

Research article

Supplementation of Inorganic Fertilizer by Black Soldier Fly Frass Enhances Plant growth, Yield, and Economic Return of Yellow Corn (*Zea mays* var. *indenata*)

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Abstract

The rising cost of synthetic fertilizers, driven by increasing raw material prices, poses a significant challenge to corn farmers and national food security. As a sustainable alternative, black soldier fly frass (BSFF) offers promise due to its nutrient-rich composition and lower production cost. This study evaluated the agronomic and economic potential of BSFF as an organic fertilizer for yellow corn (*Zea mays* var. *indenata*) under a randomized complete block design (RCBD) with six treatments: T1 (control), T2 (100% inorganic fertilizer or IF), T3 (100% BSFF), T4 (75% BSFF + 25% IF); T5 (50% BSFF + 50% IF); and T6 (25% BSFF + 75% IF), with three replications. The results revealed that T6, although slightly behind T2 in plant height, leaf number, and tasseling and silking times due to the immediate nutrient availability of IF, achieved comparable ear length, diameter, and grain yield. Economically, T6 produced the highest net benefit, surpassing T2 by 10.77%. These findings suggest that partial substitution of synthetic fertilizer with BSFF can be a cost-effective and sustainable strategy without significantly compromising productivity.

Keywords: cost-benefit analysis; *Hermetia illucens*; organic fertilizer; nutrient management; sustainability

1. Introduction

Corn (commonly referred to as maize), an important staple crop alongside rice, plays a critical role in the Philippines' food supply and livestock feed industry (Biñas, 2021; Libron et al., 2021). While white corn is a key rice substitute, yellow corn is a principal ingredient in animal feed and industrial products. As a vital grain crop, maize significantly contributes to national food security and rural livelihoods (Biñas, 2021). However, its production faces mounting challenges, particularly from biotic stresses like pests and diseases that may reduce yields by over 30% (Grote et al., 2021), a situation expected to worsen with climate change and the proliferation of susceptible varieties (Deutsch et al., 2018).

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In recent years, maize production has shown modest gains, but these are constrained by declining soil fertility, limited access to fertilizers, and inadequate farmer knowledge (CGIAR, 2019). Fertilization plays a pivotal role in maize cultivation, as it supplies essential macronutrients (nitrogen, phosphorus, and potassium or NPK), which are critical for optimal growth and development of plants (Sinha & Tandon, 2020). Nitrogen deficiency, for instance, stunts growth and reduces leaf photosynthesis, although Ning et al. (2018) found that nitrogen-deficient maize leaves had higher starch concentrations which were attributed to the accumulation of larger starch granules in bundle sheath cells. Phosphorus deficiency, on the other hand, reduces the leaf area index and limits the canopy's ability to absorb photosynthetically active radiation (PAR) (Sinha & Tandon, 2020). In contrast, potassium deficiency has been associated with impaired root and shoot growth, with studies indicating reductions in root system length, surface area, diameter, and volume (Du et al., 2017).

As population growth intensifies food demand, farmers increasingly rely on synthetic fertilizers for higher yields due to their rapid nutrient availability (Biñas, 2021). However, long-term dependence on these inputs contributes to soil degradation, nutrient leaching, and environmental harm (Ding et al., 2016). Moreover, the rising and volatile prices of imported chemical fertilizers which often exacerbated by global market shocks, pose economic burdens for smallholder farmers (Biñas, 2021). Organic fertilizers, while beneficial to soil health, release nutrients more slowly and may not meet crop needs during critical growth stages (Zhai et al., 2022).

To overcome these challenges, integrating organic and inorganic fertilizers is increasingly promoted as a sustainable nutrient management strategy. This approach improves soil structure and microbial activity, enhances moisture retention, and ensures immediate nutrient availability while reducing long-term soil degradation (Roba, 2018; Liu et al., 2020). Biñas (2021) also emphasized that it is particularly suitable for high-demand hybrid maize varieties.

One promising organic input is black soldier fly frass (BSFF), a nutrient-rich byproduct of *Hermetia illucens* larvae that can improve soil health and crop yield (Beesigamukama et al., 2020). *Hermetia illucens* is commonly utilized in organic waste processing, where both insect biomass and frass are reclaimed from waste streams and refined into products such as soil fertilizers (Aznar-Sánchez et al., 2019). Efforts to recycle organic waste using *H. illucens* larvae have gained recognition as a low-cost method for producing high-quality protein for animal feed and organic fertilizers. Optimizing the substrate composition is key to improving black soldier fly larvae (BSFL) performance and enhancing frass fertilizer quality, with a carbon-to-nitrogen (C/N) ratio of 15 shown to improve nutrient uptake, boost nitrogen and phosphorus retention, and accelerate compost maturation (Beesigamukama et al., 2021). BSFF is fortified with nitrogen, phosphorus, and potassium, and studies in other countries have demonstrated its potential to improve soil fertility and consequently increase crop productivity, particularly in maize production (Beesigamukama et al., 2020). Additionally, BSFF presents economic advantages. In the Philippines, fertilizer costs account for a significant portion of corn production expenses, and market volatility has increased the financial risks of relying solely on synthetic inputs (Biñas, 2021). Since BSFF is often produced locally from organic waste, its cost is generally lower than commercial chemical fertilizers (Beesigamukama et al., 2021), and studies report that partial substitution with BSFF can maintain yields while reducing input costs, thus improving net income for farmers (Zhai et al., 2022). However, studies related to combining BSFF and inorganic or synthetic fertilizers in tropical maize-growing regions remain limited, which highlights the need for further exploration to unlock potential ecological and economic benefits. While inorganic fertilizers offer immediate nutrients,

organic fertilizers like BSFF contribute to long-term soil health, which makes their combination a promising strategy for sustainable farming.

Hence, this study was conducted to evaluate the growth and yield performance of yellow corn (*Zea mays* var. *indenata*) when supplemented with BSFF organic fertilizer in combination with the recommended rate of inorganic fertilizer at varying ratios. Key agronomic traits and yield components were measured and analyzed, along with the cost-effectiveness of different fertilizer treatments. Economic returns were evaluated to assess the financial viability of integrating BSFF into maize fertilization practices.

2. Materials and Methods

The study was implemented at the research area of the University of Southeastern Philippines, Tagum-Mabini Campus, Mabini Unit, Pindasan, Mabini, Davao de Oro, from April to August of 2022. The area is characterized by plain topography, a tropical climate with a transition from the dry season (April to early May) to the wet season (mid-May to June), and sandy clay loam soil. The planting material used in this experiment was the Yellow Round-up Ready variety, which has a maturation period of 115 days after planting (DAP). The IF, which included urea (46-0-0), single superphosphate (SSP, 0-18-0), and muriate of potash (MOP, 0-0-60), as well as the BSFF, were sourced from a local agricultural supply store in Tagum City, Davao del Norte, Philippines.

2.1 Experimental design and treatments

The experimental area covered a total of 414 m², including alleys and drainage. Each plot measured 3 m × 5 m. The study was laid out using a randomized complete block design (RCBD) with six treatments replicated three times, resulting in a total of 18 plots. Each replication included 10 sample plants per treatment. Adequate space for 1-m alleys between plots and 1.5-m alleys between replications was incorporated to facilitate field operations and ensure proper drainage. Treatments were as follows: T1: Control (no fertilizer); T2: IF (100%); T3: BSFF (100%); T4: BSFF (75%) + IF (25%); T5: BSFF (50%) + IF (50%); and T6: BSFF (25%) + IF (75%). The percentages refer to the proportion of the total recommended fertilizer mass applied per hectare, based on soil test recommendations (discussed in Sections 2.2 and 2.3).

2.2 Soil sampling and analyses

Composite soil samples were randomly collected from the experimental area using the zigzag sampling method at a depth of 30 cm. The samples were air-dried, pulverized, and analyzed at the Regional Soils Laboratory of the Department of Agriculture, Agdao, Davao City, Philippines. Both the soil samples and BSFF underwent chemical analyses following the methods described by Calapardo and Manigo (2024). The analyses included the following: soil pH, determined using the potentiometric method (Peech, 1965); soil organic matter content, assessed through the Walkley-Black method (Nelson & Sommers, 1982); available phosphorus (P) levels, quantified using the P-Bray II extraction method (Bray & Kurtz, 1945); and exchangeable bases, such as potassium (K), analyzed using the 1N NH₄OAc (ammonium acetate) extraction method and measured via microwave plasma-atomic emission spectrometry (MP-AES) 4200 (Metson, 1956).

The BSFF used was derived from *H. illucens* larvae reared on mixed fruit and vegetable waste and underwent chemical analysis prior to application. BSFF analysis

involved determining nitrogen (%) using the Kjeldahl method (Bremner, 1960). Phosphorus (%P) content was measured using colorimetric methods with a spectrophotometer, while the concentrations of potassium (K), calcium (Ca), magnesium (Mg), and copper (Cu) were assessed via atomic absorption spectroscopy (AAS) or inductively coupled plasma (ICP), following the AA-7000 method. Analytical results formed the bases for fertilizer recommendations, as reflected in Table 1.

Table 1. Results of soil analyses and fertilizer recommendation (kg per ha⁻¹) from the Regional Soils Laboratory of the Department of Agriculture Regional Field Office XI, Philippines

Soil Analysis Result				
Soil Type: Sandy Clay Loam	pH	Organic Matter	Phosphorus (ppm)	Potassium (ppm)
Result:	6.3	0.64%	7.87	701.7
Fertilizer Recommendation (kg ha ⁻¹)				
Recommendation:	1,000.00	275.00	337.50	12.50
Per treatment:				
T1 – Control (no fertilizer)	0.00	0.00	0.00	0.00
T2 – IF (100%)	0.00	275.00	337.50	12.50
T3 – BSFF (100%)	1,000.00	0.00	0.00	0.00
T4 – BSFF (75%)+ IF (25%)	750.00	68.75	84.38	3.13
T5 – BSFF (50%)+ IF (50%)	500.00	137.50	158.75	6.25
T6 – BSFF (25%)+ IF (75%)	250.00	206.25	253.13	9.38

Note: SSP means single superphosphate; MOP means muriate of potash.

The quantities of BSFF and IF applied in each treatment were based on soil analysis recommendations and calculated using the nutrient composition of each source, as summarized in Table 2. Laboratory analysis of the BSFF used in this study showed that it contained 1.50% total nitrogen (N), 2.34% phosphorus pentoxide (P₂O₅), and 1.98% potassium oxide (K₂O) per kilogram of dry sample. These concentrations were used to compute the actual amounts of nutrients supplied per hectare in each treatment.

2.3 Cultural management

The experimental area was meticulously prepared through a two-time plowing and harrowing process in order to achieve the desired soil tilth. For planting and thinning, seeds

Table 2. Computed amounts of nutrient content applied to yellow corn plants per treatment based on laboratory analyses of soil and BSFF

Treatments	BSFF Analyses			Inorganic Fertilizer			Total		
	Total N (1.50%)	P ₂ O ₅ (2.34%)	K ₂ O (1.98%)	Total N (Urea)	P ₂ O ₅ (SSP)	K ₂ O (MOP)	Total N	P ₂ O ₅	K ₂ O
T1 – Control (no fertilizer)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
T2 – IF (100%)	0.00	0.00	0.00	126.50	60.75	7.50	126.50	60.75	7.50
T3 – BSFF (100%)	15.00	23.40	19.80	0.00	0.00	0.00	15.00	23.40	19.80
T4 – BSFF (75%) + IF (25%)	11.25	17.55	14.85	31.63	15.19	1.88	42.88	32.74	16.73
T5 – BSFF (50%) + IF (50%)	7.50	11.70	9.90	63.25	28.58	3.75	70.75	40.28	13.65
T6 – BSFF (25%) + IF (75%)	3.75	5.85	4.95	98.88	45.56	5.63	102.63	51.41	10.85

Note: N = Nitrogen; P₂O₅ = Diphosphorus pentoxide; K₂O = Potassium oxide; SSP = Single superphosphate; MOP = Muriate of potash

of yellow corn were sown on ridges with two seeds per hill to ensure an optimal planting distance of 75 cm between rows and 25 cm between hills to promote proper root development, nutrient uptake, and overall crop performance. Ten days after sowing, thinning was performed, leaving one plant per hill. In terms of fertilizer application, BSFF was applied basally at planting, while IF was applied in two splits as a side dressing: the first at 15 DAP, and the second at 45 DAP. In terms of crop protection, herbicide was applied to control weeds, and synthetic pesticides were used when pests or diseases were detected. The plants were watered every morning, using a sprinkler. For harvesting, yellow corn was manually harvested at physiological maturity, approximately 105 DAP. The corn was harvested early in the morning and stored in a cool, shaded area to ensure quality handling throughout the process.

2.4 Data gathering and analyses

A calibrated meter stick was used to measure the height of the plant from the base to the tip of the plant at 15, 30, and 45 DAP. The number of leaves was counted at the same intervals, from the lower to the upper section of the plant. The number of days to 50% tassel was recorded by counting the days from planting to the point when 50% of the plants bore flowers. Similarly, the number of days to 50% silking was noted by counting the days from planting to the day when 50% of the plants started producing silk. Corn ear length was measured in centimeters by selecting 10 de-husked ears randomly from each

replicate. The same samples were used to determine the ear diameter using a tape measure around the middle of the ear. The weight of the corn ears, both with and without husks, was recorded in grams using a digital weighing scale, and the average weight across all treatments was calculated.

The total yield per plot was recorded and calculated using the formula for average yield per hectare (equation 1), while the net benefit (NB) analysis was performed following the method of Zhai et al. (2022) with slight modifications (equation 2), where AY represents the average yield; GP is the grain price based on the current farm gate price; FC includes the fixed costs, such as seed, herbicide and pesticide, labor, and machinery costs; and VC refers to the variable costs, mainly consisting of the costs of chemical fertilizers and commercial organic fertilizer. The unit is in Philippine Peso (PhP).

$$\text{Average Yield (kg ha}^{-1}\text{)} = (\text{plot yield (kg)} / \text{plot size}) \times 10,000 \text{ m}^2 \quad (1)$$

$$\text{NB (PhP ha}^{-1}\text{)} = (\text{AY} \times \text{GP}) - (\text{FC} + \text{VC}) \quad (2)$$

The collected data were subjected to analysis of variance (ANOVA) to assess the overall effects of the treatments on the measured variables. Following this, Tukey's honest significant difference (HSD) test was applied at a 5% significance level (95% confidence level) to identify specific differences between the treatment groups.

3. Results and Discussion

3.1 Agronomic characteristics

3.1.1 Plant height and leaf count

Fertilizer application significantly influenced the vegetative growth of yellow corn, as reflected in both plant height and number of leaves among all sampling periods (Figure 1). At 15, 30, and 45 DAP, plants treated with 100% IF (T2) recorded the greatest height, followed closely by those under the 25% BSFF + 75% IF treatment (T6). In contrast, the control treatment (T1), which received no fertilization, consistently showed the shortest plants. These trends are notable throughout the entire observation period. These findings demonstrate the essential role of external nutrient supply in supporting early vegetative development, particularly nitrogen which is critical for cell division and elongation (Sinha & Tandon, 2020).

The observed superior height in T2 and T6 relates to the immediate availability of nitrogen from inorganic fertilizers, which enhances internode expansion and leaf area development (Du et al., 2017; Libron et al., 2021). The performance of T6 (tailing T2) suggests that partial substitution of IF with BSFF can maintain growth vigor due to BSFF's slow-release nitrogen and its contribution to improved soil structure and microbial activity (Beesigamukama et al., 2020; Roba, 2018). While BSFF alone (T3) showed moderate plant height, its performance showed the value of nutrient mineralization over time, although less immediate than synthetic inputs (Purbajanti et al., 2019).

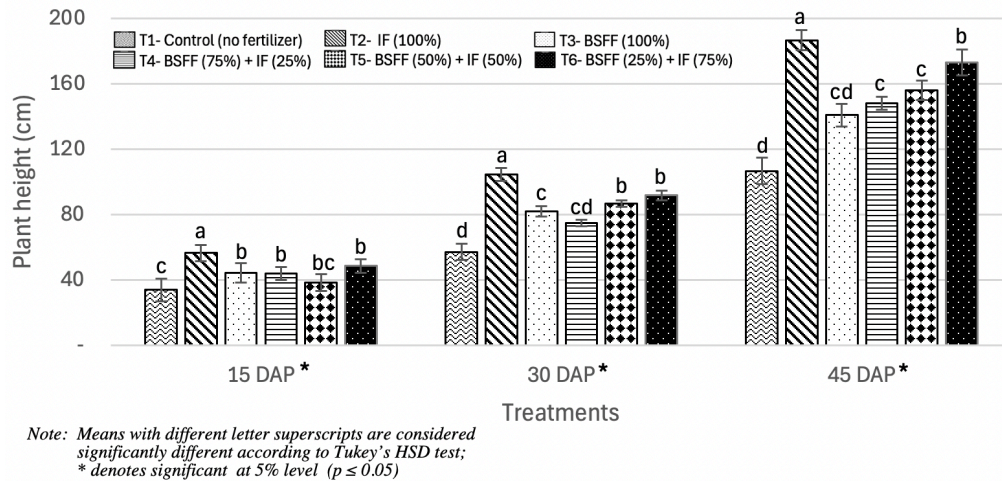


Figure 1. Plant height of yellow corn influenced by different ratios of BSFF and IF application at three growth periods

Similarly, leaf production followed a consistent pattern across growth stages (Figure 2). The highest number of leaves per plant was recorded in T2 throughout, with T6 producing comparable leaf counts at 45 DAP. T1 again had the lowest values which stresses the effect of nutrient availability on foliar development. Nitrogen plays a direct role in chlorophyll synthesis and leaf initiation, thus its deficiency limits canopy expansion and reduces plant's photosynthetic capacity (Zhang et al., 2020; Biñas, 2021). The reduced number of leaves under BSFF-alone treatments is attributed to gradual nutrient release, which may not fully meet the crop's peak demand during early vegetative stages.

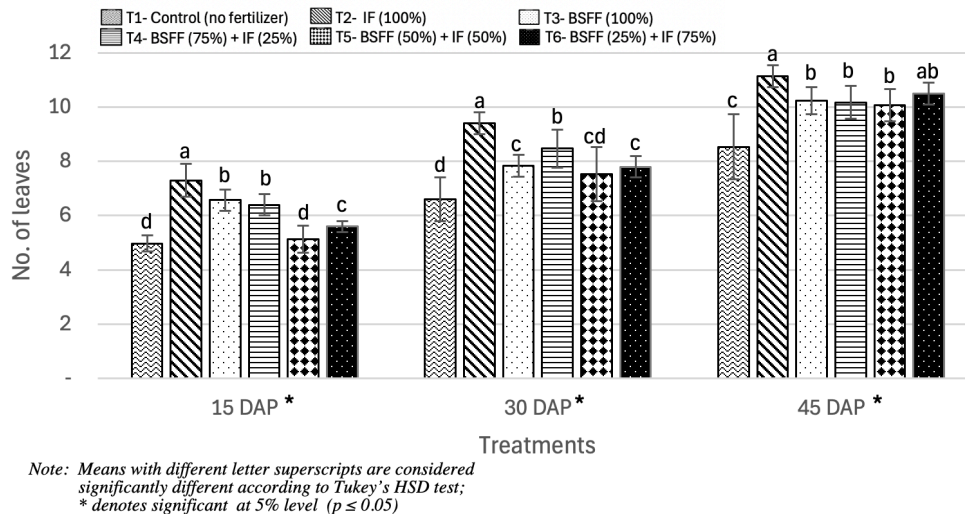


Figure 2. Number of leaves of yellow corn influenced by different ratios of BSFF and IF application at three growth periods

Biñas (2021) consistently highlighted the importance of balanced fertilization in promoting vegetative growth. The slight reduction in leaf count observed in organic-based treatments compared to full inorganic fertilizer applications suggests that while BSFF may not fully match the rapid nitrogen release profile of synthetic fertilizers, it can still support healthy plant growth. The availability of essential nutrients plays a crucial role in leaf development, and deficiencies in these nutrients are a primary factor which limits leaf production. The findings on leaf numbers produced aligns with the findings of Purbajanti et al. (2019), who observed that the mineralization of organic materials gradually released nutrients essential for plant growth. However, this process takes time, as organic fertilizers release nutrients more slowly but retain them in the soil for extended periods which provide long-term benefits. In contrast, inorganic fertilizers supply nutrients more readily, which promotes rapid plant growth and increased leaf production. Zhang et al. (2020) further emphasized that inorganic fertilizer application enhances leaf area development by increasing the number of leaves and consequently improved overall plant vigor.

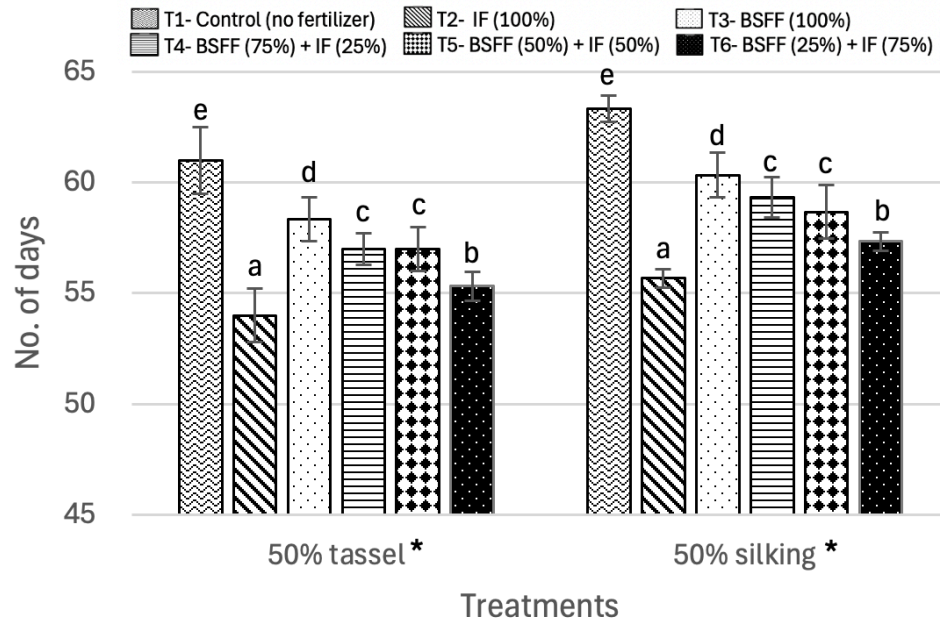
3.1.2 Days to 50% tassel and 50% silking

The timing of reproductive development in corn, particularly tasseling and silking, was significantly influenced by the different fertilizer treatments (Figure 3). Plants that received 100% IF (T2) exhibited the earliest tasseling (54 DAP) and silking (55.67 DAP), followed closely by those under T6 (25% BSFF + 75% IF), which reached 50% tasseling and silking at 55.33 and 57.33 DAP, respectively. In contrast, the control treatment (T1) exhibited the most delayed reproductive development, tasseling at 62 DAP and silking at 63.33 DAP. These results clearly reflect the role of nitrogen availability in initiating reproductive processes in maize (Sanagi et al., 2021).

Nitrogen is a key driver of reproductive growth. It promotes the development of reproductive sinks, influencing floral differentiation and timing (Mikkelsen & Hartz, 2008). The rapid transition to flowering observed in T2 and T6 is attributable to the immediate availability of nitrogen from inorganic fertilizer to meet the high nutrient demand of maize during this critical phase (Libron et al., 2021). The comparable performance of T6 indicates that supplementing inorganic fertilizer with BSFF can sustain sufficient nitrogen availability to trigger timely flowering while reducing total synthetic input.

On the other hand, treatments relying more heavily on BSFF alone (T3) or at higher proportions (T4 and T5) resulted in delayed tasseling and silking. This is conceivably due to the slower rate of nitrogen mineralization from organic sources, which may not immediately fulfill the crop's nutrient requirements during peak growth stages (Gebremikael et al., 2022). In this study, the BSFF applied had a relatively low nitrogen content (1.5%), which may have limited its capacity to drive early reproductive transitions independently.

The two-day gap observed between tasseling and silking in most treatments, particularly in T2 and T6, falls within the typical synchrony range for maize hybrids under favorable growing conditions (Nielsen, 2019). Tight synchrony between male and female flowering phases is critical for successful pollination and kernel set, and any delay in silking relative to tasseling may compromise yield potential. The effective synchrony seen in T6 further supports the viability of integrating BSFF with inorganic fertilizer as a strategy to maintain reproductive efficiency while enhancing sustainability.



*Note: Means with different letter superscripts are considered significantly different according to Tukey's HSD test; * denotes significant at 5% level ($p \leq 0.05$)*

Figure 3. Number of days to 50% tassel and 50% silking of yellow corn as influenced by different ratios of BSFF and IF application

3.2 Yield components

3.2.1 Corn ear length and diameter

Corn ear length and diameter are key yield components that directly influence grain weight and overall productivity. This study showed significant variation in these traits across fertilizer treatments (Figure 4). The longest and thickest ears were produced by plants under T6 (25% BSFF + 75% IF), closely followed by those in T2 (100% IF). In contrast, the shortest and narrowest ears were recorded in the control treatment (T1), which received no fertilization.

These results emphasize the importance of balanced nutrient supply during the reproductive phase of corn. Nitrogen, phosphorus, and potassium are particularly vital for ear development, as they contribute to kernel number, ear elongation, and cob filling (Sinha & Tandon, 2020; Grote et al., 2021). The desirable performance of T6 indicates that partial replacement of inorganic fertilizer with BSFF can effectively support ear development, presumably due to BSFF's contribution to improved soil structure, microbial biomass, and gradual nutrient release (Beesigamukama et al., 2020).

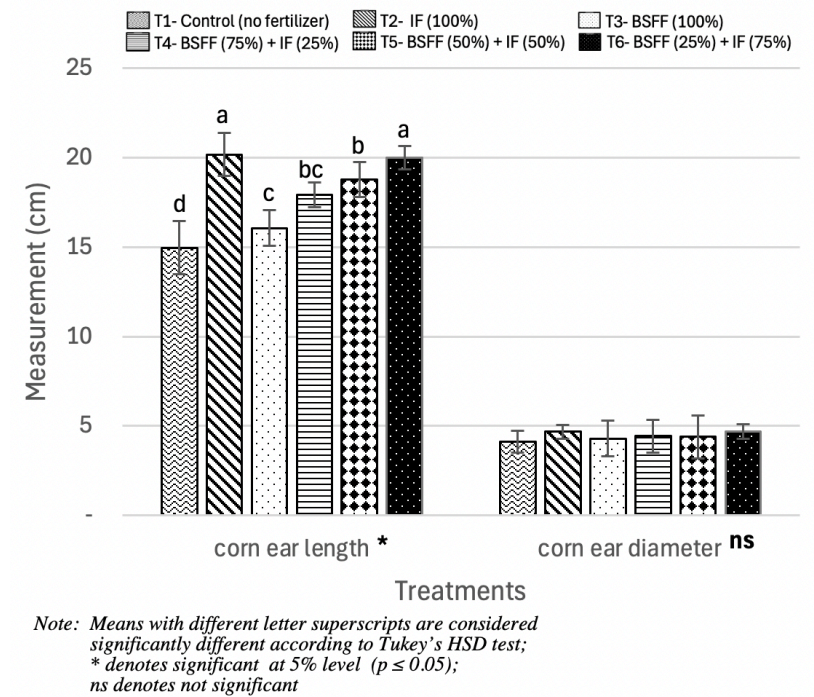


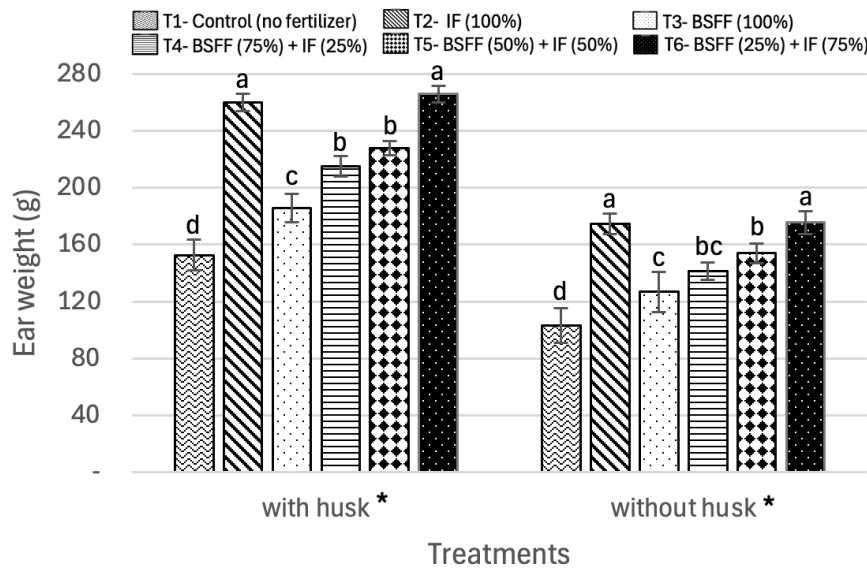
Figure 4. Corn ear length and diameter of yellow corn as influenced by different ratios of BSFF and IF application

The intermediate values observed in T3 (BSFF alone) and other combination treatments (T4 and T5) further demonstrate that while BSFF enhances long-term soil fertility, it may require supplementation to meet the peak nutrient demands of maize during cob formation. The mineralization process in BSFF, though beneficial over time, is typically slower compared to the immediate nutrient availability from synthetic fertilizers (Purbajanti et al., 2019; Gebremikael et al., 2022).

Additionally, the enhanced ear size in T6 supports the findings of Kebli and Sinaj (2017), who reported that BSFF-based fertilizers improve soil nutrient status and physical conditions conducive to reproductive growth. Furthermore, Lopes et al. (2022) highlighted that combining BSFF with chemical fertilizers significantly enhances yield parameters due to synergistic effects on nutrient uptake and physiological functions. The consistent increase in ear size observed in T6 underscores the practical potential of integrated nutrient management strategies in improving maize productivity while minimizing synthetic input reliance.

3.2.2 Corn weight with and without husk

Corn ear weight, both with and without husk, directly reflects yield potential and grain filling efficiency. Significant variations were observed among treatments (Figure 5). The heaviest ears occurred in T6 (25 % BSFF + 75 % IF) and T2 (100 % IF), while the lightest were in the control (T1). These results parallel trends in ear length and diameter, showing that combining bio-organic and inorganic fertilizers optimizes nutrient availability during the reproductive stage.



Note: Means with different letter superscripts are considered significantly different according to Tukey's HSD test;
 * denotes significant at 5% level ($p \leq 0.05$)

Figure 5. Corn ear weight with and without husk of yellow corn as influenced by different ratios of BSFF and IF application

The superior performance of T6 suggests that partial replacement of synthetic fertilizer with BSFF maintains high yield through improved soil structure, microbial activity, and gradual nutrient release (Beesigamukama et al., 2020; Gebremikael et al., 2022). Balanced nutrient supply is essential for kernel formation and cob filling. Nitrogen promotes grain number, phosphorus supports root and reproductive growth, and potassium aids carbohydrate translocation and water balance (Du et al., 2017; Sinha & Tandon, 2020).

It is also important to note that nutrient inputs across treatments were not equalized for total N, P, and K. While T2 received higher nitrogen and slightly more phosphorus than T6 (Table 2), T6 had greater potassium availability, likely due to BSFF supplementation. This may have contributed to its superior ear morphology, as phosphorus enhances root vigor and reproductive development, while potassium supports carbohydrate translocation, enzymatic activity, and water regulation, which are critical functions for grain filling and cob formation (Du et al., 2017; Sinha & Tandon, 2020). Moreover, the fertilizer application rates in this study were based on pre-planting soil analysis conducted by a certified soil laboratory. This ensured that site-specific nutrient deficiencies were addressed, enhancing the reliability and practical relevance of the treatments applied. The strong yield performance of T6 should be interpreted not only as an outcome of organic-inorganic integration but also considering its improved total nutrient profile, strategic nutrient timing, and feedstock-based nutrient quality. These findings underscore that nutrient quantity, not just fertilizer source, plays a critical role in determining yield traits. Future studies may benefit from standardizing NPK inputs across treatments or employing nutrient-equivalent designs to better isolate the effects of BSFF and assess its long-term agronomic benefits.

3.3 Economic benefit

Economic analysis is an essential component in evaluating the practical application of different fertilization strategies in crop production. In this study, the net benefit of each treatment was calculated by considering both the income from grain yield and the costs associated with production. The results revealed significant differences in net returns among treatments which emphasize the influence of nutrient management not only on crop productivity but also on farm profitability. Here, VC included treatment-specific inputs such as the cost of chemical fertilizers, BSFF, and fuel for fertilizer application. In contrast, FC comprised expenses consistent across treatments, including seeds, herbicide and pesticide application, labor, and machinery.

Among the six treatments evaluated, the application of 25% BSFF combined with 75% inorganic fertilizer (T6) was the most notable treatment which resulted in the highest net benefit of about PhP 304,595.90 per hectare (Table 3). This value was notably higher than the PhP 274,986.80 ha⁻¹ obtained from the 100% IF (T2) which marked a 10.77% increase in profit. This finding indicates that integrating BSFF with synthetic fertilizer not only sustains high yield performance but also improves cost-efficiency. The lowest net benefit, recorded in the control treatment (T1) at PhP 167,654.80 ha⁻¹, reinforces the critical role of fertilization in achieving economic viability in corn production.

The trend observed in Table 3 is visually supported by the bar graph shown in Figure 6, which depicts the significant differences in net benefit across treatments. The combined applications of BSFF and IF (T4, T5, and T6) produced higher net benefits than BSFF alone (T3) or the control (T1). Specifically, T6 (25% BSFF + 75% IF) achieved the highest net benefit, while T5 (50% BSFF + 50% IF) and T4 (75% BSFF + 25% IF) showed intermediate economic returns. This demonstrates that partial substitution of inorganic fertilizer with BSFF can enhance profitability, with higher proportions of IF generally supporting greater net benefit in this study.

Table 3. Economic benefit of yellow corn as influenced by different ratios of BSFF and IF application

Treatment	Average Yield (kg ha ⁻¹)	Grain Price (PhP kg ⁻¹)	Total Income (PhP ha ⁻¹)	Total Cost (VC + FC; PhP ha ⁻¹)	Net Benefit (PhP ha ⁻¹)
T1 – Control (no fertilizer)	11,720 ^e	20.09	235,454.80	67,800.00	167,654.80
T2 – IF (100%)	19,220 ^{ab}	20.09	386,129.80	111,143.00	274,986.80
T3 – BSFF (100%)	14,220 ^d	20.09	285,679.80	80,700.00	204,979.80
T4 – BSFF (75%) + IF (25%)	16,480 ^c	20.09	331,083.20	83,311.00	247,772.20
T5 – BSFF (50%) + IF (50%)	17,450 ^b	20.09	350,570.50	95,921.00	254,649.50
T6 – BSFF (25%) + IF (75%)	20,310 ^a	20.09	408,027.90	103,432.00	304,595.90

Notes: VC = Variable cost; FC = Fixed cost; Means with different letters indicate significant differences among treatments based on Tukey's HSD test at p<0.05.

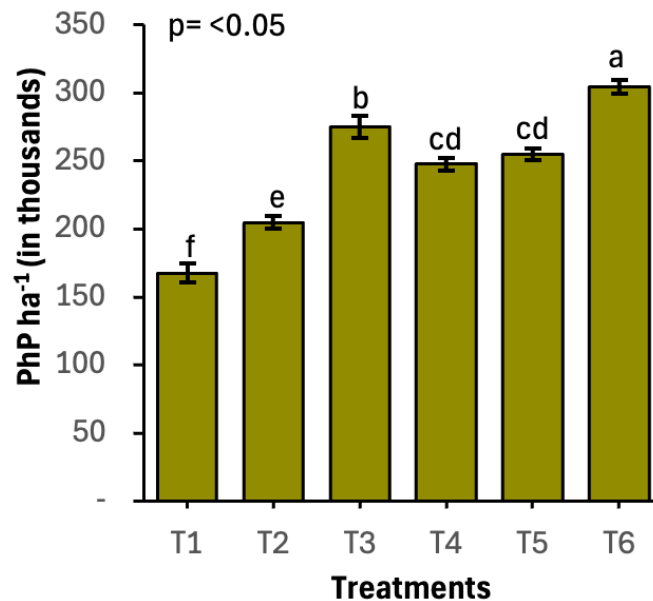


Figure 6. Net benefit (PhP ha⁻¹ in thousands) of yellow corn as affected by varying combinations of BSFF and IF applications. Bars with different letters indicate significant differences among treatments based on Tukey's HSD test at $p < 0.05$.

It is also important to consider that the nutrient levels, particularly nitrogen, phosphorus, and potassium, varied across treatments, which may have contributed to the observed economic differences. For instance, T6 not only received relatively high nitrogen levels but also benefited from additional phosphorus and potassium contributed by BSFF. These nutrients are essential for grain filling, kernel development, and stress tolerance, and their presence probably enhanced yield efficiency relative to the cost incurred. The economic superiority of T6 thus reflects not only the optimized balance of nutrient availability but also the reduced reliance on costly synthetic inputs.

These findings demonstrate the strong economic potential of integrating BSFF as a partial substitute for inorganic fertilizer. When applied in appropriate ratios, BSFF helps maintain high yield performance while lowering production costs, which offers a strategic advantage for resource-limited farmers. This cost-efficient and environmentally conscious approach supports the use of BSFF-based fertilization as a practical and sustainable nutrient management solution for yellow corn cultivation.

4. Conclusions

The findings of this study demonstrate that while the application of 100% inorganic fertilizer (IF) resulted in the most vigorous vegetative growth in yellow corn, the combination of 25% black soldier fly frass (BSFF) and 75% IF (T6) produced comparable yield performance and the highest net economic benefit. This suggests that partial substitution of synthetic fertilizer with BSFF can be a cost-effective and sustainable strategy without significantly compromising productivity.

The agronomic and economic performance of T6 highlights the potential of integrated nutrient management, particularly for resource-constrained farming systems that seeks to reduce reliance on costly chemical fertilizers. Moreover, the added contribution of BSFF to soil structure and fertility may provide longer-term benefits beyond immediate yield response. However, the variation in total nutrient inputs across treatments, particularly nitrogen, phosphorus, and potassium, should be taken into account when interpreting these results. Future studies are recommended to further evaluate the optimal BSFF–IF ratios under nutrient-balanced conditions and to investigate their long-term impacts on crop productivity, soil health, and microbial dynamics across multiple cropping cycles.

5. Authors' Contributions

Bryl I. Manigo: Conceptualization, project supervision, data analysis and interpretation, and reviewing and editing of manuscript. Albert Roy C. Sibuan: Conceptualization, project implementation, manuscript draft preparation, and data processing and analysis. Ulysses P. Besas: Conceptualization and reviewing and editing of manuscript.

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6. Conflicts of Interest

The authors declare that there are no conflicts of interest associated with this work.

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