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Research Article

Intercropping of Sweet Corn (*Zea mays* L. var. *saccharata*) and Turmeric (*Curcuma longa* L.) for the Management of Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) and its Economic Feasibility

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Abstract

This study evaluated the ecological, agronomic, and economic effectiveness of intercropping sweet corn (*Zea mays* L. var. *saccharata*) with turmeric (*Curcuma longa* L.) against monoculture sweet corn for the management of the fall armyworm, *Spodoptera frugiperda* (J. E. Smith), and enhancement of land productivity. The experiment was conducted over two successive sweet corn cropping cycles and one turmeric cycle in Indonesia. The results varied temporally: the first cropping cycle showed no significant effect on vegetative pest infestation or damage. However, in the second cycle, the established intercropping system significantly reduced the percentage of infested plants, leaf damage intensity, and larval populations of *S. frugiperda*. Crucially, ear infestation was significantly lower in the intercropping plots during both cycles. Agronomically, reduced pest pressure led to significantly higher sweet corn cob weight in the second cycle under intercropping than under monoculture. Economically, the intercropping system demonstrated superior financial viability, yielding nearly six times higher net profit. This profitability was confirmed by strong metrics: Revenue/Cost (R/C), Benefit/Cost (B/C), and Return on Investment (ROI) ratios of 2.50, 1.502, and 150.2%, respectively, all exceeding monocultures. The lower break-even point with intercropping also indicated superior land-use efficiency. These overall findings suggest that the sweet corn–turmeric intercropping system is a sustainable, profitable, and ecologically sound strategy for *S. frugiperda* management and improving agricultural resilience.

Keywords: *Spodoptera frugiperda*, intercropping, pest management, economic viability, productivity

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Sweet corn (*Zea mays* L. var. *saccharata*) is a vital global crop, yet its productivity is severely threatened by the invasive and highly polyphagous fall armyworm, *Spodoptera frugiperda* (J. E. Smith). Originating from the Americas, *S. frugiperda* has spread rapidly across Africa and Asia, with its presence in Indonesia confirmed in 2019, causing significant damage to sweet corn (Siswanto, Prasetyo, & Yuniarti, 2023; Syafria, Reflinaldon, & Nelly, 2023; Wilyus, Siregar, & Aulia, 2022). This pest's high fecundity, broad host range, and strong dispersal ability can lead to yield losses of up to 70% (Harrison et al., 2019). Over-reliance on synthetic insecticides for control has led to the development of resistance, environmental degradation, disruption of beneficial insects (Gutiérrez-Moreno et al., 2019), and escalating production costs (Hruska, 2019). The pest's adaptability and resistance to conventional methods (Yu, 2014) necessitate the adoption of ecologically sound alternatives.

Intercropping, the simultaneous cultivation of multiple crops, is a promising agroecological strategy that improves pest regulation, enhances biodiversity, and optimizes land-use efficiency (Brooker et al., 2015; Wilyus et al., 2025). Its mechanisms include interference with host-plant detection, enhanced natural enemy habitats, and modified microclimates unfavorable to pests (Letourneau et al., 2011; Ratnadass et al., 2012). Integrating aromatic or bioactive plants that release insecticidal or repellent secondary metabolites is particularly effective at reducing pest colonization and damage.

Turmeric (*Curcuma longa* L.) possesses well-documented pesticidal properties, from both leaves and rhizomes, with research focused on its rhizome compounds (curcuminoids, turmerone, essential oils) exhibiting insecticidal, antifeedant, and repellent effects against various pests, including *Spodoptera litura*, *Plutella xylostella*, and *Tribolium castaneum* (Rajashekar, Bakthavatsalam, & Shivanandappa, 2012). Turmeric contains volatile chemicals such as α-turmerone, curlone, ar-turmerone, β-sesquiphellandrene, α-zingiberene, germacrone, terpinolene, ar-curcumene, and α-phellandrene (Dosoky, Satyal, & Setzer, 2019). Beyond direct effects, turmeric indirectly influences pest populations by altering microhabitats and supporting natural enemies, aligning with Integrated Pest Management (IPM) principles (Harrison et al., 2019).

Agronomically, turmeric's 8–10-month maturity allows for intercropping with two to three sweet corn cycles, enabling multi-season pest suppression (Wilyus et al., 2025). However, most research on turmeric's pest-suppressive effects is limited to controlled conditions, failing to capture complex field interactions, and few studies investigate its role in intercropping, especially against the aggressive *S. frugiperda*. Furthermore, existing intercropping studies are often short-term, neglecting long-term ecological dynamics, pest recruitment, and the conservation of natural enemies across multiple cycles.

Economically, turmeric's high demand in the pharmaceutical and spice industries offers additional income for smallholder farmers, enhancing the feasibility of turmeric-based intercropping systems. While maize intercropping with legumes or cereals has been studied for *S. frugiperda* control (Midega et al., 2018), the sweet corn-turmeric combination remains largely unexplored. Comprehensive empirical field studies are needed to assess its performance across pest density, damage intensity, crop yield, and land use efficiency. Crucially, any viable pest management strategy must be economically sound. Therefore, alongside ecological indicators, robust economic assessments—including the Revenue/Cost (R/C) ratio, Benefit/Cost (B/C) ratio, Return on Investment (ROI), and Break-Even Point (BEP)—are essential for evaluating profitability and scalability (Kahan, 2013). This economic dimension is often neglected, representing a critical gap, particularly for smallholder farmers who prioritize profitability and low risk (Altieri, Funes-Monzote, & Petersen, 2015; Food and Agriculture Organization [FAO], 2017).

Therefore, this study addresses these gaps by evaluating the effectiveness of intercropping sweet corn with turmeric in managing *S. frugiperda* populations, reducing infestation damage, and

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improving land productivity. It further aims to analyze the system's ecological dynamics, including its impact on insect biodiversity, and to determine its economic feasibility through robust profitability metrics. This research contributes to understanding turmeric's functional role in pest-suppressive intercropping and supports the development of resilient, low-input, farmer-adopted agricultural practices in tropical regions.

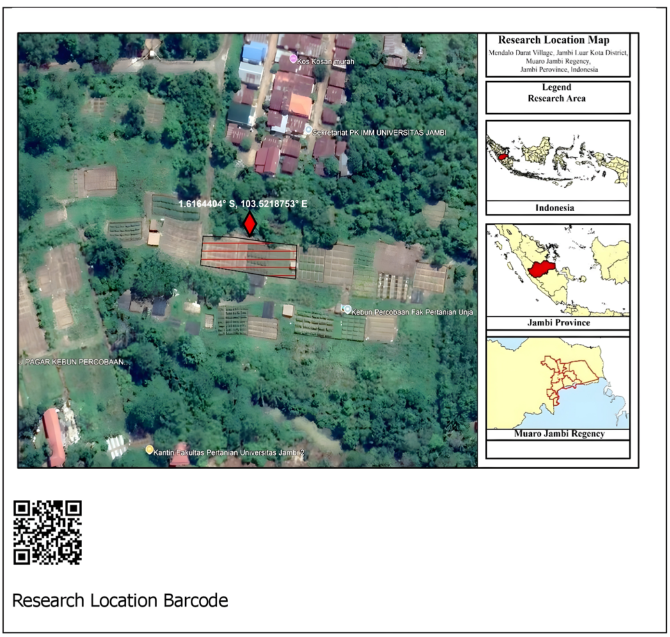
Materials and Methods

Study Area and Duration

This study was conducted at the Teaching and Research Farm and the Entomology Laboratory of the Faculty of Agriculture, Universitas Jambi, located in Mendalo Indah Village, Jambi Luar Kota Subdistrict, Muaro Jambi Regency, Indonesia, as shown in Figure 1. The experiment spanned from July 2024 to April 2025, covering two sweet corn cropping cycles and one turmeric cycle. Climatic conditions at the site during the study period were characterized by a monthly average temperature of 25.71 °C (ranging from a minimum of 23.05 °C to a maximum of 29.78 °C), an average monthly precipitation of 214.58 mm (with 17.33 rainy days), a relative humidity of 86%, and a mean daily sunshine duration of 6.90 hours (Climate Data, 2022).

Figure 1

Research Location



Experimental Design

The study employed a comparative field design to assess the effectiveness of two distinct cropping patterns: Treatment (A) Monoculture planting of sweet corn (*Zea mays* L. var. *saccharata*); and Treatment (B) Intercropping of sweet corn with turmeric (*Curcuma longa* L.). Each treatment was established in a single large plot measuring 20 m × 10 m (200 m^2), representing a replicated field trial in which the plot itself served as the experimental unit for measurement and comparison. A 10 m buffer zone, kept unplanted and weed-free, was maintained between the two treatment plots to prevent potential confounding effects, minimize insect movement, and ensure independence between the cropping systems. The experiment was conducted sequentially across two successive sweet corn cycles (Cycle 1 and Cycle 2) and a single turmeric cycle.

Planting Configuration

Treatment A (Sweet Corn Monoculture): Sweet corn seeds (Bonanza F1 hybrid variety, procured from a certified agricultural supply store) were planted by dibbling at a standard spacing of 75 cm × 40 cm. This resulted in a total population of 473 sweet corn plants within the plot.

Treatment B (Sweet Corn-Turmeric Intercropping): Turmeric seedlings, three months old with a minimum of three fully expanded leaves (sourced from local farmers in Ibru Village, Muaro Jambi Regency), were transplanted one week prior to the sweet corn sowing date. Turmeric was planted at a spacing of 75 cm × 40 cm. Sweet corn was then sown diagonally between the turmeric rows, following a 2:1 *Legowo row* pattern. This configuration resulted in a plant population of 473 turmeric clumps and 201 sweet corn plants within the plot.

For the second sweet corn cycle (Cycle 2), seeds were dibbled 15 days after Cycle 1 harvest, using the same planting positions as the initial sowing to maintain consistency in spatial arrangement and minimize disturbance to the established turmeric plants.

Land Preparation and Crop Maintenance

Land Preparation (Initial Cycle): The initial land preparation involved manual clearing and mechanized plowing and harrowing to a depth of 20-30 cm using a tractor. The soil was then manually leveled. Organic fertilization was standardized based on planting density. Chicken manure was applied at a rate of 250 kg per plot for the monoculture (Treatment A) and 500 kg per plot for the intercropping (Treatment B). For the turmeric in Treatment B, 650 planting holes (each 20 cm x 20 cm x 20 cm) were prepared prior to transplanting.

Land Preparation (Second Sweet Corn Cycle): Land preparation for Cycle 2 involved chopping and removing residual corn stubble, weed control, and shallow tillage. Supplemental organic fertilization was applied at a rate of 0.25 liters of chicken manure per planting hole to support the sweet corn's nutritional needs and rapid growth, as the established turmeric crop was already utilizing soil resources.

Crop Maintenance: Standardized crop maintenance practices were applied equally to both treatments. Fertilization used equivalent types and dosages of Urea, Triple Superphosphate (TSP), and Potassium Chloride (KCl), applied at key growth stages in accordance with established sweet corn nutrient requirements. Manual irrigation was provided as needed. Weed management was carried out regularly through manual weeding, often combined with hilling to support plant stems. Crucially, no synthetic chemical pesticides, including insecticides or fungicides, were applied throughout the entire study duration to allow the natural dynamics of the *S. frugiperda* population and the effects of the intercropping system to be observed without chemical interference.

Sampling Method and Observational Units

A systematic sampling method was applied to select observation units within each treatment plot. In both treatments, five sample plots were established, each comprising 25 corn plants. These plants served as the primary units for recording all observational parameters related to *S. frugiperda* incidence and crop productivity. Observations were conducted at regular intervals throughout crop growth to ensure accurate, consistent data collection. The experimental layout and sample plot configuration are illustrated in Figure 2.

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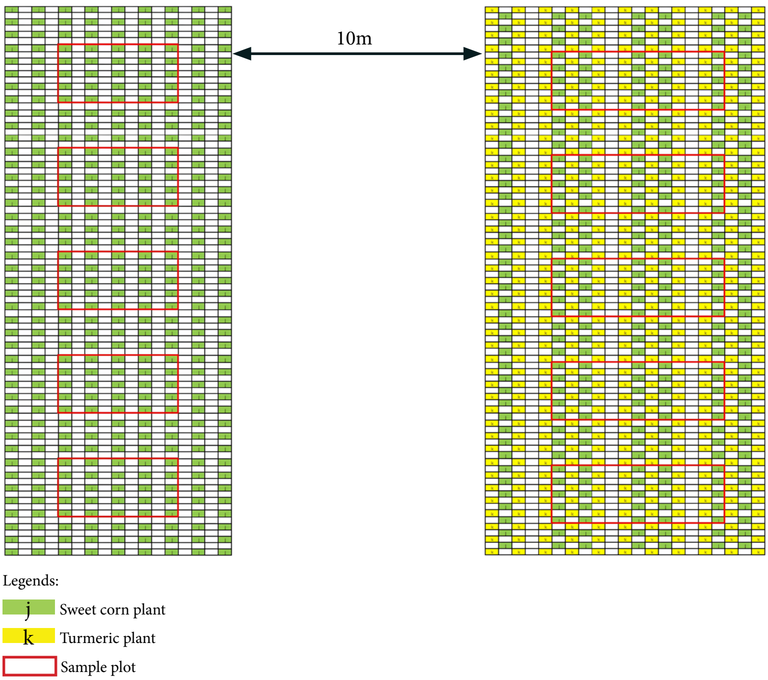
Figure 2

Layout of the Experimental Plots in the Field

Treatment A
(monoculture of sweet corn)

Treatment B
(Intercropping of sweet corn and turmeric)



Sampling Method and Observational Units

The study assessed the ecological, agronomic, and economic performance of the cropping systems using the following indicators:

A. Ecological and Pest Impact Indicators (Sweet Corn)

Observations for these variables were conducted weekly from 2 to 8 weeks after sowing (WAS) to capture population dynamics during the most vulnerable vegetative and early reproductive stages of sweet corn. Ear infestation was assessed at harvest.

1. **Percentage of Infested Plants (P):** Assessed by examining all 25 corn plants in each sample plot.

$$P = \frac{a}{b} \, x \, 100\%$$

Where: P = Percentage of infested plants; a = Number of infested plants; b = Total number of observed plants.

2. **Severity of Leaf Damage (I):** Assessed weekly on 5 randomly selected plants per sample plot using the visual rating scale of Davis, Ng, and Williams (1992), which ranges from 0 (no damage) to 9 (complete destruction).

$$I = \Sigma \frac{(ni \ x \ vi)}{(Z \ x \ N)} \ x \ 100$$

Where: I = Severity of Infestation (%); ni = Number of plants showing damage at scale i; vi = Damage scale value at level i; Z = Highest scale value used (9); N = Total number of plants observed (25)

3. **Larval Population Density of *S. frugiperda*:** Recorded weekly from 2 to 8 WAS and again at harvest. This observation frequency was chosen to capture population dynamics across the most vulnerable growth stages of sweet corn, when foliage development and tasseling coincide with the preferred feeding and oviposition periods of *S. frugiperda*. Weekly monitoring also allowed detection of rapid changes in larval abundance, as the pest can complete one larval instar in less than a week under tropical conditions, and provided timely information for effective control decisions. All 25 corn plants per sample plot were thoroughly examined (leaves, stems, tassels, and ears). The total number of larvae (instars 1–6 collectively) found per plant was recorded to represent the total larval abundance.

4. **Percentage of Infested Ears:** Assessed at harvest (≈ 70 DAS) by examining all harvested ears from the 25 plants in each sample plot for signs of *S. frugiperda* damage (larvae, frass, tunnels, or damaged kernels).

$$P = \frac{a}{b} \ x \ 100\%$$

Where: P = Percentage of infested ears; a = Number of infested ears; b = Total number of ears observed

B. Agronomic Yield Indicators

1. Sweet Corn Yield: Recorded at harvest (≈ 70 DAS) from all 25 sample plants. Physiological indicators of harvest maturity included drying and browning of silks, green and fresh husks, full ear size, and well-filled kernels with milky sap upon pressing. Measured parameters included average ear weight (grams), average ear length (centimeters), and the proportion of ears categorized as marketable (free from *S. frugiperda* damage).

2. Turmeric Yield: Recorded at 8 months after planting. Yield measurements were based on fresh rhizome weight from three randomly selected turmeric clumps per sample plot, extrapolated to estimate yield per hectare based on the actual planting density. The economic value of turmeric production was calculated using the prevailing market price at the time of harvest.

C. Economic Feasibility Indicators

The economic performance of each cropping pattern was assessed over the entire experimental period (one turmeric cycle encompassing two sweet corn cycles). This approach ensures a realistic comparison of profitability, as it accounts for the total inputs and outputs of the long-term intercropping system. The following metrics were used:

1. **Revenue/Cost (R/C) Ratio (Profitability Indicator):** This metric measures the amount of revenue generated per unit of production cost (Soekartawi, 2002). The R/C Ratio is calculated as total revenue divided by total production cost. An R/C ratio greater than 1 indicates that the system is profitable.

2. **Benefit/Cost (B/C) Ratio (Efficiency Indicator):** This indicator measures the net returns (Benefit = total revenue minus total production cost) generated per unit of cost (Boardman et al., 2018). A higher B/C ratio reflects greater financial efficiency. The B/C ratio is calculated by dividing the net benefit (total revenue minus total production cost) by the total production cost, providing a clear measure of the system's economic efficiency.

3. **Return on Investment (ROI) (%) (Investor Interest Indicator):** This indicator expresses net profit as a percentage of the total investment, providing a standardized measure of profitability (Brigham & Houston, 2019). The ROI is calculated by dividing net profit by total production cost, then multiplying the result by 100% to express it as a percentage.

4. **Break-Even Point (BEP) (Risk Indicator):** Determines the minimum production volume or land area required to cover all production costs (Garrison, Noreen, & Brewer, 2021). BEP measures the financial risk; a lower BEP signifies lower risk and higher land-use efficiency.

The use of R/C, B/C, ROI, and BEP provides a holistic assessment of economic viability, moving beyond simple net profit. While R/C and B/C ratios assess profitability and operational efficiency, ROI is critical for investment comparison, and BEP is essential for risk assessment and setting production targets, particularly for smallholder farmer adoption.

Data Analysis

Data for all variables (infestation percentage, damage severity, larval population, ear infestation, and yield components) were first averaged for the 25 plants within each sample plot to obtain one mean value per plot. These five plot means per treatment served as the replicates for statistical analysis, thereby preventing pseudoreplication.

Before comparison, the data underwent normality testing. Means from the monocropping and intercropping treatments were compared using an Independent Samples t-test at a significance level of $\alpha=0.05$ to determine significant differences between the two cropping patterns. For data that did not meet the assumptions of normality (where noted in the results), the non-parametric Mann–Whitney U test was applied.

Economic feasibility indicators were calculated using standard formulas and interpreted descriptively to provide a detailed comparison of the profitability and financial sustainability of the intercropping system versus the monoculture system.

Results and Discussion

Percentage of Sweet Corn Plants Infested by *Spodoptera frugiperda*

Normality tests confirmed that the percentage infestation data for sweet corn plants by *Spodoptera frugiperda* from 2 to 5 weeks after sowing (WAS) in both cropping cycles were normally distributed, allowing analysis using an independent-samples t-test. At 6 WAS, infestation reached 100% in both Treatment A (monoculture) and Treatment B (sweet corn–turmeric intercropping), so data at this stage are presented descriptively.

The effects of monoculture (Treatment A) and sweet corn–turmeric intercropping (Treatment B) on the percentage of sweet corn plants infested by *S. frugiperda* during the first and second planting cycles are shown in Table 1.

Table 1

Percentage of Sweet Corn Plants Infested by Spodoptera frugiperda

Treatment	Plant Infested (Mean ± SD) (%)				
	2 WAS	3 WAS	4 WAS	5 WAS	6 WAS
First Corn Planting Cycle					
Sweet corn Monoculture	16.00 ± 4.00a	37.60 ± 10.00a	53.60 ± 19.71a	91.20 ± 7.15a	100.00 ± 0.00a
Sweet corn-turmeric intercropping	13.60 ± 7.26a	28.00 ± 11.66a	50.40 ± 18.02a	91.20 ± 9.12a	100.00 ± 0.00a
Second Corn Planting Cycle					
Sweet corn Monoculture	31.2 ± 9.54a	84.00 ± 5.65a	96.80 ± 6.40a	100.00 ± 0.00a	100.00 ± 0.00a
Sweet corn-turmeric intercropping	5.60 ± 3.57b	16.00 ± 6.32b	28.00 ± 17.20b	68.00 ± 24.65b	100.00 ± 0.00a

Note: Within each cropping cycle, means followed by the same letter in the same column are not significantly different according to an independent-samples t-test (α = 0.05) for 2 to 5 WAS. Data at 6 WAS are presented descriptively because 100% infestation was observed in both treatments.

Table 1 indicates that, despite numerically lower values in the intercropping treatment, no statistically significant differences in the percentage of infested plants were observed between monoculture and intercropping during the first cropping cycle (2–6 WAS). This suggests that the initial establishment of turmeric provided insufficient visual or chemical complexity to significantly deter the mobile adult *S. frugiperda* moths (Hong-Zu et al., 2022).

In sharp contrast, the second cropping cycle revealed a strong and significant suppressive effect of the intercropping system. Infestation levels were significantly lower in the sweet corn–turmeric intercropping treatment from 2 to 5 WAS compared to monoculture. For example, at 4 WAS, monoculture was nearly fully infested (96.80%), whereas intercropping-maintained infestation below 30% (28.00%). These results demonstrate the increasing pest-suppressive benefits of the intercropping system over time, which became clearly evident after turmeric's full canopy development.

The monoculture system creates a homogenous, resource-rich environment that facilitates rapid pest colonization and proliferation (Januarisya, Prabowo, & Lestari, 2023; Utami & Ismanto, 2015). Conversely, intercropping enhances both visual and chemical complexity, which is known to disrupt pest host-finding behavior (Hong-Zu et al., 2022). Specifically, the presence of the established turmeric crop in the second cycle provided a larger, denser canopy, altering the microclimate and creating shade. This structural disruption likely contributed to the delayed and reduced infestation rates by impairing the pest's ability to visually locate host plants (Moreiral et al., 2016). Furthermore, the established turmeric rhizomes and foliage release essential oils containing volatile compounds (e.g., turmerone) that act as natural repellents, disrupting the pest's chemoreception and reducing feeding and oviposition, even at low concentrations (Gosal & Hosang, 2022; Wilyus et al., 2025).

Intensity of *Spodoptera frugiperda* Damage on Sweet Corn Leaves

Normality tests for leaf damage intensity data in both planting cycles confirmed normal distribution, allowing for an independent-samples t-test analysis. The effects of cropping treatment on the severity of leaf damage caused by *S. frugiperda* are presented in Table 2.

Table 2

Intensity of Spodoptera frugiperda Damage on Sweet Corn Leaves

Treatment	% Leaf Damage (Mean ± SD)						
	2 WAS	3 WAS	4 WAS	5 WAS	6 WAS	7 WAS	8 WAS
First Corn Planting Cycle							
Sweet corn Monoculture	6.66 ± 5.24[a]	14.68 ± 3.72[a]	28.44 ± 7.76[a]	33.78. ± 7.44[a]	40.46 ± 7.76[a]	41.34 ± 9.36[a]	42.68 ± 3.53[a]
Sweet corn-turmeric intercropping	2.20 ± 1.55[a]	8.46 ± 0.98[b]	28.88 ± 6.10[a]	36.44 ± 4.60[a]	38.68 ± 5.13[a]	41.76 ± 9.35[a]	44.02 ± 7.24[a]
Second Corn Planting Cycle							
Sweet corn Monoculture	5.32 ± 5.78[a]	30.22 ± 10.13[a]	48.42 ± 6.76[a]	61.80 ± 6.72[a]	64.92 ± 3.64[a]	65.78 ± 4.04[a]	67.54 ± 3.38[a]
Sweet corn-turmeric intercropping	0.00 ± 0.00a	2.22 ± 2.73[b]	9.32 ± 7.76[b]	27.54 ± 12.22[b]	34.22 ± 5.11[b]	34.66 ± 5.56[b]	34.66 ± 5.56[b]

Note: Within each cropping cycle, means followed by the same letter in the same column are not significantly different based on the independent samples t-test at α = 0.05.

Table 2 shows no statistically significant differences in leaf damage intensity between treatments at 2 and 4 to 8 WAS during the first corn planting cycle. However, at 3 WAS, intercropping exhibited significantly lower damage intensity, suggesting a brief delay or suppression in larval feeding. In contrast, the second planting cycle revealed clear, consistent, and sustained differences from 3 to 8 WAS. Leaf damage in monoculture was evident early (2 WAS) and intensified rapidly, reaching 67.54% at 8 WAS. Conversely, intercropping plots showed a significantly slower progression and consistently lower damage, stabilizing at approximately 34.66% from 7 WAS, indicating a suppressive effect on *S. frugiperda* feeding intensity over time. These results highlighted the potential of sweet corn-turmeric intercropping in moderating *S. frugiperda* damage, especially in successive planting cycles. Although both treatments eventually reached full infestation by the generative phase, as observed by Megasari and Khoiri (2021), the severity and overall damage were lower in the intercropping treatment.

These findings highlight the functional role of intercropping in delaying infestation onset and mitigating cumulative pest impacts. By increasing the structural, visual, and chemical complexity of the canopy, the presence of the fully established turmeric crop in the second cycle interfered with *S. frugiperda*'s ability to detect and utilize its preferred host (maize). This modification in canopy architecture, light interception, humidity, and volatile organic compound composition collectively contributed to reduced host-finding efficiency and delayed oviposition (Moreiral et al., 2016). Consequently, pest population growth proceeded more slowly, resulting in lower overall infestation pressure and protected foliage, both of which are vital for photosynthetic efficiency and subsequent yield development.

Population of *Spodoptera frugiperda* Larvae

Normality test results for *S. frugiperda* larval population data from the first planting cycle (3 to 8 WAS) indicated normality, allowing independent-samples t-test analysis. Data at 2 WAS were non-normally distributed and analyzed using the non-parametric Mann–Whitney U test. In the second planting cycle, larval population data at 3, 4, 5, 6, and 8 WAS met normality assumptions for independent t-test analysis, while 2 WAS data were analyzed with the Mann-Whitney U test. Observations at 7 WAS in the second cycle are presented descriptively due to an unsuitable distribution of data. The results of *S. frugiperda* larval population comparisons are presented in Table 3.

Table 3

Population of Spodoptera frugiperda (Mean ± SD Larvae per 25 Plants)

Treatment	Population (Mean ± SD)						
	2 WAS	3 WAS	4 WAS	5 WAS	6 WAS	7 WAS	8 WAS
First Corn Planting Cycle							
Sweet corn Monoculture	1.60±2.30[a]	1.60±1.67[a]	3.20±2.16[a]	7.00±4.06[a]	1.60±0.89[a]	1.80±1.30[a]	5.20±1.30[a]
Sweet corn-turmeric intercropping	0.60±0.89[a]	1.60±2.30[a]	2.80±2.48[a]	3.60±1.81[a]	1.20±4.09[a]	2.20±2.38[a]	3.40±1.94[a]
Second Corn Planting Cycle							
Sweet corn Monoculture	1.80±4.28[a]	7.60±4.50[a]	17.60±2.30[a]	13.80±7.25[a]	2.00±0.70[a]	0.00±0.00[a]	6.40±5.63[a]
Sweet corn-turmeric intercropping	0.00±0.00[a]	0.20±0.44[a]	4.20±2.58[a]	4.40±2.96[a]	1.40±0.54[a]	0.00±0.00[a]	2.00±2.23[a]

Note: In the first planting cycle, means followed by the same letter in the same column are not significantly different based on the independent t-test (3–8 WAS) or Mann–Whitney U test (2 WAS) at a 5% significance level. In the second cycle, comparisons at 2 WAS were conducted using the Mann–Whitney U test, and comparisons at 3–6 and 8 WAS were conducted using the independent t-test. Data from the second cycle at 7 are presented descriptively.

Table 3 indicates no significant difference in *S. frugiperda* larval populations between treatments in the first planting cycle (2–8 WAS), suggesting limited initial suppression. However, in the second maize planting cycle, larval populations were significantly lower in intercropping from 3 to 5 WAS than in monoculture, reflecting a suppressive effect during the early to mid-vegetative stages.

These results suggest that turmeric intercropping notably reduced *S. frugiperda* density during early to mid-growth stages in the second cycle, despite a limited effect in the first cycle. In the second planting cycle, the *S. frugiperda* population was higher in corn monoculture than in the corn and turmeric intercropping system. Monoculture creates a more open, uniform environment, leading to increased pest populations (Januarisya et al., 2023). This condition indicates that plant diversity in intercropping systems plays a role in suppressing pest populations, consistent with the findings of Wilyus et al. (2025), who reported that intercropping patterns are effective in reducing *S. frugiperda* populations, especially during the early phase of plant growth. However, at 6 and 8 WAS, population sizes decreased in both treatments, and the differences were no longer significant. This decline in pest populations is likely due to two key factors:

1. **Host Plant Phenology:** Around 6 WAS, sweet corn plants are typically near the end of the vegetative phase. As new, tender leaf production ceases, host suitability declines.

S. frugiperda females preferentially oviposit on young, actively growing foliage, so the reduction in new growth decreases host attractiveness and subsequent larval recruitment.

2. **Ecological Regulation (Natural Enemies):** The population decline at 6–8 WAS may also reflect increased activity of natural enemies, such as parasitoids and predators. These beneficial insects often reach higher abundance during the mid- to late-vegetative stages of maize. The presence of intercropped turmeric could further enhance these populations by providing an altered microhabitat, shelter, or alternative resources, thereby supporting enhanced biological control and contributing to the natural population decline observed (Harrison et al., 2019).

Percentage of Ears Attacked by *Spodoptera frugiperda*

Normality tests confirmed normal distribution for the percentage of infested ears in both cycles, allowing an independent-samples t-test analysis. The results comparing sweet corn monoculture and intercropping on ear infestation are presented in Table 4.

Table 4

Percentage of Sweet Corn Ears Attacked by Spodoptera frugiperda

Treatment	% of Total Ears Attacked (Mean ± SD)	
	9 WAS	10 WAS
First Corn Planting Cycle		
Sweet corn Monoculture	17.60 ± 2.19[a]	21.60 ± 4.56[a]
Sweet corn-turmeric intercropping	11.20 ± 5.21[b]	14.40 ± 5.36[b]
Second Corn Planting Cycle		
Sweet corn Monoculture	29.60 ± 10.03[a]	33.60 ± 14.02[a]
Sweet corn-turmeric intercropping	5.60 ± 2.19[b]	12.00 ± 2.82[b]

Note: Within each planting cycle, means followed by different letters in the same column are significantly different according to the independent samples t-test at the 5% significance level

This is a critical finding that relates to yield protection. In both the first and second planting cycles, the percentage of sweet corn ears attacked by *S. frugiperda* was significantly higher in monoculture compared to intercropping at both 9 and 10 WAS. Intercropping reduced ear infestation by approximately 6–7 percentage points in the first cycle and by nearly 3 times as much in the second cycle (e.g., 12.00% vs. 33.60% at 10 WAS). These results demonstrate the effectiveness of sweet corn–turmeric intercropping in reducing *S. frugiperda* damage at the ear stage, particularly in successive planting cycles. The observed suppressive effect may be attributed to factors such as disruption of host locations by adult moths (i.e., reduced egg masses), altered microhabitat conditions, or repellent effects from the turmeric crop.

Importantly, sustained protective effect in the reproductive phase of maize is vital, as larval feeding transitions from leaves to ears during this stage, causing direct damage to yield quantity and market quality (Azwana, 2021). The reduced ear infestation is attributed to the sustained visual and chemical disruption provided by the turmeric canopy, which successfully interfered with the host-finding behavior and oviposition site selection of adult *S. frugiperda* moths even as the sweet corn matured.

Production of Sweet Corn

Sweet corn production was assessed based on cob weight (grams) and cob length (centimeters). Normality tests confirmed normal distributions for both variables in both cycles, allowing an independent-samples t-test. The effects of sweet corn monoculture and intercropping on these yield parameters are summarized in Table 5.

Table 5

Effect of Sweet Corn Monoculture and Intercropping with Turmeric on Cob Weight and Cob Length

Treatment	Cob Weight (g) (Mean ± SD)	Cob Length (cm) (Mean ± SD)
First Corn Planting Cycle		
Sweet corn Monoculture	260.40 ± 41.33[a]	18.42 ± 2.87[a]
Sweet corn-turmeric intercropping	270.52 ± 5.13[a]	16.30 ± 3.94[a]
Second Corn Planting Cycle		
Sweet corn Monoculture	121.16 ± 15.59[a]	13.12 ± 2.84[a]
Sweet corn-turmeric intercropping	208.00 ± 16.12[b]	15.96 ± 0.76[a]

Note: Within each planting cycle, means followed by different letters in the same column indicate significant differences based on the independent samples t-test at the 5% significance level.

Table 5 shows no statistically significant differences in cob weight or cob length between treatments during the first planting cycle, suggesting that the initial intercropping did not negatively impact sweet corn productivity.

However, in the second cycle, a significant agronomic benefit of intercropping emerged: cob weight was higher in the intercropping system (208.00 g) than in monoculture (121.16 g), despite similar cob lengths. This suggests that the substantial reduction in pest damage (Tables 2–5) in the intercropping plots allowed the sweet corn plants to allocate significantly more photosynthates and assimilates to ear development, thereby enhancing yield quality and market value (Wilyus et al., 2025).

The overall reduction in cob weight in both treatments from Cycle 1 to Cycle 2 (e.g., intercropping dropped from 270.52 g to 208.00 g) is likely due to the natural decline in soil nutrient availability and intensified resource competition between the sequential sweet corn crop and the already fully established, long-duration turmeric plants. Despite this systemic reduction, the significantly better performance of the intercropping system over the monoculture in Cycle 2 underscores its superior pest-suppressive capacity and its ability to maintain yield stability under high pest pressure. The consistent protection of the plant during the critical vegetative phase ensured sufficient resource accumulation, resulting in better ear development compared to the severely damaged monoculture crop. Nevertheless, this positive response may not necessarily persist beyond the second cycle without appropriate soil fertility management, as continuous intercropping could eventually deplete soil nutrients and reduce productivity. Therefore, the present findings should be interpreted within the two-cycle experimental context, and further studies across additional cycles are needed to evaluate the long-term sustainability of the system.

Beyond pest suppression and yield protection, intercropping contributes to agroecosystem stability by improving habitat complexity and microclimatic conditions that indirectly favor the persistence of natural enemies. In this system, turmeric does not necessarily act as a nectar or pollen source. However, its canopy structure and spatial arrangement may provide shelter and moderate environmental conditions for parasitoids and predators, thereby supporting biological control. This aligns with the principles of agroecology and Integrated Pest Management (IPM), promoting biodiversity and reducing reliance on chemical insecticides (Saslidar, Rusdy, & Hasnah, 2022).

Economic Feasibility of Cropping Systems

The economic performance was assessed over the entire 10-month experimental period, encompassing one full turmeric cycle and two successive sweet corn cycles. This approach was essential to capture the true profitability of the long-duration intercropping system, as the high-value turmeric rhizomes were harvested only once. Evaluating economic performance after harvest of both component crops provides a more comprehensive and realistic representation of the intercropping system, reflecting the complete input–output relationship and the true profitability of the integrated production cycle.

The economic feasibility of sweet corn monoculture and sweet corn–turmeric intercropping systems was assessed using four robust metrics: Revenue/Cost (R/C) ratio, Benefit/Cost (B/C) ratio, Return on Investment (ROI), and Break-Even Point (BEP). The use of these multiple indicators provides a holistic assessment of economic viability, which is essential for smallholder farmers' adoption decisions: R/C and B/C assess profitability and operational efficiency; ROI provides a standardized measure for investment comparison; and BEP is critical for risk assessment and setting production targets (Kahan, 2013). Results are summarized in Table 6.

Table 6

Comparison of Economic Feasibility Between Sweet Corn Monoculture and Sweet Corn–Turmeric Intercropping Systems (Values in parenthesis are in USD)

Component	Sweet Corn Monoculture	Sweet Corn-Turmeric Intercropping
Total production cost per hectare	Rp 50,925,000 (3,183.00)	Rp 177,432,500 (11,089.53)
Revenue per hectare	Rp 96,000,000 * (6,000.00)	Rp 443,990,000 ** (27,749.38)
Net Profit per hectare	Rp 45,075,000 (2,817.00)	Rp 266,557,500 (16,659.84)
R/C ratio	1.88	2.50
B/C ratio	0.885	1.502
ROI (%)	88.5%	150.2%
BEP based on production volume	25,462.5 ears	15,444 ears; 14,654 kg turmeric rhizome
BEP based on land area (hectares)	0.614 ha	0.418 ha

Note: * Generated from two sweet corn cropping cycles. **Generated Rp $366,660,000$ from turmeric, and Rp $77,330,000$ from two sweet corn cropping cycles.

Table 6 clearly demonstrates that the sweet corn–turmeric intercropping system is substantially more economically viable. Although the intercropping system required a significantly higher total production cost (Rp 177,432,500), it generated considerably greater total revenue (Rp 443,990,000) and a net profit of Rp 266,557,500. This represents a nearly six-fold increase in net income compared to the monoculture system (Rp 45,075,000). The increased revenue, largely driven by the high-value turmeric component, more than compensated for the additional input expenses.

Financial indicators further reinforce this advantage:

a. The R/C ratio for intercropping was 2.50, indicating that for every unit of currency invested, 2.50 was returned in revenue, significantly better than the 1.88 ratio for monoculture

(Biswas et al., 2023).

b. The B/C ratio of 1.502 for intercropping (vs. 0.885 for monoculture) indicates superior financial efficiency, yielding a net return per unit of cost of 1.502 (Arsyad et al., 2020).
c. The Return on Investment (ROI) reached 150.2% in the intercropping system, far surpassing the 88.5% observed in monoculture, suggesting a much stronger appeal for investment (Legba et al., 2025; Thakur et al., 2025; Zulkarnain, Handayani, & Haryono, 2024).
d. The Break-Even Point (BEP) analysis demonstrated superior land-use efficiency. Intercropping required only 0.418 hectares to recover investment costs, compared to 0.614 hectares in monoculture. This lower BEP translates directly into lower financial risk for the farmer.

The superior economic performance is attributed to the synergistic combination of reduced pest damage leading to higher marketable sweet corn yields (Table 6) and the substantial added economic value provided by the high-demand turmeric rhizomes. These integrated outcomes align strongly with the goals of sustainable agriculture, which seek to enhance biological productivity while increasing profitability and reducing environmental impact (Altieri et al., 2015; FAO, 2017).

In summary, the sweet corn–turmeric intercropping system offers integrated benefits across ecological, agronomic, and economic dimensions. It effectively reduces *S. frugiperda* infestation and damage, enhances cob weight in the second cycle, dramatically increases profitability, and improves land-use efficiency. This diversified cropping strategy represents a viable, scalable model for smallholder farmers seeking to achieve pest resilience, yield stability, and economic sustainability in tropical agricultural systems.

Nevertheless, this study has certain limitations. The economic evaluation was conducted over two sweet corn planting cycles within a single turmeric growing cycle and under specific agroecological conditions, which may limit the generalizability of the results. Furthermore, long-term factors such as market price fluctuations, labor availability, or changes in input costs were not assessed. Future multi-season and multi-location research is therefore needed to validate the consistency and robustness of the economic advantages observed in sweet corn–turmeric intercropping systems.

Conclusion

The intercropping of sweet corn (*Zea mays* L. var. *saccharata*) with turmeric (*Curcuma longa* L.) demonstrated superior performance as an agroecological strategy for the sustainable management of *Spodoptera frugiperda*, and for significantly enhancing land productivity. The system's effectiveness was particularly pronounced in the second planting cycle, where the fully established turmeric canopy provided sustained protective benefits.

Ecologically and agronomically, the intercropping system successfully delayed pest onset and reduced infestation, significantly lowering the percentage of infested sweet corn plants, decreasing the intensity of leaf damage, and reducing larval population densities during the crucial vegetative stage (3-5 WAS). Furthermore, this protective effect extended into the reproductive phase, resulting in a substantial reduction in the percentage of *S. frugiperda*-attacked ears during both cropping cycles, thereby directly preserving marketable yield. Ultimately, reduced pest pressure contributed to higher productivity, resulting in significantly higher cob weight under intercropping than in monoculture in the second planting cycle, confirming the agronomic benefit of pest suppression.

These favorable outcomes are attributed to the multifaceted ecological functions of turmeric, specifically visual disruption (due to increased canopy complexity), chemical repellence (from volatile organic compounds), and habitat diversification for natural enemies. These mechanisms collectively align with and strengthen the core principles of Integrated Pest Management (IPM).

From an economic perspective, the long-term intercropping system demonstrated superior financial viability. Despite higher initial investment costs, the system generated nearly six times more net profit than the sweet corn monoculture. This high profitability was confirmed by the superior financial metrics: a higher Revenue/Cost (R/C = 2.50), Benefit/Cost (B/C = 1.502), and Return on Investment (ROI = 150.2%), coupled with a lower Break-Even Point (BEP).

In conclusion, the sweet corn–turmeric intercropping system provides a sustainable, pest-resilient, and economically profitable alternative to conventional monoculture. Its adoption is highly recommended to help smallholder farmers increase income, enhance the ecological stability of their agroecosystems, and reduce reliance on chemical pesticides in tropical regions. Further research across multi-site and multi-season trials is needed to validate the long-term consistency of these ecological and economic advantages.

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Conflict of Interest Statement

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

AI Disclosure

The authors confirm that this manuscript was produced without the use of artificial intelligence software for content generation or linguistic refinement. The work is entirely original.

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