertilizers have significantly increased crop productivity, their excessive and prolonged use has contributed to soil degradation, nutrient imbalance, declining microbial diversity, and environmental pollution. In tropical agricultural systems such as those in the Philippines, continuous application of chemical fertilizers has been associated with soil acidification and the deterioration of soil health, which threaten long-term crop productivity and food security (Lal, 2015). These challenges highlight the need for sustainable nutrient management approaches that can maintain crop productivity while improving soil quality. Organic fertilizers and bio-based soil amendments have emerged as viable alternatives to synthetic fertilizers. Among these, Black Soldier Fly (BSF) (Hermetia illucens) frass has attracted increasing attention due to its nutrient composition and biological properties. BSF frass consists of larval excreta, shed exoskeletons, and decomposed organic substrates that contain essential plant nutrients while stimulating soil microbial processes (Diener et al., 2011; Beesigamukama et al., 2020). Studies have shown that frass can improve soil structure, enhance nutrient retention, and stimulate microbial activity that supports plant growth and nutrient mineralization (Klammsteiner et al., 2020). The production of BSF frass also contributes to circular economy principles by converting organic waste into valuable agricultural inputs. Through the bioconversion of organic materials, BSF larvae produce nutrient-rich fertilizer containing nitrogen, phosphorus, and potassium, as well as bioactive compounds such as chitin that may enhance plant growth and resilience. Despite these promising attributes, field-based evaluations of BSF frass in specific crop production systems remain limited, particularly under Philippine agroecological conditions. Glutinous corn (Zea mays var. ceratina) is an economically important crop cultivated for fresh consumption and local markets. However, declining soil fertility and rising fertilizer costs have increasingly constrained its productivity. Sustainable nutrient management strategies integrating organic fertilizers may enhance crop performance, improve soil fertility, and increase economic returns for farmers. Therefore, evaluating the agronomic response, soil fertility effects, and economic viability of BSF frass in glutinous corn production is essential to determine its potential as a sustainable fertilizer alternative.

1.1 Background of the Study on BSF Frass Fertilization in Glutinous Corn Production

The growing demand for sustainable agricultural production has raised concerns about the long-term environmental impacts of synthetic fertilizers. Excessive fertilizer application contributes to soil degradation, nutrient imbalance, and environmental contamination, which ultimately affect crop productivity and ecosystem stability. In tropical agricultural systems such as the Philippines, prolonged chemical fertilizer use has been linked to soil acidification and declining soil fertility (Lal, 2015). Organic fertilizers are increasingly recognized for their ability to restore soil fertility and support sustainable crop production. Black Soldier Fly (BSF) frass has emerged as a promising organic fertilizer produced through the bioconversion of organic waste by BSF larvae. This material contains essential macronutrients and beneficial microorganisms that enhance soil biological activity and nutrient availability (Diener et al., 2011; Beesigamukama et al., 2020). Studies indicate that frass can improve soil structure, nutrient retention, and microbial activity, thereby promoting plant growth and productivity (Klammsteiner et al., 2020). The utilization of BSF frass also supports circular economy and sustainable waste management principles. The bioconversion process transforms organic waste into valuable agricultural inputs while reducing environmental pollution associated with waste disposal. Frass contains significant amounts of nitrogen, phosphorus, and potassium, as well as bioactive compounds such as chitin that may enhance plant growth and resilience. Despite these advantages, research evaluating BSF frass in glutinous corn production systems remains limited.

1.2 Themes and Insights from Literature on BSF Frass as Organic Fertilizer

Organic fertilizers contribute to soil fertility by enhancing microbial activity and supplying essential plant nutrients required for crop growth (Islam et al., 2017). They provide macronutrients such as nitrogen, phosphorus, and potassium as well as secondary nutrients and micronutrients that support nutrient uptake and plant development (Wortmann et al., 2019). Integrated nutrient management strategies combining organic and inorganic fertilizers have been recommended to improve soil fertility and nutrient use efficiency (Vanlauwe et al., 2015). Black Soldier Fly frass has been identified as a nutrient-rich organic fertilizer produced from insect mass-rearing systems. Frass consists of insect excreta, uneaten substrate, and shed exoskeletons that contribute to soil fertility and agricultural productivity (Menino et al., 2021). The BSF bioconversion process is highly efficient, producing stable organic fertilizer in approximately five weeks, which is considerably faster than traditional composting methods (Lalander et al., 2016; Beesigamukama et al., 2021). This process is supported by the high waste reduction capacity of BSF larvae and their associated microbial communities (Diener et al., 2011; Vogel et al., 2018). Several studies have demonstrated that BSF frass can improve plant growth, nutrient uptake, nitrogen use efficiency, and crop yields in various agricultural systems (Quilliam et al., 2020). However, the nutrient composition of frass varies depending on the feed substrate used for BSF larvae (Gärttling and Schulz, 2019; Palma et al., 2020). On average, BSF frass contains approximately 3.4% nitrogen, 2.9% phosphate, and 3.5% potassium oxide, making it comparable to compound NPK fertilizers (Gärttling and Schulz, 2019). In addition to its nutrient value, BSF frass contains chitin, a bioactive compound known to stimulate plant defense mechanisms and suppress soil-borne pathogens (Gärttling et al., 2020). Chitin and its derivatives have been shown to improve plant resistance against pests and diseases by stimulating beneficial microorganisms and activating plant immune responses (Sharp, 2013; Hadwiger, 2013). Studies also indicate that chitin-based soil amendments can suppress plant pathogens and enhance crop yields without negatively affecting soil chemical properties (Korthals et al., 2014; Debode et al., 2016).

1.3 Global and Philippine Agricultural Context of BSF Frass Utilization

Globally, sustainable agriculture has become a priority due to environmental concerns associated with intensive farming practices. The excessive use of chemical fertilizers has contributed to declining soil fertility, environmental pollution, and reduced ecosystem resilience. As a result, research efforts have increasingly focused on alternative nutrient management strategies that integrate organic fertilizers and circular waste management systems. In many regions, BSF frass is being explored as a sustainable fertilizer produced through the recycling of organic waste streams. This approach aligns with global initiatives promoting circular bioeconomy systems that convert waste into valuable agricultural inputs. However, most studies evaluating BSF frass have been conducted in controlled environments or limited cropping systems. In the Philippines, research on BSF frass as a soil amendment remains limited, particularly for crops such as glutinous corn. Existing studies have primarily focused on other organic soil amendments such as biochar and vermicast in rice and corn cultivation. Consequently, empirical evidence on the agronomic performance of BSF frass under Philippine upland farming conditions remains scarce.

1.4 Theoretical and Conceptual Basis for BSF Frass Use in Crop Fertilization

The use of BSF frass as an organic fertilizer is supported by theories of soil fertility management, nutrient cycling, and ecological agriculture. Organic nutrient sources enhance soil organic matter, improve microbial diversity, and promote nutrient cycling processes that sustain long-term soil productivity (Lal, 2015). Integrated nutrient management approaches further emphasize the combined use of organic and inorganic fertilizers to optimize nutrient availability while maintaining soil health (Vanlauwe et al., 2015). The circular economy concept also provides a conceptual foundation for the use of insect-based bioconversion systems. Through the conversion of organic waste into nutrient-rich fertilizer, BSF production reduces waste accumulation while generating sustainable agricultural inputs. These principles support the integration of BSF frass into crop production systems as a strategy for improving soil fertility and promoting sustainable agriculture.

1.5 Research Gaps in BSF Frass Application for Glutinous Corn Production

Despite increasing interest in BSF frass as an organic fertilizer, several knowledge gaps remain regarding its application in specific crops and environmental conditions. Most existing studies have been conducted under controlled conditions, with limited field-based evaluations of BSF frass in staple crops such as corn. Furthermore, the nutrient composition and fertilizing efficiency of BSF frass vary depending on feed substrates, production methods, and application rates (Gärttling and Schulz, 2019; Palma et al., 2020). These variations create uncertainty regarding optimal fertilizer application strategies and crop responses. In the Philippine context, scientific studies investigating the effects of BSF frass on crop growth, soil fertility, and economic viability remain limited. Research focusing specifically on glutinous corn production under upland conditions is particularly scarce. Addressing these gaps is necessary to determine whether BSF frass can serve as an effective and economically viable organic fertilizer for glutinous corn farmers.

1.6 Alignment of BSF Frass Fertilization with Relevant Sustainable Development Goals (SDGs)

This study contributes to several Sustainable Development Goals by promoting sustainable agricultural practices and resource-efficient nutrient management systems. The research aligns with SDG 2 (Zero Hunger) by exploring sustainable fertilization strategies that enhance crop productivity and soil fertility. It also supports SDG 3 (Good Health and Well-Being) by promoting reduced dependence on chemical fertilizers that may contribute to environmental contamination. The use of BSF frass also supports SDG 12 (Responsible Consumption and Production) through the recycling of organic waste into valuable agricultural inputs. The bioconversion process reduces waste accumulation while creating sustainable fertilizer alternatives. In addition, the study contributes to SDG 13 (Climate Action) by encouraging organic nutrient management practices that may reduce greenhouse gas emissions associated with synthetic fertilizer production and use. Finally, the research supports SDG 15 (Life on Land) by promoting soil health, microbial diversity, and sustainable land management practices.

1.7 Importance of the Study to Agricultural and Environmental Sustainability

This study contributes to multiple dimensions of sustainability, including environmental, agricultural, and socio-economic sustainability. From an environmental perspective, the use of BSF frass supports sustainable waste recycling and nutrient recovery, thereby reducing environmental pollution associated with organic waste disposal and excessive chemical fertilizer use. From an agricultural perspective, the integration of BSF frass into glutinous corn production systems may enhance soil fertility, nutrient cycling, and crop productivity. Organic amendments improve soil organic matter and microbial activity, which are essential for long-term soil health and climate-resilient farming systems. Socio-economically, the study may benefit farmers by identifying cost-effective fertilization strategies that reduce dependence on expensive synthetic fertilizers while maintaining crop productivity. Evaluating the return on investment (ROI) of different fertilizer treatments also provides practical insights for farmers and agricultural stakeholders seeking sustainable and economically viable crop production systems.

2. Materials and methods

2.1 Research Design

The study employed an experimental research design using a Randomized Complete Block Design (RCBD) with three replications to evaluate the effects of BSF frass and inorganic fertilizer combinations on glutinous corn production. Six fertilizer treatments were tested, including a control without fertilizer application, full and reduced rates of inorganic fertilizer, BSF frass alone, and integrated applications of BSF frass with inorganic fertilizer. Each block was subdivided into equal experimental plots measuring five meters by four meters with appropriate spacing between plots and blocks to minimize treatment interference. This design enabled the comparison of treatment effects on soil chemical properties, plant growth, yield attributes, and economic returns.

2.2 Locale of the Study

The study was conducted in an upland agricultural field with an experimental area of approximately 612 square meters. The area was prepared by clearing grasses, stubbles, and other plant residues prior to land preparation. Initial plowing was performed using a tractor, followed by a resting period to allow weed decomposition. A second plowing and harrowing were conducted two days before planting using an animal-drawn plow. Furrows were then constructed at a spacing of seventy-five centimeters to prepare the area for planting and fertilizer application.

2.3 Respondents of the Study

This study did not involve human respondents because it was conducted as a field experiment using glutinous corn as the experimental crop. The focus of the research was on evaluating plant growth performance, soil chemical properties, yield attributes, and economic returns under different fertilizer treatments involving BSF frass and inorganic fertilizers.

2.4 Sample and Sampling Procedure

Soil samples were randomly collected from the experimental field prior to land preparation. The collected soil was processed through pulverizing, air-drying, grinding, and screening to obtain a uniform composite sample. A one-kilogram portion of the composite soil sample was submitted to the Integrated Soils Laboratory of the Cagayan Valley Research Center in Ilagan City, Isabela for laboratory analysis of soil pH, organic matter, nitrogen, phosphorus, potassium, and selected micronutrients. To examine the effect of BSF frass on soil chemical properties, a soil incubation experiment was conducted. One kilogram of air-dried soil was placed in polyethylene containers and mixed with varying amounts of BSF frass at rates of fifty, one hundred, one hundred fifty, two hundred, and two hundred fifty grams per kilogram of soil. The mixtures were homogenized and maintained at field capacity by adding water as needed throughout the incubation period. Each treatment had three replicates and was incubated for two months. After the incubation period, soil samples were collected for analysis of pH, organic matter content, and nutrient levels using standard laboratory methods. Additional samples were submitted to the Bureau of Soils and Water Management for microbial count determination.

2.5 Research Instrument

Laboratory equipment and standard soil analysis methods were used to determine the chemical properties of both soil and BSF frass, including pH, organic matter, nitrogen, phosphorus, potassium, and selected micronutrients. Measurement tools such as rulers and vernier calipers were used to determine plant height, ear length, and ear diameter during data collection. Weighing scales were used to measure biomass and yield parameters. Soil laboratory services from the Integrated Soils Laboratory of the Cagayan Valley Research Center were utilized to obtain accurate soil chemical analyses prior to and after the experimental treatments.

2.6 Data Gathering Procedure

BSF frass used in the study was procured from the local government unit of Angeles City, Pampanga, while glutinous corn seeds (Purple EW variety) were obtained from an agricultural supply store in Maddela, Quirino. Planting was carried out by placing two seeds per hill at a spacing of twenty centimeters within furrows spaced seventy-five centimeters apart. The seeds were covered with fine soil and lightly pressed to ensure proper soil-seed contact. Replanting of missing hills was conducted five days after planting to maintain uniform plant population. Fertilizer application was based on the results of soil analysis. Complete fertilizer (14-14-14) and urea (45-0-0) served as the inorganic fertilizer sources. One-half of the recommended nitrogen and the full amount of phosphorus and potassium were applied as basal fertilizer ten days after planting, while the remaining nitrogen was side-dressed during hilling-up at twenty-five days after planting. BSF frass was applied as a soil amendment within the furrows before planting at a rate of three tons per hectare. Crop management practices were implemented throughout the growing period to ensure healthy plant development. Off-baring was performed three weeks after planting when the plants reached knee height. Hand weeding and cultivation were conducted to control weeds and maintain soil conditions. Regular monitoring was undertaken to detect and remove diseased plants, while insect infestations were managed using insecticides applied according to manufacturer recommendations. Harvesting was conducted when corn ears reached the soft dough stage. Twelve representative plants were randomly selected from each plot for measurement of growth and yield parameters. Corn ears from these plants were measured for length, diameter, and weight, while the entire plant was cut at ground level to determine biomass weight. Yield per net plot was measured by weighing all corn ears harvested from the plot, and the results were used to compute projected yield per hectare.

2.7 Data Analysis Techniques

The collected data on soil properties, plant growth, yield components, and biomass were subjected to statistical analysis using the Statistical Tool for Agricultural Research (STAR) software. Analysis followed the Randomized Complete Block Design to determine differences among treatment means. Treatment comparisons were conducted using Tukey's Honest Significant Difference (HSD) test at the one percent level of significance. An economic evaluation was also conducted using a cost and return analysis. Production costs were calculated based on the prevailing prices of farm inputs and labor within the study area. Gross income was determined using the market price of corn per kilogram, while net income was obtained by subtracting the total cost of production from the gross income. Return on investment was then computed by dividing the net income by the total production cost and multiplying the result by one hundred to determine profitability.

3. Results and Discussion

3.1 Soil Fertility and Nutrient Characteristics

3.1.1 Initial Soil Chemical Properties

The soil used in the experiment was characterized by very strongly acidic conditions with a pH of 4.61. Organic matter was very low at 1.91 percent, while organic carbon and nitrogen were also low at 1.11 percent and 0.09 percent, respectively. Available phosphorus was extremely low at 1.59 ppm, and exchangeable potassium measured 79.70 ppm, indicating limited nutrient availability and poor soil fertility. These results indicate that the experimental soil was nutritionally deficient and required nutrient supplementation for optimal crop production. Soil pH strongly influences nutrient availability by affecting chemical reactions and nutrient forms in the soil. Low organic matter levels reduce soil structure stability, nutrient retention, and microbial activity, which are essential for sustainable crop production. The low phosphorus level is also below the critical threshold required for most crops, indicating a strong likelihood of nutrient limitation (Brady & Weil, 2017; Havlin et al., 2014). Potassium deficiency further limits plant physiological processes such as enzyme activation, water regulation, and stress tolerance (Marschner, 2012). Therefore, the initial soil condition highlights the need for nutrient amendments to improve soil fertility and crop productivity.

3.1.2 Nutrient Composition of BSF Frass

Laboratory analysis showed that the BSF frass had a slightly alkaline pH of 7.27 and very high organic matter content of 70.18 percent. Organic carbon was measured at 40.70 percent, while nitrogen, phosphorus, and potassium levels were also high. The product had a C/N ratio of 11.59, indicating a mature organic amendment with rapid decomposition potential. The frass also contained micronutrients such as copper, zinc, manganese, and iron. These characteristics indicate that BSF frass is a nutrient-rich organic fertilizer capable of improving soil fertility. Organic matter improves soil structure, water retention, nutrient storage, and microbial activity, all of which contribute to plant growth (Brady & Weil, 2017; Lal, 2015). Organic carbon enhances soil aggregation and nutrient retention capacity, thereby supporting sustainable crop productivity (Havlin et al., 2014). The narrow C/N ratio suggests rapid mineralization and availability of nitrogen to plants. In addition, the presence of micronutrients such as iron, manganese, copper, and zinc contributes to enzyme activation, chlorophyll synthesis, and metabolic processes in plants (Marschner, 2012; Alloway, 2008). Unlike most inorganic fertilizers that primarily supply nitrogen, phosphorus, and potassium, BSF frass provides a broader nutrient spectrum that can enhance soil fertility and plant nutrition (Havlin et al., 2014; Brady & Weil, 2017).

3.1.3 Soil Properties After BSF Frass Application

Application of BSF frass improved the chemical properties of the soil across all treatments. Soil pH increased to a range between slightly acidic and slightly alkaline conditions. Organic matter increased progressively with higher frass rates, reaching more than six percent at higher application levels. Total nitrogen, available phosphorus, and exchangeable potassium also increased substantially as the rate of BSF frass increased. The improvement in soil chemical properties indicates that BSF frass contributed significant organic inputs and nutrients to the soil. Higher organic matter levels enhance soil aggregation, water-holding capacity, and cation exchange capacity, which improve nutrient retention and microbial activity (Brady & Weil, 2017; Lal, 2015). The increase in nitrogen indicates that BSF frass serves as a source of mineralizable nitrogen that can sustain plant growth over time (Havlin et al., 2014). Similarly, higher phosphorus levels suggest improved phosphorus availability through microbial activity and organic acid production stimulated by organic amendments (Marschner, 2012). The increase in potassium also supports plant physiological processes such as water regulation, enzyme activation, and stress tolerance (Havlin et al., 2014). These findings demonstrate that BSF frass enhances soil fertility and nutrient cycling, supporting improved crop productivity. Similar improvements in soil nutrient status have been reported when insect frass is used as an organic amendment (Beesigamukama et al., 2020; Klammsteiner et al., 2020).

3.2 Agronomic Performance of Glutinous Corn

3.2.1 Plant Height

Plant height varied significantly among fertilizer treatments. The tallest plants during early growth were observed in treatments receiving combined applications of BSF frass and inorganic fertilizer. Treatments with integrated fertilization produced taller plants than the unfertilized control and the treatment with BSF frass alone. At harvest, plants receiving BSF frass combined with reduced inorganic fertilizer rates recorded the greatest height, followed closely by treatments with full inorganic fertilizer rates. The improved plant height observed in treatments containing BSF frass indicates enhanced nutrient availability and improved soil conditions. Organic amendments gradually release nutrients through microbial decomposition, which sustains plant growth during later stages of development (Havlin et al., 2014; Marschner, 2012). Integrated nutrient management practices provide both readily available nutrients from inorganic fertilizers and slow-release nutrients from organic sources, resulting in balanced plant nutrition and improved crop growth (Diacono & Montemurro, 2010; Beesigamukama et al., 2020). The comparable growth between reduced NPK combined with BSF frass and full NPK treatments suggests that BSF frass can partially substitute inorganic fertilizers while maintaining crop performance.

3.2.2 Ear Length and Ear Diameter

Significant differences were also observed in ear length and ear diameter among fertilizer treatments. The longest and thickest corn ears were produced by treatments receiving both inorganic fertilizer and BSF frass. Treatments receiving only inorganic fertilizer also produced relatively large ears, while the control treatment produced the smallest ear size. BSF frass alone improved ear size compared with the unfertilized treatment but did not reach the same level as integrated fertilizer treatments. The improved ear development in treatments receiving BSF frass suggests enhanced nutrient availability during reproductive growth stages. Nitrogen, phosphorus, and potassium are essential for reproductive development and assimilate translocation in maize. Organic amendments improve soil structure, microbial activity, and nutrient retention, which support continuous nutrient uptake during grain formation (Havlin et al., 2014; Marschner, 2012). The comparable ear development between reduced NPK combined with BSF frass and full NPK treatments indicates improved nutrient use efficiency. Integrated fertilization has been shown to improve yield components in maize by synchronizing nutrient availability with plant demand (Diacono & Montemurro, 2010; Beesigamukama et al., 2020).

3.2.3 Biomass Production

Biomass production differed significantly among treatments. The highest biomass accumulation was observed in plants receiving combined applications of BSF frass and full inorganic fertilizer rates. Treatments with inorganic fertilizer alone produced lower biomass than integrated fertilization but still exceeded the control. Plants treated with BSF frass alone produced greater biomass than the unfertilized treatment but less than those receiving inorganic fertilizer. The higher biomass production in treatments combining BSF frass and inorganic fertilizers indicates improved nutrient availability and better soil conditions that supported plant growth. Biomass accumulation in maize is strongly influenced by adequate nitrogen supply, balanced phosphorus and potassium nutrition, and favorable soil physical conditions (Marschner, 2012; Havlin et al., 2014). Organic amendments increase soil organic matter, enhance microbial activity, and improve nutrient retention, which prolong nutrient availability throughout the cropping season (Brady & Weil, 2017; Lal, 2015). These improvements contribute to increased vegetative growth and dry matter accumulation. Organic amendments such as BSF frass also improve soil structure and water-holding capacity, which further supports plant growth.

3.3 Yield Performance of Glutinous Corn

The yield of glutinous corn differed significantly among fertilizer treatments. The unfertilized control produced the lowest yield. Application of BSF frass alone increased yield substantially compared with the control. Treatments receiving inorganic fertilizer produced higher yields than those receiving BSF frass alone, while the highest yield was recorded in the treatment combining BSF frass with the full recommended rate of inorganic fertilizer. The higher yield observed in integrated fertilizer treatments demonstrates the complementary effects of organic and inorganic nutrient sources. Inorganic fertilizers provide readily available nutrients that support early crop growth, while organic amendments such as BSF frass supply slow-release nutrients and improve soil biological processes (Havlin et al., 2014; Marschner, 2012). Organic amendments also improve soil aggregation, nutrient retention, and microbial activity, which enhance nutrient uptake efficiency and sustain crop productivity (Brady & Weil, 2017; Lal, 2015). Similar findings have been reported in studies where Black Soldier Fly frass improved maize productivity and nutrient use efficiency when combined with mineral fertilizers (Beesigamukama et al., 2020; Schiavone et al., 2022). These results indicate that BSF frass functions as a complementary nutrient source that enhances soil fertility and supports stable yield performance under integrated fertilization systems.

3.4 Economic Viability of BSF Frass Application

Economic analysis showed that fertilizer treatments differed considerably in production cost, gross income, net income, and return on investment. The treatment combining BSF frass with reduced inorganic fertilizer rates produced the highest return on investment, indicating the most economically efficient fertilization strategy. Although the treatment combining BSF frass with the full recommended fertilizer rate produced the highest yield, its return on investment was lower due to higher production costs. These findings demonstrate that profitability in crop production depends not only on yield but also on input costs. Integrated nutrient management strategies that combine organic amendments with reduced inorganic fertilizer rates can improve economic returns by maintaining crop productivity while lowering fertilizer expenses. Previous studies have shown that combining organic and inorganic fertilizers improves nutrient use efficiency and profitability in crop production systems (Diacono & Montemurro, 2010; Beesigamukama et al., 2020). The results therefore suggest that integrating BSF frass with reduced inorganic fertilizer rates provides a cost-effective and sustainable nutrient management strategy for glutinous corn production.

4. Conclusion & Recommendations

The study demonstrated that the application of Black Soldier Fly (BSF) frass significantly improved soil fertility by increasing soil pH, organic matter, nitrogen, phosphorus, and potassium levels, thereby enhancing nutrient availability in the soil. The integration of BSF frass with inorganic fertilizers improved agronomic performance, including plant height, ear characteristics, biomass accumulation, and yield of glutinous corn compared with the control and single-source fertilization treatments. The combined application of BSF frass with full NPK fertilizer produced the highest biomass and yield, while BSF frass integrated with reduced NPK rates achieved comparable crop performance, indicating a synergistic interaction between organic and inorganic nutrient sources. Economic evaluation further revealed that the combination of BSF frass with reduced inorganic fertilizer rates generated the highest return on investment, demonstrating that integrated fertilization can improve profitability while maintaining productivity. Overall, BSF frass proved to be an effective organic amendment that enhances soil health, supports crop growth, and contributes to sustainable and economically viable glutinous corn production.

Based on the findings of the study, the integration of BSF frass with reduced rates of inorganic fertilizer is recommended as an effective nutrient management strategy for glutinous corn production, as it can improve yield and profitability while reducing reliance on synthetic fertilizers. BSF frass may be incorporated into fertilization programs as a complementary organic amendment to enhance soil organic matter, nutrient retention, and soil biological activity, thereby supporting long-term soil fertility. Further studies are recommended to evaluate the long-term effects of repeated BSF frass application on soil properties and crop productivity, determine appropriate application rates and timing under different agroecological conditions, and assess its effectiveness in other crops and cropping systems. In addition, agricultural extension agencies and policymakers may promote BSF frass as a sustainable fertilizer alternative that supports climate-resilient agriculture and circular waste management initiatives.

The study was conducted under specific upland field conditions within a single cropping season, and the results therefore reflect the response of glutinous corn under the environmental and soil conditions present during the experimental period. Variations in climatic conditions, soil characteristics, pest incidence, and other environmental factors may influence crop response to BSF frass and fertilizer treatments in other locations or seasons. Consequently, the findings should be interpreted within the context of the study site and duration, and further research is necessary to validate the results under different agroecological environments and long-term production systems.

Compliance with ethical standards

This study was conducted by the author as an experimental field investigation evaluating the effects of Black Soldier Fly (BSF) frass and inorganic fertilizer combinations on soil properties, plant growth, yield, and economic returns of glutinous corn under upland conditions. The research involved soil sampling, laboratory analysis, and crop production experiments using standard agronomic and soil science procedures. The study did not involve human participants or animals and was conducted following established agricultural research practices and methodological procedures consistent with experimental crop production studies.

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