Spodoptera frugiperda MANAGEMENT IN *Zea mays* L. USING VINASSE AND CORN-MULBERRY MULCHING †

[MANEJO DE *Spodoptera frugiperda* EN Zea mays L. UTILIZANDO VINAZA Y MANTILLO DE MAÍZ-MORERA]

Ramiro Gaibor-Fernández[1], Sergio Rodríguez-Rodríguez[2], Juan José Reyes-Pérez[1], María Jiménez-Pizarro[2], Beatriz González-Rosales[3], Lilian Jacas-Vega, Tomás Rivas-García[4], and Luis Guillermo Hernández-Montiel[5*]

[1] Universidad Técnica Estatal de Quevedo. Av. Quito. Km 1 ½ vía a Santo Domingo. Quevedo, Los Ríos, Ecuador.
[2] Universidad de Granma. Bayamo, Granma, Cuba.
[3] Instituto de Investigaciones "Jorge Dimitrov". Bayamo, Granma. Cuba.
[4] CONACYT-Universidad Autónoma Chapingo, Carretera Federal México-Texcoco km 38.5, San Diego 56230, México.
*[5] Centro de Investigaciones Biológicas del Noroeste S.C., Instituto Politécnico Nacional No. 195, Colonia Playa Palo de Santa Rita Sur, La Paz, Baja California Sur, México. Email. * lhernandez@cibnor.mx*
‡ Corresponding author

SUMMARY

Background: Soil cover with crop residues is an ancient tradition that is gaining momentum in conservation agriculture´s current trends. **Objective:** The objective of this research is to evaluate the effect of soil mulching with corn-mulberry on *Spodoptera frugiperda* management in corn *Zea mays* variety Tuson after imbibition in vinasse. **Methodology:** The first part of the experiment evaluates the effect on germination with seed previously soaked in vinasse in 1:15 ratio under controlled conditions for 30 min. The second part was developed in the Unidad Empresarial de Base "Antonio Maceo" Yara, Granma, Cuba under field conditions, which consisted of two treatments: (T1) corn-mulberry soil mulching 2 t ha^{-1} before planting and (T2) control group without cover. The percentage of maize plants were evaluated from 1 to 3 and from 4 to 5 degrees in damage at 30 days, in addition to agricultural yield at 150 days. Both experimental stages were performed in a randomized complete block design (RCBD). **Results:** The results showed that germination percentages increased by using 1:15 vinasse, whereas the corn-mulberry soil cover decreased *S. frugiperda* incidence at the same time and increased agricultural yields. **Implications:** Future studies should find an equilibrium point that guarantees the use of crop residuals as agroecological practices in soil protection and conservation, as well as in animal feed sources in places and season where natural forage is affected. **Conclusion:** Soil cover with corn-mulberry mulching from leaf waste before sowing decreases *S. frugiperda* incidence and corn yield increases.
Keywords: Conservation agriculture; crop residues; organic mulches; *Morus alba*; pest control.

RESUMEN

Antecedentes: La cobertura del suelo con residuos de cosecha es una tradición milenaria que cobra auge en tendencias actuales en la agricultura de conservación. **Objetivo:** El objetivo de esta investigación fue evaluar la cobertura del suelo con maíz-morera para el manejo de *Spodoptera frugiperda*, en maíz, variedad Tusón, previa imbibición en vinaza. **Metodología:** La primera parte del experimento evalúa el efecto sobre la germinación con semilla previamente remojada en vinaza en proporción 1:15 bajo condiciones controladas por 30 min. La segunda parte se desarrolló en la Unidad Empresarial de Base "Antonio Maceo" Yara, Granma, Cuba en condiciones de campo, la cual constó de dos tratamientos: (T1) suelo maíz-morera acolchado 2 t ha-1 antes de la siembra y (T2) testigo grupo sin cobertura. Se

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ISSN: 1870-0462.
ORCID = Ramiro Gaibor-Fernández (https://orcid.org/0000-0002-0981-2000), Sergio Rodríguez-Rodríguez (https://orcid.org/0000-0003-2923-5092), Juan José Reyes-Pérez (https://orcid.org/0000-0001-5372-2523), María Jiménez-Pizarro (https://orcid.org/0000-0003-1548-4135), Beatriz González-Rosales (https://orcid.org/0000-0002-9289-2645), Lilian Jacas-Vega (https://orcid.org/0000-0003-0813-2625), **Tomás Rivas-García** (https://orcid.org/0000-0003-1035-4112), **Luis Guillermo Hernández-Montiel** (https://orcid.org/0000-0002-8236-1074)

evaluó el porcentaje de plantas de maíz de 1 a 3 y de 4 a 5 grados en daño a los 30 días, además del rendimiento agrícola a los 150 días. Ambas etapas experimentales se realizaron en un diseño de bloques completos al azar (RCBD). **Resultados:** Los resultados mostraron que los porcentajes de germinación aumentaron con el uso de vinaza 1:15, mientras que la cobertura del suelo de maíz-morera disminuyó la incidencia de S. frugiperda al mismo tiempo que aumentó los rendimientos agrícolas. **Implicación:** Futuros estudios deberán encontrar un punto de equilibrio que garantice el uso de residuos de cultivos como prácticas agroecológicas en la protección y conservación de suelos, así como en fuentes de alimentación animal en lugares y temporadas donde se afecta el forraje natural. **Conclusión:** La cobertura del suelo con acolchado de maíz-morera a partir de residuos foliares antes de la siembra disminuye la incidencia de S. frugiperda y aumenta el rendimiento del maíz.

Palabras clave: Agricultura de conservación; residuos de cosecha; mantillos orgánicos; *Morus alba*; control de plagas.

INTRODUCTION

Corn (*Zea mays*, L.) is the second most important grain in the human food chain at the world level after rice (*Oryza sativa*, L.). It occupies the first place as raw matter for the production of the balanced feed used in domestic animal species (León *et al.,* 2018). From 2013-2014, 973.9 million tons (MT) of corn were produced worldwide with a yield of 5.20 t ha^{-1} average. The American continent is the area with the greatest world production (53%) and the United States of America is the main producer and exporter at the world level (León *et al.,* 2018).

The fall armyworm, cutworm, or owlet moth *Spodoptera frugiperda* (Smith) (*Lepidoptera: Noctuidae*) is a larva that may cause serious damage. The adult insect is not the one that causes these affectations – but the larval stage is (Delgado and Gaona, 2012). This pest attacks corn, sorghum (*Sorghum bicolor*, L), rice (*Oryza sativa*), cotton (*Gossypium herbaceum*, L.), vegetables (horticulture), and ornamental plants, among others. At first, some translucid points appear; then, small perforations and finally, strong defoliation with large cuts can be observed (Murua and Virla, 2004). Unfortunately, bibliography on the use of *Morus alba* -known as white mulberry for pest control- is not sufficient although some studies have been performed based on the chemical compounds found in its different parts (Landero *et al.,* 2017).

Conventional agriculture is based on the use of large amounts of fertilizers and pesticides (Canwat and Onakuse, 2022). Although they initially allow increase in production, they are also responsible for different associated problems, such as decrease in organic matter, soil erosion, or environmental contamination (van der Werf *et al.,* 2020). Thus, in the last decades, interest has grown in developing alternative and sustainable practices that require using fewer external inputs, among which mulch or soil mulching is found (Frutos *et al.,* 2016; Oluseun and Adebukola, 2021). Even though mulches are well known to promote soil water retention and by improving soil health, weed suppression, and grain yield and quality (El-Beltgi *et al.,* 2022), they can also have a role in suppress insect pest and disease pathogens (Jabran, 2019). For example, wheat and sunn straw caused impact on Colorado potato beetle (*Leptinotarsa decemlineata*) and disease lesser cornstalk borer (*Elasmopalpus lignosellus*) (Brust, 1994; Gill *et al.,* 2010).

On the other hand, one of the sub-products to obtain alcohol (ethanol) -starting from sugarcane molasses- is called vinasse. Vinasse has a high organic matter and low pH (from 4 to 5), which implies biochemical oxygen demand (BOD) from 40.000 to 60.000 mg O_2 L^{-1} and a high concentration of potassium (K^+) ion. Thus, vinasses that derive from ethanol production have the possibility of being used as water and nutrient sources (González *et al.,* 2014). Therefore, the objective of this research is to evaluate the effect of soil with corn-mulberry mulching on *Spodoptera frugiperda* management in maize variety Tuson previously imbibed in vinasse.

MATERIALS AND METHODS

Vinasse effect on germination

The research methodology was performed in the Empresa de Semillas de Granma, Ministry of Agriculture in Bayamo, Granma, Cuba to evaluate the effect of vinasse on seed germination. For this purpose, 500 certified seeds of maize variety Tuson were selected. Two treatments were performed: (T1) 250 seeds imbibed for 30 min in vinasse from the Empresa Azucarera Arquímedes Colina de Mabay, Bayamo, Granma. The vinasse was diluted in a ratio of 1:15 (v/v); (T2) 250 seeds imbibed for the same interval (30 min) in distilled water. Once the seeds were imbibed, they were placed on metal trays with sterile humid sand and set in growth chambers. On day 5, the germination percentage of each 50 seeds was determined as replicates, dividing the number of seeds by the total seeds placed to germinate, all multiplied by 100 (ISTA, 1999).

Effect of corn-mulberry soil mulching on *Spodoptera frugiperda*

This research was performed at the Unidad Empresarial de Base Antonio Maceo, Municipality of Yara from the Empresa Agroindustrial de Granos Fernando Echenique, Granma Province, Cuba on vertisol-type soil in 2020 (Hernández *et al.,* 2015). For this purpose, 200 m^2 were selected and divided into two plots of 100 m^2 each. On one of the two parts, after soil preparation and before sowing, (T1) a mixture of maize crop residue (90%) and fresh mulberry variety cordate leaf mulching (10%) were scattered (2 t ha^{-1}) previous to fragmentation to obtain a homogeneous mixture. The other (T2) 100-m^2 plot was considered the control group with no crop residue applied. Maize sowing was performed on 5 May 2020 with the hybrid Tuson variety. Previous to sowing, T1 seeds were imbibed previously in vinasse in a dilution ratio of 1:15 for 30 min, considering the results of the first part of the experiment.

To determine the severity of the pest attack, sampling in field was performed 30 days after maize plants germinated in both treatments, considering that the crop is most affected by the first 40 days. The British-flag sampling method was used by selecting five points at random and avoiding at all times the border effect. In each point, 10 plants were lineally evaluated for a population of 50 plants per sampling point. The damage caused by the pest was observed on the verticil-circular leaf arrangement around the stem- and on the leaf of the last visible ligule, which corresponds to the 5-degree scale proposed by Fernández and Expósito (2000) who considered 4-5 degrees as the greatest damage. Both areas were divided into five 20 m^2 plots to facilitate weighing the replicates in the final yield maize evaluation. Harvest was performed 150 days after sowing and dry grain yield was determined in t ha^{-1}.

Variables assessed

Two of the variables measured the percentages of maize plants with *S. frugiperda* damage in degrees from 1-5: 1-3 and 4-5 degrees, both according to the methodology of Fernández and Expósito (2000) at 30 days after sowing; the third variable measured agricultural maize yield by weighing corn after shucking the cobs with the dry grain at 150 days after sowing.

Following Fernández and Expósito (2000) methodology, the verticil and ligule of the last visible petiole (stalk) was described, which corresponded to the 5-degree scale proposed by these authors, and according to the scale shown in Table 1. The type of damage caused by the pest in the plant leaf area with four and five degrees were those of the greatest damage due to the severe affectations caused on the leaf verticil.

Table 1. Scale to estimate the visual damage caused by *Spodoptera frugiperda* attack to maize variety Tuson plants in Yara, Granma, Cuba.

Degree	Damage characteristics
1	No visible damage or only causing from one to three plants with window-pane damage.
2	More than three plants with window-pane damage and /or from 1-3 degrees with less than 10 mm damage.
3	More than three with less than 10 mm damage, and from 1-3 degrees greater than 10 mm damage.
4	From three to six plants with damage greater than 10 mm and/or verticil destroyed more than 50%.
5	More than six plants with greater damage than 10 mm and/or the verticil totally destroyed.

Source: Fernández and Expósito, 2000.

Statistical processing

The comparison between the two treatments for the variable percentage of maize plants with *S. frugiperda* damage from 1-3 and those from 4-5 degrees was processed statistically by the analysis of proportions to determine the existence of significant difference for a level of likelihood of 5.0% for each marker. The statistical process was performed with the program CompraProWin 2.0.1 (Castillo and Miranda, 2014) which compares multiple ratios by calculating the confidence intervals and correcting with the Wald Chi-Squared Test (Wald, 1943).

For the variable percentage of germination and agricultural yield of dry maize, the comparison between treatments was performed by the Student's t-Test for a likelihood of 5.0%, considering that the data of these variables were adjusted to a normal distribution by the modified Shapiro-Wilk's test (Mahibbur and Govindarajulu, 1997).

A Principal Component Analysis (PCA) was performed to reduce the dimensions and find existing relationships between individuals and variables of the study through a biplot representation. As individuals, the two treatments (T1) with the corn-mulberry application and (T2) the control group were selected; as variables, the maize plants with *S. frugiperda* damage from 1-3 and those from 4-5 were also selected, as well as agriculture yield. The statistical processing of the Student's t-test and the PCA were performed by the statistical package Infostat 2019 (Di Rienzo *et al.*, 2019).

RESULTS AND DISCUSSION

Germination percentage

The maize variety Tuson seeds in T1 -imbibed for 45 min in vinasse-reduced to the ratio 1:15 and reached a germination average of 94%, showing significant differences concerning T2 with seeds imbibed in distilled water (control) (Fig. 1). This result can be explained as a consequence of potassium (K), calcium (Ca), magnesium (Mg), nitrogen (N), and sulfur (S) found in vinasse, mainly K (González *et al.*, 2014).

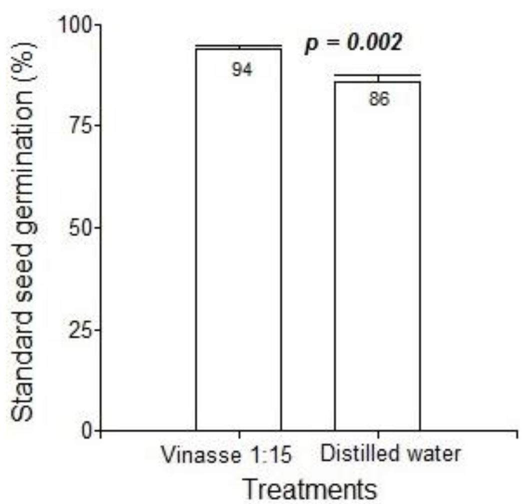

Figure 1. Percentage of germinated maize variety Tuson in the treatment (T1) with seeds imbibed in vinasse reduced to 50% and T2 seeds imbibed in distilled water. Values of $p < 0.05$ indicate significant differences when the Student's t-test was applied.

Increasing seed germination percentages of economically important crops by sustainable methods is a viable alternative from several points of view. In first place, high germination percentages are achieved, which guarantee a greater plant population per sowing area and at the same time favor greater soil cover for the crop of agricultural interest with less space for arvense plants (weeds) that compete for nutrients, water and vital space. In the same manner, a greater population correlates directly with greater agricultural yield (Ionescu *et al.*, 2020). In this case, as in maize cultivation, it generates a greater amount of biomass that can be used as soil cover or animal feed. Thus, a greater population generates better uniformity and avoids undesirable re-sowing.

González *et al.* (2014) evaluated the effect of vinasse in dilutions 1:1, 1:5, 1:10, and 1:20 on soybean (*Glycine max*), wheat (*Triticum aestivum*) and quinoa (*Chenopodium quinoa*) in controlled conditions. Their results showed that pure vinasse inhibited germination totally of the three species used. In the lowest dilution (1:1) soy and quinoa germination were null, whereas wheat was delayed and achieved final germination of 42%. Moreover, the results showed that with diluted vinasses (1:5; 1:10 or 1:20), germination of the three assayed species went over 90% germination (González *et al.*, 2014).

Ramana *et al.* (2002) studied the effects of different concentrations of distillery effluent on seed germination from some vegetables, such as: tomato (*Solanum lycopersicum*), onion (*Allium cepa*), cucumber (*Cucumis sativu*), chili (*Capsicum annum*) and squash (*Cucurbita máxima*). No evidence was found at low concentration nor an inhibitor effect except for tomato. Nevertheless, at high concentrations (75 and 100%) limitations in germination were observed, finding that at a concentration of 5% of distillery effluent, the critical nature increased for tomato and squash and 25% for the rest of the crops. Based on tolerance to the distillery effluent, the crops in study were arranged based on tolerance: cucumber > chili > onion > bottle gourd (*Lagenaria siceraria*) > tomato. The authors concluded that the effect of distillery effluents is species-specific for each crop; thus, these effluents should be considered as a risk before using them in the pre-sowing stage (Ramana *et al.*, 2002).

As mentioned before, vinasse has a great apport of potassium (K), and despite potassium Kdoes not form part of any organic molecule or plant structure, it is the nutrient accumulated by sweet corn because it plays a fundamental role in processes, such as photosynthesis, osmoregulation, protein synthesis, carbohydrate formation and translocation, and enzyme activation, which directly affect sweet corn quality and productivity (Hawkesford *et al.*, 2012). But on the other hand, high dosage of K may produce negative effects on plants and the environment. When a high application of this nutrient is performed on soil, it may be harmful on seed germination (Takasu *et al.*, 2014) and plant growth as a consequence of salinity effect. Furthermore, it may also cause antagonism on magnesium (Mg) absorption, increase loss by lixiviation, and restrict the enzymatic activity associated to nitrogen absorption by the plant (Guo *et al.*, 2015).

Percentages of plants with *Spodoptera frujiperda* damage from 1-3 and 4-5

The application of crop residue combination and corn-mulberry in T1 before sowing showed interesting results. Significant differences were found between treatments for the percentage of plants affected in both treatments with damage in 1-3 and 4-5 degrees (figures 2 and 3).

In the plot with crop residue applied before sowing and related to no application, 80% of maize plants were affected by the pest in degrees 1-3 in damage; in 20% of the plants sampled, damage levels were from 4-5 degrees. In the control (T2) or without crop residue, 64% of maize plants were affected in degrees 1-3 damage, and in 36% from 4-5 degrees.

During all the plant cycle, maize is exposed to the attack of pests that may cause economic losses to the producer. The main pest is the fall armyworm (*S. frugiperda*). A severe attack of this Lepidoptera (above 20% of infestation) may reduce yield from 10% to 60%, which has a bearing on low crop productivity of dry maize (flint corn) in the Ecuadoran coastline (Valarezo *et al.,* 2010).

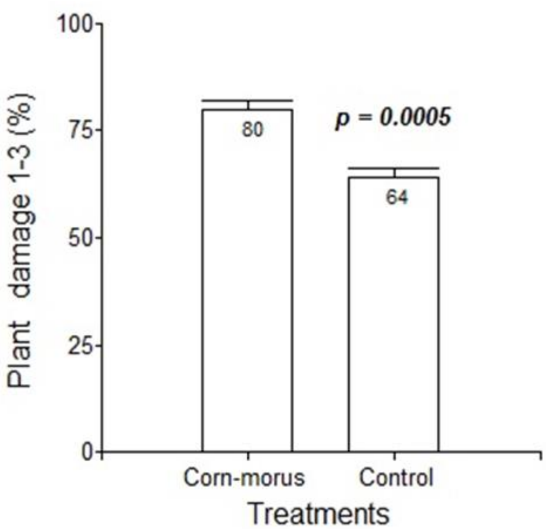

Figure 2. Percentage of maize variety Tuson plants with *Spodoptera frujiperda* damage from 1-3 degrees in treatment T1 with crop residual before sowing with a proportion of 90% corn plant crop residue and 10% of fresh mulberry leaf biomass compared with T2 or no application (control). Different letters indicate significant differences (p ≤ 0.05) by the analysis of ratios.

The greatest percentage of maize plants affected with 4-5 degrees by *S. frugiperda* was observed in T2 without corn-mulberry harvest residue causing a decrease in agricultural yield by pest damage of 28.9% compared to T1 with crop corn-mulberry residue, and a significant decrease of 0.28 MT ha^{-1}, which may constitute an alternative for pest management (Figure 4).

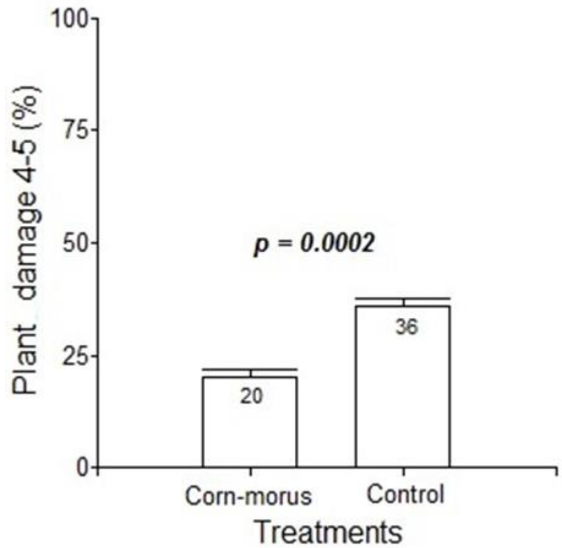

Figure 3. Percentage of maize variety Tuson plants with *Spodoptera frujiperda* damage from 4-5 degrees in treatment T1 with crop residual before sowing with a proportion of 90% corn plant crop residue and 10% of fresh mulberry leaf biomass compared with T2 or no application (control). Different letters indicate significant differences ($p \leq 0.05$) by the analysis of ratios.

To reduce the damage caused by *S. frugiperda,* farmers apply a great amount of agrochemical products of varied toxicity as a control method, which has caused the destruction of beneficial organisms and toxic waste substances in the air, soil, and water. This situation likely occurs because some farmers may not know the existence of biological pesticides that help to decrease the use of chemicals, thus avoiding economic, social, and environmental problems (Muñoz *et al.,* 2017).

Although no research works were found related to the use of Morus for pest control, the results in this study may have been related to the presence of the chemical compounds identified in mulberry leaf parts. For example, steroids, saponins, tannins, phenols, terpenoids, and flavonoids have demonstrated antibacterial and antifungal activities or their proven anthelmintic effect Chen *et al.,* 2021). Moreover, amino acids, vitamins, and mineral traces may individually or combined have a repellent effect on insects or provide the plants with internal resistant mechanisms to attack the pest. This aspect may be favorable because Morus aerial biomass has approximately 20% of raw protein on a dry base (Díaz *et al.*, 2017).

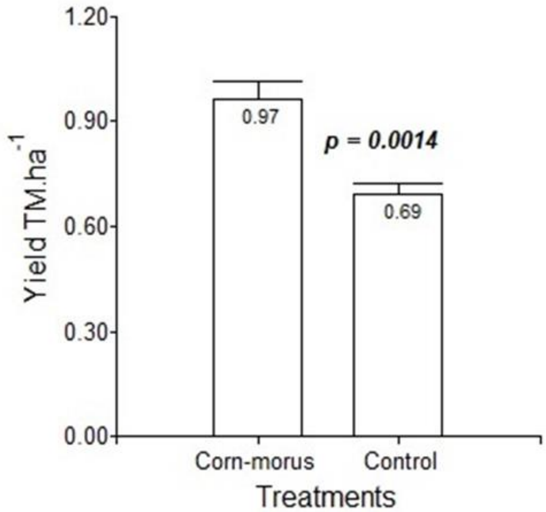

Figure 4. Agricultural yield of maize variety Tuson in treatment T1 with crop residual before sowing with a proportion of 90% corn plant crop residue and 10% of fresh mulberry leaf biomass compared with T2 or without application (control). Different letters indicate significant differences of $p \leq 0.05$ by the Student's t-test.

Morus leaf biomass shows a fast decomposition in soil (Medina *et al.*, 2009), which as an additional benefit improves soil structure and nutritional balance. The representation of the analysis biplot of the principal components (Figure 5) showed that all the analysis variability (100%) was explained by component one (PC1), which is considered the most important. The control (T2) was characterized more by the predominance of maize plants with damage from *S. frugiperda* with degrees from 4-5, whereas T1 based on corn-mulberry was the treatment that reached the greatest yield and where plants affected by the pest were predominantly in degrees 1-3 and in a lower number from 4-5.

In a study in Porto Viejo, Manabí, Ecuador about the effect of biological pesticides, Muñoz *et al.* (2017) found the greatest percentages of affectation by *S. frugiperda* and its incidence in maize yield with 28.0% and the lowest in the control treatment without any product application. The greatest yields were reached in the treatment with the application of the chemical pesticide Lambda Cialotrina + Tiametoxan 1,5 mL L^{-1} of water and Methakill 15 mL L^{-1} of water. The biological pesticide Methakill 15 mL L^{-1} of water reached the best rate of a marginal return.

The phenolic compounds shown in mulberry aerial biomass can alter proteins and cellular membranes, synthetizing new ones, inhibiting enzymes, and forming bisulphite bridges that are interspersed on the cell wall and/or in the DNA molecule (Oh *et al.*, 2013), both in maize plants and in insect larvae. This aspect opens new perspectives for new research lines.

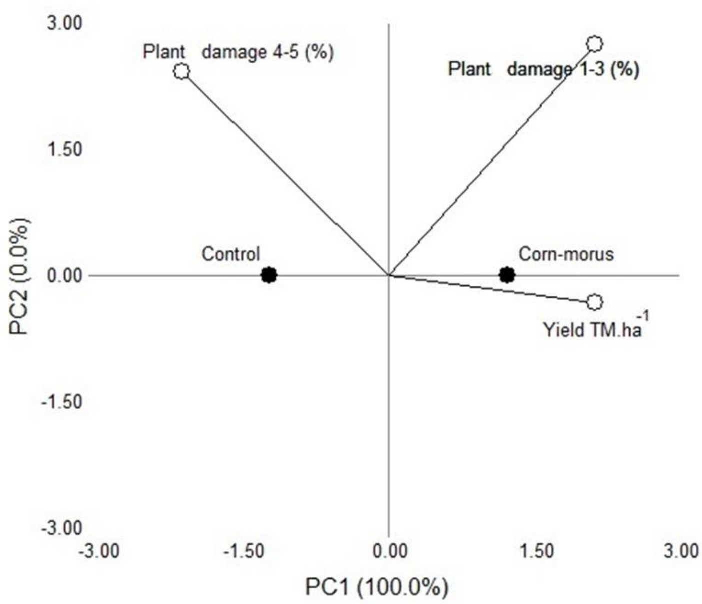

Figure 5. Biplot of the principal component (PC) analysis for the two treatments (T1 and T2) assumed as individuals, and agricultural yield and percentages of the plant affected at 1-3 and 4-5 degrees as variables.

In China, the combination of mulberry and grass (pasture) reduces erosion of rain water toward the slope, intercepting superficial runoff and turning it into underground filtration. Meanwhile, the fallen leaves and buds cover the soil to increase moisture and fertility content, providing enough water and nutrient supply for mulberry growth. This cultivation pattern has played important roles in water and soil erosion control, collecting rainwater, increasing soil moisture content, and recycling fertilizers. According to an investigation, mulberry interspersed with grass in the back part of the leveled pits can reduce soil erosion in 124.5 t ha^{-1} increasing moisture content on the soil layer of 50–100 cm from 13% - 5% and increasing organic substance content in 3% (Jian *et al.,* 2012). With this respect, a more detailed review of the importance and experience in using mulberry in agriculture can be found in Rodríguez *et al.* (2022).

Maize increased in agricultural yield in T1 where corn-mulberry mulching was applied, which can be explained using covers in different forms that derive in physical soil effects. Some examples are emerging weed reduction, evaporation decrease, microclimate modification of the cultivated plants, humidity conservation, increase in soil water infiltration, runoff and temperature control, erosion decrease, and soil structure improvement (Bravo *et al.,* 2004; Barrios *et al.,* 2006 and Haruna *et al.,* 2018). Its use in conservation agriculture is currently credited as an alternative facing conventional agriculture and as a way of attenuating degradation of perishable natural resources, among which soil is found (Corsi *et al.,* 2012; Friedrich *et al.,* 2012; Kassam *et al.,* 2015).

Minimum soil disturbance or conservational agriculture enhances soil biological properties, thereby improving soil fertility management and plant nutrition. Mulching of crop residues protects the soil surface and adds carbon to improve soil fertility management, providing habitat for insect predators especially spiders, earwigs, beetles, and ants (Harrison *et al.,* 2019). In previous research, the application of wheat straw much decreased the proliferation of potato beetle in potato fields by significantly increasing the population of predators that could antagonise the eggs and second instars or it (Brust, 1994). Another indirect impact was the application of Sunn hemp straw (*Crotalaria juncea* L.) that provides an alternaive inhabitance to the insect pest in busch bean (*Phaseolus vulgaris* L.) to manage the disease lesser cornstalk borer (*Elasmolpalpus lignosellus*) (Gill *et al.,* 2010).

However, this type of conservational agriculture or minimal soil disturbance is still insufficient for extensive application due to multiple causes. Those that can be mentioned are the scarce use of harvest waste in agricultural cultivations, in some cases, because their use and benefit on soil conservation are still unknown (Velázquez *et al.,* 2002; Varma *et al.,* 2015; Obi *et al.,* 2016; Akintola *et al.,* 2019). The tradition of using harvest waste as cattle feed is strongly established, which makes this problem more difficult to find a point of equilibrium to guarantee its use as an agroecological practice for soil protection and conservation (Wang *et al.,* 2016; Akande and Olorunnisola, 2018; Oleseun and Adebukola, 2021). On the other hand, sources for animal feed should be guaranteed in places or seasons of the year when natural pasture is affected (Baltenweck *et al.,* 2020; Grote *et al.,* 2021). These aspects can be made known to farmers through demonstrative field training, highlighting that the worst option is burning harvest residue or only using the same cultivation waste without combining it with a different type of agroecological practices. Sometimes waste of the same crop may become a pest host, which is the case of *S. frugiperda* and maize harvest residue.

CONCLUSIONS

The results in this study showed that when vinasse is used in a dilution of 1:15, germination percentages increase over 90% in maize (*Z. mays*) var. Tuson seeds. Soil cover with corn-mulberry mulching from leaf waste before sowing decreases *S. frugiperda* incidence and corn yield increases. Further studies should be performed on the phenolic compounds shown in mulberry aerial biomass, as previously mentioned because this aspect opens new perspectives for new research lines.

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Not applicable

Compliance with ethical standards. Not applicable

Data availability. All data is presented in the presented the present paper.

Conflict of interests. The authors declare that they have no competing interests.

Author contribution statement (CRediT)
R. Gaibor-Fernández – Conceptualization, validation, investigation, writing—original draft preparation; **S. Rodríguez-Rodríguez –** Conceptualization, methodology, formal analysis, supervision, project administration, and funding acquisition; **J.J.Reyes-Pérez.-** Methodology, writing—review and editing; **M. Jiménez-Pizarro** – software; **B. González-Rosales** – validation; **L.G. Hernández-Montiel** - data curation; **T. Rivas-García** - writing—review and editing, visualization.

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