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Spodoptera frugiperda (Lepidoptera: Noctuidae) infestation in maize and its management using mulberry organic residues*

Infestación de *Spodoptera frugiperda* (Lepidoptera: Noctuidae) en maíz y su manejo usando residuos orgánicos de morera

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Abstract

Introduction. Soil incorporation of *Morus alba* biomass mitigates *Spodoptera frugiperda* damage in maize, through the release of bioactive secondary metabolites with antifeedant properties. **Objective.** To characterize farmer perceptions of *Spodoptera frugiperda* severity and evaluate the efficacy of *Morus alba* residue incorporation as a sustainable management strategy in the Mocache canton, Ecuador. **Materials and methods**. The research was conducted between December 2023 and May 2024. The study consisted of two phases: a survey of farmers and a field experiment. The farmers were surveyed regarding the agronomic practices they implemented to manage *S. frugiperda*. The experiment was conducted in the locality of Jesús del Gran Poder and consisted of three treatments: i) a control without pest management or residue incorporation (Control); ii) soil incorporation of 1 t ha^{-1} of a mixture of maize residues (80 %) and fragmented mulberry cv. Tigreada (20 %) (M+M); and iii) the application of methomyl insecticide. The variables of severity of infestation and agricultural yield were evaluated. A randomized complete block design with three treatments and three replicates was employed. Treatment means were compared using Duncan's multiple range test ($\alpha = 0.05$). Statistical processing was performed using the InfoStat package. **Results**. Residue incorporation reduced severe foliar damage (grades 4–5) to 29.6%, significantly lower than the control (36.1%; $p < 0.05$). Grain yield reached 4.1 t ha^{-1} with residues, statistically comparable to methomyl (4.6 t ha^{-1}) and 17 % higher than the control (3.5 t ha^{-1}). **Conclusions**. The high perception of severity of *S. frugiperda* by farmers corresponds with high levels of infestation, associated with inadequate agronomic practices and poor technical training. The maize and mulberry residues incorporated into the soil reduce severity and allow obtaining yields like the insecticide, validating its effectiveness as a management alternative in Ecuador and similar regions.

Keywords: fall armyworm, integrated pest management, soil amendments, *Zea mays*, *Morus alba*.

Resumen

Introducción. La incorporación al suelo de *Morus alba* mitiga el daño de *Spodoptera frugiperda* en maíz, por la liberación de metabolitos secundarios antialimentarios. **Objetivo**. Caracterizar las percepciones de los agricultores sobre la severidad de *Spodoptera frugiperda* y evaluar la eficacia de la incorporación de residuos de *Morus alba* como una estrategia de manejo sostenible en el cantón Mocache, Ecuador. **Materiales y métodos**. La investigación se realizó entre diciembre 2023 y mayo 2024. El estudio consistió en dos fases: una encuesta a agricultores y un experimento de campo. Se encuestó sobre las prácticas agronómicas para manejar *S. frugiperda*. El experimento se realizó en la localidad de Jesús del Gran Poder y consistió en tres tratamientos: i) control sin manejo (control); ii) incorporación al suelo de 1 t ha^{-1} de una mezcla de residuos de maíz (80 %) y morera fragmentada cv. Tigreada (20 %) (M+M); y iii) aplicación del insecticida metomilo. Se evaluaron las variables severidad de la infestación y rendimiento. Se empleó un diseño de bloques completos aleatorizados con tres tratamientos y tres réplicas. Las medias se compararon utilizando la prueba de Duncan (α = 0,05). El procesamiento estadístico se realizó con InfoStat. **Resultados**. La incorporación de residuos redujo el daño foliar (grados 4–5) al 29,6 %, significativamente menor que el control (36,1 %; $p < 0{,}05$). El rendimiento de grano alcanzó 4,1 t ha^{-1} con residuos, estadísticamente comparable al metomilo (4,6 t ha^{-1}) y 17 % mayor que el control (3,5 t ha^{-1}). **Conclusiones**. La alta percepción de la severidad de *S. frugiperda* por los agricultores se corresponde con altos niveles de infestación, asociados a prácticas agronómicas inadecuadas y escasa capacitación. Los residuos incorporados al suelo reducen la severidad y permiten obtener rendimientos similares al insecticida, validando su efectividad como alternativa de manejo en Ecuador y regiones similares.

Palabras clave: gusano cogollero, manejo integrado de plagas, enmienda al suelo, *Zea mays*, *Morus alba*.

Introduction

Maize (*Zea mays* L.) is one of the most important cereals for human consumption worldwide, along with rice (*Oryza sativa* L.), and is a key ingredient in livestock feed (Liu et al., 2023). Global dry maize production exceeds one billion tons annually, more than half of which comes from the Americas, with the United States being the leading producer, yielding averages above five tons per hectare (Rodríguez et al., 2023). In Ecuador, maize cultivation is established in the main tropical regions during the rainy season, when humidity and temperature conditions favor both germination and vegetative development of the crop, where more than 300,000 hectares are planted each year, reaching a production of over one million tons, with yields of 3.68 t ha^{-1} (Instituto Nacional de Estadística y Censos [INEC], 2024).

Most of the national production is concentrated in the provinces of Guayas (15.8 %), Los Ríos (34.2 %), and Manabí (34.5 %) (INEC, 2024). This activity provides employment for over 140,000 people, accounting for 11 % of the country's economically active agricultural workforce (INEC, 2024). The maize production in the Mocache canton, located in the province of Los Ríos, is mainly small-scale family farms in a range from 1 to 10 ha (Torres Navarrete et al., 2015). However, phytophagous pests such as *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) negatively impact maize crops in maize-growing regions of Ecuador. *Spodoptera frugiperda*, also known as fall armyworm, is a polyphagous pest of great agricultural importance. In maize crops, damage is concentrated mainly in the apical meristem. Initial symptoms appear as perforations in the leaves and can progress to severe defoliation, which affects the growth and development of the plant (Desika et al., 2024).

Spodoptera frugiperda is one of the pests that devastate maize crops in tropical regions. Significant damage occurs during the early stages of insect development, when it feeds on the young foliage and apical bud of the plant. Meristem destruction can slow growth and potentially cause plant death. Additionally, attack severity indicates a

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negative correlation with agricultural yield (Martinez-Martinez et al., 2019). In severe infestations, yield loss can reach up to 40 % (Ruiz-Sanchez et al., 2023).

Spodoptera frugiperda develops rapidly in the warm and humid conditions characteristic of tropical and subtropical regions. The ideal temperature for its life cycle is between 25 and 30 °C, although it can complete its development within a wider range, approximately 10 to 40 °C. Moderate to high relative humidity favors the survival of eggs and larvae, while intense and continuous rainfall can cause significant mortality in the early larval stages (Malekera et al., 2022). This pest is extremely polyphagous, affecting more than 70 plant families; however, it shows a marked preference for cultivated grasses such as maize, sorghum, rice, and sugarcane. Its ability to utilize alternative hosts during periods of absence of the main crop allows the insect to maintain its populations (Montezano et al., 2018).

In Ecuador's maize-producing regions, optimal climatic conditions promote the reproduction and distribution of *Spodoptera frugiperda*. Warm temperatures accelerate their biological cycle, enabling multiple generations and high population. Adults lay their eggs on plants, and the newly emerged larva moves throughout the plant and disperse via wind through a mechanism called "ballooning". The efficient dispersal strategy, coupled with the constant availability of host plants, ensures a wide and uniform distribution across maize-producing regions (Chirinos et al., 2024). Different species of grass used for animal feed were also observed, including some from the *Poaceae* family that are identified as pest hosts (Adnan et al., 2024).

Spodoptera frugiperda infestations peak during the rainy and warm season, which coincides with the maize planting season in the Mocache canton. The crop is most susceptible at early vegetative stages, particularly from emergence to the V6 stage (six fully developed leaves), where larval feeding can cause the highest plant mortality. Fall armyworm infestation is directly favored by agronomic practices such as monoculture, staggered planting, and indiscriminate use of insecticides (Gaibor-Fernández et al., 2023). Reliance on synthetic insecticides to control *Spodoptera frugiperda* has harmful effects. According to Gaibor-Fernández et al. (2023), intensive use of these insecticides promotes pest resistance, reduces the abundance of pollinators and natural enemies, and alters agroecological stability. Therefore, it is necessary to implement sustainable management alternatives to this pest on this important crop.

Mulberry (*Morus alba* L.) is widely used as fresh livestock feed (Pereira et al., 2021). However, when incorporated into the soil, it releases large amounts of bioactive compounds (such as alkaloids, phenols, flavonoids and tannins), which have antifeedant effects and inhibit pest growth (Gvozdenac et al., 2021). *Spodoptera frugiperda* pupation occurs in the soil, where the decomposition of *Morus alba* releases volatile compounds that can exert a bioactive effect, manifesting as direct toxicity and inhibition of development in the pupal phase. This disruption to the metamorphic process suppresses adult emergence and reduces the population's reproductive potential, contributing to its biocontrol (Gvozdenac et al., 2021). Although studies on the bioinsecticidal properties of *Morus alba* are scarce, it was recently discovered that an extract of leaves proved toxic to *Aedes aegypti* larvae even at low doses, demonstrating its larvicidal effect. Due to its bioactive compounds, mulberry can be a suitable substitute for synthetic insecticides, as products derived from it are safe, low-cost, and available in many regions of the world (Muflikhah, 2023).

The management of *Spodoptera frugiperda* in the Mocache maize-growing canton relies heavily on chemical insecticides. Given the bioinsecticidal potential of incorporating *Morus alba* residues, there is a need to evaluate the use of this pest management alternative under field conditions. Therefore, the objective of this research was to characterize farmer perceptions of *Spodoptera frugiperda* severity and evaluate the efficacy of *Morus alba* residue incorporation as a sustainable management strategy in the Mocache canton, Ecuador.

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Materials and methods

Location of the study site

The study was conducted between December 2023 and May 2024. Five localities were selected (Table 1), in the Mocache canton, Los Ríos province, Ecuador. A total of 100 farmers were surveyed on twenty farms in each locality with the aim of diagnosing problems associated with *S. frugiperda* management. The research consisted of two phases, a survey of farmers, and a field experiment.

Table 1. Geographic coordinates, latitude and longitude, in degrees, minutes, and seconds for the five sampled locations: Las Palmas, Pechiche, Barro Colorado, Jesús del Gran Poder, and Las Campanas. Los Ríos Province, Ecuador. 2024.

Cuadro 1. Coordenadas geográficas, latitud y longitud, en grados, minutos y segundos de las cinco localidades muestreadas: Las Palmas, Pechiche, Barro Colorado, Jesús del Gran Poder y Las Campanas. Provincia Los Ríos, Ecuador. 2024.

No.	Localities	Geographic coordinates	
		Latitude	Longitude
1	Las Palmas-East	1°12’11.08764” S	79°27’32.67648” W
2	Pechiche-South center	1°5’5.72424” S	79°29’51.3312” W
3	Barro Colorado-West	1°5’38.56668” S	79°31’25.32648” W
4	Jesús del Gran Poder-West	1°7’49.10268” S	79°29’47.88204” W
5	Las Campanas-South	1°18’0.62712” S	79°29’59.52516” W

Description of the farmers survey and *Spodoptera frugiperda* severity in maize

A structured survey was administered to farmers to identify the agronomic practices implemented for managing *S. frugiperda*. The instrument included multiple-choice questions about planting dates (early or late), soil preparation methods, crop rotation, pesticide application, and other management alternatives, such as the use of trap crops and the installation of capture traps. Farmers were also asked whether they had received technical training. The survey was validated through expert review and administered in person. The severity of the pest attack was determined through field sampling 30 days after maize germination (cv. INIAP H-601). This timing was chosen because the crop is more susceptible to pest attack at this stage. A semi-systematic W-shaped sample was used to collect the field data (Food and Agriculture Organization of the United Nations & Centre for Agriculture and Bioscience International, 2019).

In each of the 20 selected farms, 1 ha sampling area was considered. Within this area, five points were selected in a W-shape, as previously described. Ten consecutive plants (3 linear meters) were evaluated, totaling fifty plants (15 linear meters). The damage caused by the pest to the bud and the leaf with the last visible ligule of each plant was quantified using a five-grades scale. According to this scale, grades four and five were considered the most severe (Toepfer et al., 2021). A proportion analysis with a significance level of 5 % was performed to determine the differences in *S. frugiperda* infestation. This analysis was performed using CompraProWin 2.0.1 software (Castillo & Miranda, 2014).

Field experiment on the management of *Spodoptera frugiperda* using *Morus alba*

A field experiment was conducted in the Jesús del Gran Poder locality, which was chosen due to the presence of *M. alba* commercial plantations. The soil was classified as a Fluvisol; it presented a base saturation of 50 %, a value that indicates an intermediate state, without predominance of acidity or alkalinity, and its formation was influenced by alluvial deposits (Espinoza et al., 2018). The soil was prepared using minimum tillage, which included breaking up the soil, harrowing and furrowing. Sowing took place on 21 December 2023 at a distance of 0.90 x 0.30 m. The main agronomic management tasks consisted of adding a 15–15–15 fertilizer to the soil before sowing, two manual weedings for weed control, three irrigation sessions, and a manual harvest 120 days after sowing (DAS).

The experiment consisted of three treatments: i) a control without pest management or residue incorporation; ii) incorporation of 1 t ha^{-1} of a mixture of maize residues (80 %) and mulberry cv. Tigreada (20 %) fragmented to a size ≤1 cm (M+M); and iii) Methomyl was applied with a manual backpack sprayer when the foliar damage was 20 %, at a dose of 1 kg ha^{-1} of the commercial product (Methomyl 90 % SP). These treatments made it possible to compare the effect of incorporating organic residues with chemical control. Pest infestation severity was assessed at 30 DAS using the above-described methodology. Dry grain yield was estimated using equation 1:

$$Yield\ (t\ ha^{-1}) = \frac{Fw\ (kg/plot) \times 10 \times (100 - MC) \times 0.8}{(100 - adjusted\ MC\ \times Pa\ (m^2)} \qquad (1)$$

Where, Fw is the fresh mass (kg), MC is the moisture content of the grains (%) and the adjusted MC (14 %), 0.8 is the threshing coefficient, and Pa is the harvested plot area (m^2) (Evans and Fischer, 1999).A randomized block design with three treatments and three replicates (3 × 3) was used, and each experimental plot measured 67.5 m^2 and contained 250 plants per plot. Yield and severity data evidenced normal distribution according to the Shapiro-Wilk test ($p > 0.05$), allowing comparison between treatments using Duncan's test ($p \leq 0.05$). Statistical processing was performed using the InfoStat package version 2019.

Results

Farmers' perceptions on maize production systems

The results of the proportion analysis showed statistically significant differences ($p \leq 0.05$) between locations for the variables late sowing (Ls) and good soil preparation (GSP), while no differences were found for early sowing (Es) and crop rotation and polyculture (CRaP). Regarding Ls, Las Campanas location showed the highest percentage (50 %) compared to the other locations, whose values were lower and ranged between 10 % and 25 %. For GSP, Jesús del Gran Poder and Las Palmas registered the highest values, with 40 % and 30 % respectively, compared to the locations with the lowest percentages, which ranged between 0 % and 10 % (Table 2).

Regarding the Es variable, its values ranged between 0 % and 5 %. A similar result was observed for CRaP, with values ranging between 0 % and 15 %. Respondents from all five locations considered the quality of soil preparation insufficient due to the short time between preparation and effective soil depth. However, 100 % of respondents in Las Campanas and Barro Colorado considered soil preparation insufficient (Table 2). Participants expressed a lack of agronomic knowledge regarding crop rotation and polyculture practices.

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Table 2. Comparative analysis of early sowing (Es), late sowing (Ls), good soil preparation (GSP), and crop rotation and polyculture (CRaP) practices, showing significant differences between localities. Los Ríos province, Ecuador. 2024.

Cuadro 2. Análisis comparativo de las prácticas de siembra temprana (Es), siembra tardía (Ls), buena preparación del suelo (GSP), rotación de cultivos y policultivo (CRaP), mostrando diferencias significativas entre las localidades. Provincia Los Ríos, Ecuador. 2024.

No.	Localities	Es (%)	Ls (%)	GSP (%)	CRaP (%)
1	Las Palmas	0 a	10 b	30 a	0 a
2	Pechiche	5 a	10 b	10 b	5 a
3	Barro Colorado	0 a	25 b	0 b	0 a
4	Jesús del Gran Poder	5 a	20 b	40 a	5 a
5	Las Campanas	0 a	50 a	0 b	15 a

Es: Early sowing. **Ls**: Late sowing. **GSP**: Good soil preparation. **CRaP**: Crop rotation and polyculture. Different letters in the columns indicate significant differences ($p \leq 0.05$), proportion analysis with CompraProWin 2.0.1. / **Es**: Siembra temprana. **Ls**: Siembra tardía. **GSP**: Buena preparación del suelo. **CRaP**: Rotación de cultivos y policultivo. Letras diferentes en las columnas indican diferencias significativas ($p \leq 0,05$), análisis de proporciones con CompraProWin 2.0.1.

Respondents indicated that biocontrol of *S. frugiperda* was minimal (5 %), limited only to the localities of Pechiche and Las Campanas. To manage the pest, a considerable number of chemical pesticides were used in the rest of the study area. The highest proportion of treated area was recorded in Las Palmas and Barro Colorado (50 %), followed by Pechiche (45 %), Las Campanas (35 %) and Jesús del Gran Poder (25 %) (Table 3).

Table 3. Types of control strategies, biopesticides, chemical pesticides, trap crops, and capture traps, implemented for the management of *Spodoptera frugiperda* across the five evaluated localities. Los Ríos province, Ecuador. 2024.

Cuadro 3. Tipos de estrategias de control, bioplaguicidas, plaguicidas químicos, cultivos trampa y trampas de captura, implementadas para el manejo de *Spodoptera frugiperda* en las cinco localidades evaluadas. Provincia Los Ríos, Ecuador. 2024.

No.	Localities	Bp (%)	Cp (%)	Tc (%)	Ct (%)
1	Las Palmas	0 a	50 a	0 a	0 a
2	Pechiche	5 a	45 a	0 a	5 a
3	Barro Colorado	0 a	50 a	0 a	0 a
4	Jesús del Gran Poder	0 a	25 b	0 a	5 a
5	Las Campanas	5 a	35 ab	10 a	0 a

Bp: Biopesticides. **Cp**: Chemical pesticides. **Tc**: Trap crop. **Ct**: Capture traps. Different letters in the columns indicate significant differences ($p \leq 0.05$), proportion analysis with CompraProWin 2.0.1. / **Bp**: Biopesticidas. **Cp**: Pesticidas químicos. **Tc**: Cultivo trampa. **Ct**: Trampas de captura. Las letras diferentes en las columnas indican diferencias significativas ($p \leq 0,05$), análisis de proporciones con CompraProWin 2.0.1.

The use of control strategies based on attraction and capture was insignificant. Las Campanas reported using trap crops (10 % adoption), while capture traps were only implemented in 5 % of localities Pechiche and Jesús del Gran Poder (Table 3). According to the respondents, the traps contained a mixture of water, soap, and adhesive. For crop traps, they used oregano (*Origanum vulgare* L.), basil (*Ocimum basilicum* L.), and marigold (*Tagetes erecta* L.).

Farmers considered experience of more than five years in maize cultivation to be low (≤ 15 %) and homogeneous across localities. The highest rates were found in Las Palmas, Jesús del Gran Poder and Las Campanas (15 %), followed by Pechiche (10 %). Notably, Barro Colorado was the exception, presenting the least experience in cultivation, yet showing the highest level of training (20 %), significantly different from the other localities (Table 4).

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Table 4. Percentage distribution of farmers with more than five years of consecutive experience in maize cultivation (Ep) and their level of training received (Tr) for crop management, showing statistical differences ($p \leq 0.05$) between study localities. Los Ríos province, Ecuador. 2024.

Cuadro 4. Distribución porcentual de los agricultores con más de cinco años de experiencia consecutiva en el cultivo de maíz (Ep) y su nivel de capacitación recibida (Tr) para el manejo del cultivo, mostrando diferencias estadísticas ($p \leq 0{,}05$) entre localidades de estudio. Provincia Los Ríos, Ecuador. 2024.

No.	Localities	Ep (%)	Tr (%)
1	Las Palmas	15 a	5 b
2	Pechiche	10 a	0 b
3	Barro Colorado	0 b	20 a
4	Jesús del Gran Poder	15 a	5 b
5	Las Campanas	15 a	0 b

Ep: Experience >5 consecutive years in maize cultivation. **Tr**: Training received. Different letters in the columns indicate significant differences ($p \leq 0.05$), proportion analysis with CompraProWin 2.0.1. / **Ep**: Experiencia >5 años consecutivos en el cultivo de maíz. **Tr**: Formación recibida. Letras diferentes en las columnas indican diferencias significativas ($p \leq 0{,}05$), análisis de proporciones con CompraProWin 2.0.1.

High infestation (H^3) showed no significant differences between localities, and its values ranged from 20 % to 35 %. The highest level of medium infestation (M^2) was recorded in Las Campanas (55 %), Barro Colorado (40 %) and Pechiche (40 %). The lowest values (L^1) were observed in Jesús del Gran Poder (5 %) and Las Palmas (15 %). The highest percentages of absence of infestation (Ni^0) were observed in Jesús del Gran Poder (45 %) and Las Campanas (40 %), compared to the lowest values recorded in Barro Colorado (25 %), Pechiche (10 %), and Las Palmas (0 %) (Table 5).

Table 5. Percentage distribution of *Spodoptera frugiperda* attack severity levels (H^3: high infestation, M^2: medium infestation, L^1: low infestation, Ni^0: no infestation) on maize crops in five rural localities within the Mocache canton, Ecuador, highlighting significant differences ($p \leq 0.05$) through proportion analysis. Los Ríos province, Ecuador. 2024.

Cuadro 5. Distribución porcentual de los niveles de severidad del ataque de *Spodoptera frugiperda* (H^3: infestación alta, M^2: infestación media, L^1: infestación baja, Ni^0: infestación nula) en el cultivo de maíz en cinco localidades rurales del cantón Mocache, Ecuador, destacando diferencias significativas ($p \leq 0{,}05$) mediante análisis de proporciones. Provincia Los Ríos, Ecuador. 2024.

No.	Localities	H^3 (%)	M^2 (%)	L^1 (%)	Ni^0 (%)
1	Las Palmas	30 a	15 b	15 a	40 a
2	Pechiche	25 a	40 a	25 a	10 b
3	Barro Colorado	20 a	40 a	15 a	25 ab
4	Jesús del Gran Poder	30 a	20 b	5 b	45 a
5	Las Campanas	35 a	55 a	10 ab	0 b

H^3: High infestation. **M^2**: Medium infestation. **L^1**: Low infestation. **Ni0**: No infestation. Different letters in the columns indicate significant differences ($p \leq 0.05$), proportion analysis with CompraProWin 2.0.1. / **H^3**: Infestación alta. **M^2**: Infestación media. **L^1**: Infestación baja. **Ni0**: Sin infestación. Letras diferentes en las columnas indican diferencias significativas ($p \leq 0{,}05$), análisis de proporciones con CompraProWin 2.0.1.

Morus alba as viable alternative for managing *Spodoptera frugiperda* in the field

Significant differences (Duncan's test, $p \leq 0.05$) were observed between treatments in the variables infestation severity grades 1–3 (S^1), and grades 4–5 (S^2). The highest severity values of *S. frugiperda* infestation were observed

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in the control group (64.0 % and 36.1 %). Followed by the group in which residues were incorporated into the soil (50.1 % and 29.6 %). Finally, Methomyl insecticide demonstrated the lowest severity (39.7 % and 18.6 %) (Table 6).

Table 6. The effect of incorporating crop residues (*Morus alba* and *Zea mays*) and the insecticide methomyl into the soil on the severity of foliar damage to the INIAP H-601 hybrid. Los Ríos province, Ecuador. 2024.

Cuadro 6. Efecto de la incorporación de residuos de cultivos (*Morus alba* y *Zea mays*) y del insecticida metomilo al suelo sobre la severidad del daño foliar al híbrido INIAP H-601. Provincia Los Ríos, Ecuador. 2024.

No.	Treatments	S^1 (%)	S^2 (%)
1	Insecticide (Methomyl)	39.7 c	18.6 c
2	Residues (Maize+Mulberry)	50.1 b	29.6 b
3	Control	64.0 a	36.1 a

S^1: Infestation severity grades 1–3. **S^2**: Infestation severity grades 4–5. Different letters in the columns indicate significant differences according to Duncan's test (p ≤ 0.05). / **S^1**: Grados de severidad de la infestación 1-3. **S^2**: Grados de severidad de la infestación 4-5. Letras diferentes en las columnas indican diferencias significativas según la prueba de Duncan ($p \leq 0,05$).

Significant differences (Duncan's test, $p \leq 0.05$) were observed between treatments in the grain yield. The highest yields were obtained with the Methomyl (4.6 t ha^{-1}), and the residues of *M. alba* and *Z. mays* (4.1 t ha^{-1}). These differed with the control that obtained the lowest yield (3.5 t ha^{-1}) (Figure 1).

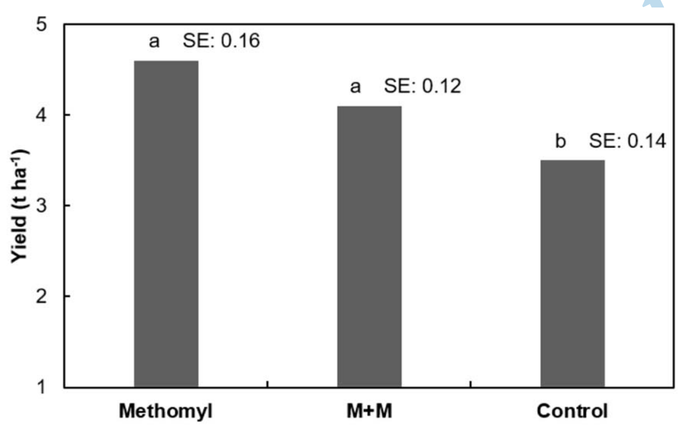

Figure 1. Response of grain yield of maize cultivar INIAP H-601 to incorporation of crop residues (*Morus alba* and *Zea mays*) into the soil and application of the insecticide methomyl in the management of *Spodoptera frugiperda*. Los Ríos province, Ecuador. 2024.

Different letters on the bars indicate significant differences (Duncan's test, $p \leq 0.05$). **SE**: Standard error. **M+M**: Residues of *Morus alba* and *Zea mays*.

Figura 1. Respuesta del rendimiento de grano del cultivar de maíz INIAP H-601 a la incorporación al suelo de residuos de los cultivos (*Morus alba* y *Zea mays*) y la aplicación del insecticida metomilo en el manejo de *Spodoptera frugiperda*. Provincia Los Ríos, Ecuador. 2024.

Letras diferentes sobre las barras indican diferencias significativas (prueba de Duncan, $p \leq 0,05$). **SE**: Error estándar. **M+M**: Residuos de *Morus alba* y *Zea mays*.

Discussion

The results of this research show that between 10 % and 50 % of farmers in the locations evaluated sowed maize late. This situation exposes the crop to suboptimal conditions for its development (Limongi-Andrade et al., 2024). In Mocache, the optimal planting time for dryland maize is around January 1st to 15th. Two or three consecutive rains are needed to thoroughly moisten the soil. This timing allows the grain formation and filling stage to develop during the rainiest months (February-March), ensuring a successful harvest and adequate yield. In addition, planting outside the optimal season increases the crop's vulnerability to attack by pests such as *S. frugiperda* (Mestanza-Uquillas et al., 2025). This is consistent with the high levels of infestation documented in this study.

Respondents documented that good soil preparation practices impact the management of *S. frugiperda*. It can destroy shelters and pupae, exposing insects to desiccation, predators, and adverse environmental conditions (Boukari et al., 2023). Soil health is strengthened by improving structure, aeration, biological activity and nutrient availability, which translates into greater plant vigor from early stages. Vigorous plants can better withstand pest pressure, exceeding the economic damage threshold and having less impact on yield (Garrido-Jurado et al., 2020). In a scenario of late planting and suboptimal conditions, such as those documented in this study, water and nutrient stress are considered likely to increase the susceptibility of maize to *S. frugiperda* attack (Fonteyne et al., 2023). Inadequate soil preparation would compromise plant vigor and affect the crop's ability to tolerate and recover from foliar damage (Tolon-Becerra et al., 2011). Therefore, farmers are advised that proper soil preparation contributes to the management of *S. frugiperda*.

The results of this study reveal low adoption of crop rotation and polyculture, fundamental integrated pest management (IPM) practices that disrupt pest life cycles and reduce populations. Their limited use may have contributed to the high levels of *S. frugiperda* infestation observed. Maize monoculture systems provide a continuous supply of hosts, creating favorable conditions for the establishment and multiplication of *S. frugiperda* by removing the temporal and spatial barriers that naturally limit population growth. In contrast, diversified systems, such as polycultures and agroforestry, improve ecological resilience to pests by promoting habitat for natural enemies (Hailu et al., 2018; Rosas-García, 2020).

Respondents reported insufficient use of biopesticides due to their limited knowledge of the topic. This situation represents an opportunity to move towards more sustainable production systems that strengthen technology transfer and training in the use of biological control agents. These agents, based on nematodes, bacteria and entomopathogenic fungi, are essential for the sustainable management of *S. frugiperda* (Bahadur & Acharya, 2019; Castruita-Esparsa et al., 2017; García-Riaño et al., 2021).

Farmers responded that they used synthetic chemical insecticides for the control of *S. frugiperda* in all the locations surveyed. These products are believed to contribute to the development of pest resistance to certain active ingredients and pose a risk of human exposure to these substances (Van Den Berg & Du Plessis, 2022). The absence of ethological management strategies for *S. frugiperda* highlights the insufficient technical training of farmers in these pest control methods, which could be reversed with the implementation of an adequate training system in ethological alternatives for pest control (Gomero, 2018).

As an alternative to the use of broad-spectrum insecticides, botanical control strategies can be used. Secondary metabolites such as rotenone are present in native plants such as *Tephrosia vogelli*, *Annona squamosa*, and *Nicotiana tabacum*. Likewise, species such as *Chrysanthemum* spp., *Azadirachta indica*, *Cymbopogon nardus*, and *Ocimum basilicum* contain pyrethrin, and their extracts can be used as an agroecological alternative for managing *S. frugiperda* (Bhosle et al., 2025). In this context, the characterization of farms as family units, mostly managed by older people and retirees from non-agricultural sectors, highlights the importance of considering the capacity and experience of farmers to adopt recommended sustainable technologies for pest management (Njuguna et al., 2021).

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Farmers' limited experience and low levels of technical training represent a significant limitation to the implementation of new pest management approaches. In contrast, the adoption of participatory methodologies in training programs constitutes a viable alternative to overcome these knowledge barriers. This participatory approach could help farmers acquire new learning directly in their own communities and farms, which is essential to achieve effective management of *S. frugiperda* (Barba et al., 2015; Landini & Villafuerte-Almeida, 2022).

The farmers' perceptions coincided with the predominant trend of medium (M^2) and high (H^3) infestations in most areas. These results suggest the strong influence of specific local factors. The most relevant of these are: 1) inefficient application of integrated management practices, 2) limited technical training for farmers, 3) possible presence of alternative hosts of the *Poaceae* family in the vicinity, and 4) favourable climatic conditions (temperature 25 to 30 °C, and relative humidity 70 to 90 %) for insect proliferation. The concurrence of these factors explains the incidence of severe crop damage (Barkessa et al., 2025).

Considering the pest management strategies evaluated in the field, the insecticide methomyl was the most effective in reducing the severity of the infestation by *S. frugiperda*. Its high effectiveness is attributed to its immediate biocidal action, which operates through direct contact and ingestion on the larvae. However, it is important to note that continued dependence on chemical insecticides can generate resistance problems in pest populations and cause a negative impact on the beneficial insects present in the agroecosystem (Burgos et al., 2023).

Incorporation of a combination of residues of *M. alba* and *Z. mays* into the soil shows significant potential as a biocontrol strategy against *S. frugiperda* pupae in the soil. The secondary metabolites present in the leaves and stems of these plants, including alkaloids, terpenoids and phenolic compounds, can exert biocidal effects or inhibit pupal development (Zhang et al., 2022). Furthermore, it has been observed that modifying soil conditions (e.g. changes in humidity, pH, temperature and structure) as result of incorporating plant material can negatively affect the viability and emergence of adults. This dual action establishes incorporation of *M. alba* into the soil as a promising resource within integrated management strategies, providing a sustainable alternative that reduces reliance on synthetic pesticides (Ain et al., 2023).

The yield obtained in the experiment was considered acceptable (3.5–4.6 t ha^{-1}). The higher yield observed with the application of insecticides, and residues *M. alba* and *Z. mays* can be attributed to the effective control of *S. frugiperda* during critical stages of crop development, which minimized losses due to reduced foliar damage (Vélez et al., 2021).

The lack of significant differences between crop residues and insecticide suggests that this practice could be a sustainable alternative in maize production. The incorporation of organic residues of *M. alba* and *Z. mays* during soil preparation is a viable alternative for the farmer. Its incorporation into the soil improves fertility and biological activity. It significantly reduces the costs of acquiring insecticides and the hours of application, favoring a natural suppression of *S. frugiperda* with adequate yields. The above could be related to the gradual release of nutrients, which improves the soil's physical, chemical and biological properties, as well as having a suppressive effect on pests in the soil (Bayissa et al., 2023). These results reinforce the effectiveness of incorporating practices such as returning crop residues of *Z. mays* and *M. alba* to the soil into management strategies for *S. frugiperda*.

Conclusions

The high perception of severity of *Spodoptera frugiperda* by farmers corresponds to high levels of infestation in Mocache, associated with inadequate agronomic practices and poor technical training. The incorporation of maize and mulberry residues into the soil reduces the severity of the pest and allows the obtaining of yields similar to the application of the insecticide, which validates its effectiveness as a management alternative. The feasibility of integrating organic waste into management strategies opens a way to reduce dependence on synthetic insecticides

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and move towards sustainable production systems. The strengthening of local capacities through training programs in biological control and integrated pest management will be decisive in mitigating the impact of *Spodoptera frugiperda* in Ecuador and similar regions.

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Interests conflict

The authors declare no conflicts of interest.

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