Colegio de
Postgraduados

Corn-neem soil cover and neem (*Azadirachta indica* A. Juss.) extract application for the *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) management in corn (*Zea mays* L.)

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ABSTRACT

Objective: To evaluate the soil cover with corn-neem biomass for the *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) management in the INIAP H601 corn hybrid, at Pechiche, Los Ríos, Ecuador.

Design/Methodology/Approach: Two treatments were evaluated: 1) a treatment using corn-neem soil cover at 2.0 t ha^{-1} before sowing, plus two foliar applications, 10 and 20 days after sowing; 2) a control treatment without soil cover, in a completely randomized design. The variables evaluated were the percentage of corn plants with 1st to 3rd degree damage and 4th to 5th degree damage (30 days after sowing), Leaf Area Index (LAI), and agricultural yield.

Results: Under field conditions, both treatments had no significative differences in the 1st to 3rd degrees damages (69.0% impact). However, there were significative differences in the 4th to 5th degree damages (31.0%) in the control and the soil cover (15.0%). Additionally, LAI and dry grain yield were higher. There was a linear but inverse relationship regarding LAI and yield in plants with 4th to 5th degree damage.

Limitations/Implications: The availability of neem tree biomass could be a limitation, if this technology is applied to larger land areas.

Findings/Conclusions: Corn-neem soil cover plus a foliar application decreased the *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) impact and increased LAI and agricultural yield.

Keywords: pests, bioinsecticide, yield.

INTRODUCTION

Corn (*Zea mays* L.) is native to Central America, particularly Mexico. Corn has a wide-spread and diversified tradition as human food; however, its growth, development,
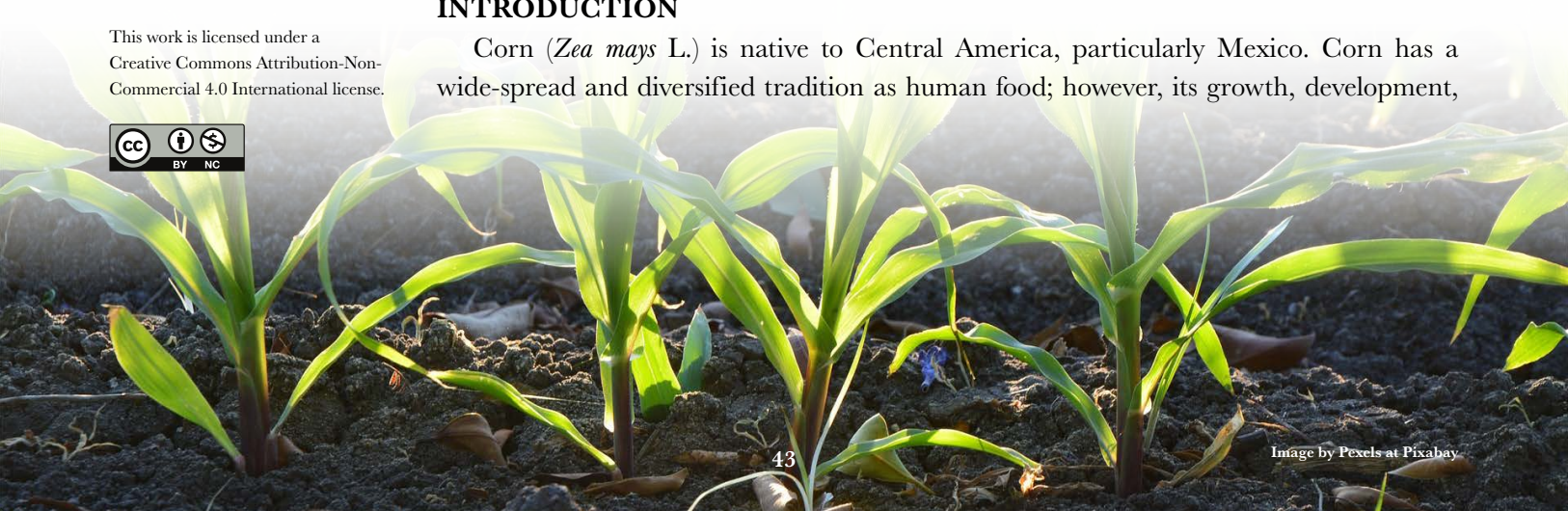
and final grain yield can be impacted by several causes, such as management practices, environmental factors, and pests (Ángel, 2015). *Spodoptera frugiperda* is one of these pests.

Armyworm (*Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae)) is an invasive pest that causes losses in several crops. It is endemic to the tropical regions of the western hemisphere (Njuguna *et al.*, 2021). Armyworm is one of the main corn pests. Although it causes more damages during the initial growth and development of the crop, it can attack crops at any point of the growing cycle (Reséndiz *et al.*, 2006).

In order to attack and mitigate the effects of this pest, different control methods have been applied with different levels of success throughout the years. They have included chemical, traditional, mechanical, and biological methods (Ángel *et al.*, 2015).

From a control point of view, the greatest success is achieved applying chemical methods. However, they have adverse side effects because they pollute water, soil, and air. Additionally, this situation has side effects on human health and reduces the populations of beneficial insects which can (to a certain degree) control the pests. These beneficial insects include ladybugs, lacewings, and some parasitoid wasps (Hernández *et al.*, 2018), mainly from the Ichneumonidae super-family (Rodríguez, 2018).

One of the disadvantages of the indiscriminate use of chemical products to control pest insects is the resistance that they develop to this type of products; *Spodoptera frugiperda* larvae survive despite the chemical applications (Rodríguez, 2018). In contrast, an alternative pest control method is the use of biological products. This practice lacks the problems caused by chemical products (Badii y Abreu, 2006) and does not impact the staff that handles and applies the product in the field (Rodríguez, 2018).

Therefore, the objective of this research was to evaluate the soil cover using corn-neem biomass for the *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) management in the INIAP H601 corn hybrid, at Pechiche, Los Ríos, Ecuador.

MATERIALS AND METHODS

The experiment was carried out at Los Ríos, Pechiche, Ecuador. The soil of the area is clay loam (Soil Survey Staff, 2003). The variety of corn grown for the experiment was INIAP H601. Two treatments were evaluated: 1) a treatment using corn-neem soil cover at 2.0 t ha^{-1} before sowing, plus two foliar applications, 8 and 15 days after sowing; 2) a control treatment without soil cover.

Six-hundred certified seeds of the INIAP H601 corn cultivar were selected. The seeds were imbibed in distilled water for 24 hours before sowing.

Under field conditions, 200 m^2 were selected. They were divided into two plots of 100 m^2 each. After soil preparation and before the sowing took place, a 2.0 t ha^{-1} mixture of 90.0% corn (*Zea mays* L.) waste and 10.0% of fresh neem (*Azadirachta indica* A. Juss.) leaves was spread over the soil previous solarization for 15 days. Both corn and neem leaves had been previously cut and homogeneously mixed. In that same plot, neem leaf extract was applied to corn leaves, 10 and 20 days after germination. The applications were carried out following the method described by Osuma (2005): 800g of neem leaves per 8 liters of water. The completely randomized design was developed under field conditions.

Neither corn waste, nor neem leaf extract were applied in the 100 m^2 control plot. Corn was sown in November, 2020.

In order to determine the seriousness of the *S. frugiperda* attack, the field sampling was carried out 30 days after the germination of the plants, since the crops receive the greatest impact within the first 40 days. The x-shape sampling method was used and five points were randomly selected, avoiding the border effect at all times. From each point, 10 linear plants were evaluated, obtaining a 50-plant population per sampling point. The damage caused to the whorl and the last visible ligule of the leaf of each plant was observed. The five-degree scale proposed by Fernández and Expósito (2000) was used. These authors consider the fourth and fifth degrees as the degrees of greatest damage.

Both areas were divided into five 20-m^2 plots, in order to make it easier to weight the replicates in the final grain yield evaluation. Harvest was carried out 120 days after the sowing and dry grain yield was determined in t ha^{-1}. The spray watering method was used to meet the water requirements of the crops during the main stages of the vegetative cycle of the plants.

The following variables were evaluated:

1) Percentage of corn plants with 1st to 3rd degree damage caused by *Spodoptera frugiperda*. Evaluated according to the methodology proposed by Fernández and Expósito (2000), 30 days after sowing.
2) Percentage of corn plants with 4th to 5th degree damage caused by *S. frugiperda*. Evaluated according to the methodology proposed by Fernández and Expósito (2000), 30 days after sowing.
3) Leaf Area Index. The LAI was determined in the ripening stage, following the recommendations of Montgomery (1911), using 0.75 as correction coefficient for corn crops.
4) Corn agricultural yield. One-hundred fifty days after sowing, dried corn was de-kernelled and weighted.

The 1st to 3rd and the 4th to 5th degree damage percentage variables of the two treatments were analyzed using a test for comparing two proportions. Meanwhile, the LAI and the dry corn grain agricultural yield variables were analyzed using the Student's t-test (5.0% probability). Taking into account this data, the variables were adjusted to a normal distribution with a modified Shapiro-Wilk test (Rahman and Govindarajulu, 1997).

Two simple linear regression analysis were carried out. The first regressor variable was the amount of plants with 1st to 3rd degree damage, while the second variable included the amount of plants with 4th to 5th degree damage. Both LAI and dry corn grain yield were the dependent variables of the analysis. The aim of this analysis was to determine the existence of a linear relationship between both regressor variables, regarding each dependent variable by itself. The following statistic values of the simple linear regression variables were determined: adjusted coefficient of determination (R^{2}Aj.), estimated value (Est.), standard error of the estimation (EE), significance (p), and Mallow's Cp.

The data was processed using the Infostat 2019 statistical package software (Di Rienzo *et al.*, 2019).

RESULTS AND DISCUSSION

There were no significative differences between the treatments regarding the INIAP H601 corn cultivar with 1st to 3rd degree damage caused by *S. frugiperda* (Figure 1a). The treatments were: 1) corn-neem soil cover plus two neem extract foliar applications and 2) control without soil cover. The percentage of damaged plants was 69.0% for both treatments.

Meanwhile, there were significative differences (Figure 2b) between both treatments regarding the percentage of plants with 4th to 5th degree damage. In the treatment with soil cover plus two foliar applications only 15.0% of the plants were damaged, while the percentage of damaged plants was double in the control treatment, reaching 31.0%.

Neem leaf extracts do not only control pests; they also disturb their feeding habits, inhibit their growth, and impact their mating and oviposition, without phytotoxic effects and causing damage to the environment, inducing resistance in the pest, or generating any kind of waste on the plants or the harvest (Subbalakshmi *et al.*, 2012). However, Gutiérrez *et al.* (2010) did not record the expected results from the use of 20.8% neem oil, perhaps as a consequence of the phytotoxic effect of such concentration; nevertheless, the defoliation degree by *Spodoptera frugiperda* diminished.

Both treatments showed significative differences regarding the Leaf Area Index (Figure 2a). The highest LAI (5.2) was obtained with the corn-neem cover treatment plus two applications, significatively exceeding the value of the control treatment (3.8).

The LAI recorded a significative decrease in the control treatment which provides clear evidence of the defoliation caused by the attack of the pest. In the said treatment, the pest impacted 31.0% of the leaves, causing 4th and 5th degree damage (the most severe damages).
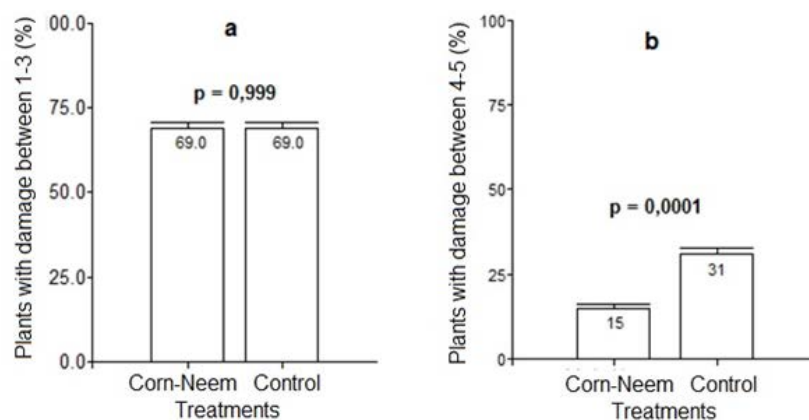

Figure 1. Percentage of plants of INIAP H601 corn cultivar with 1st to 3rd (Figure 1a) and 4th to 5th (Figure 1b) degree damage caused by *Spodoptera frugiperda*. Comparison of the corn-neem cover, plus two neem extract foliar application and control or treatment without soil cover. Different letters indicate significative differences (p≤0.05) in the proportion analysis.
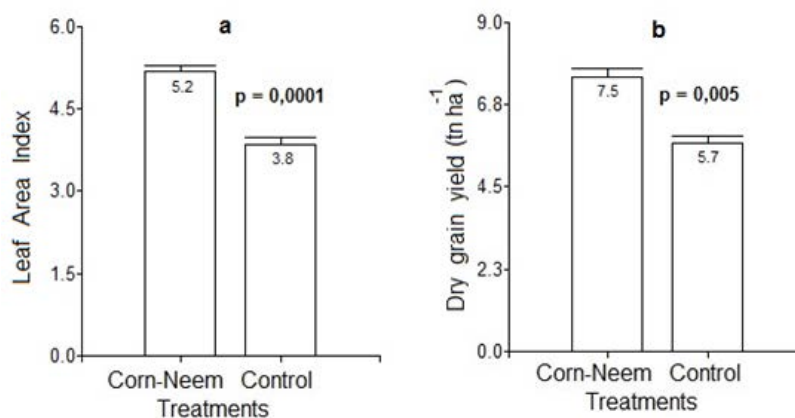
Figure 2. Leaf Area Index (Figure 1a) and dry grain yield (Figure 1b). Comparison of the effect of the corn-neem cover, plus two applications of neem leaves, with the treatment without cover (control treatment). Different letters mean significative differences ($p \leq 0.05$), using the Student's t-test.

The management of any agricultural plantation —particularly of corn, a plant with a C4 photosynthetic path— has the aim of improving solar energy use, through photosynthesis, a function that results in the production of dry matter (Castellanos *et al.*, 2017). This use is based on the development of an appropriate area of the leaves, whose surface can be determined through its Leaf Area Index (LAI).

The LAI provides an estimate of the relation between biomass production and the final crop yield. This relation can be impacted by management, climate, and pest factors (Intagri, 2017).

Rodríguez *et al.* (2007) consider that leaf area and the Leaf Area Index play a key role as regulators of the amount of solar radiation that reaches the plant's basal area. Regarding photosynthetic activity, it is the first responsible for solar radiation interception, consequently favoring a greater leaf area development. Therefore, as a consequence of its greater photosynthetic activity, plants cover a greater soil surface, favoring an increase in the plant's total biomass. This reduces the depopulation that hinders the development of weeds and plant coverage, which regulates soil temperature (thermoregulation).

The LAI obtained was higher when the soil was covered with corn-neem waste (plus two foliar applications) than with the control treatment. The former treatment could have resulted in a significative increase in dry grain yield (Figure 2b).

The simple linear regression (Table 1) in which the regressor variable was the number of plants with 1st to 3rd degree damage did not record significative differences ($p > 0.05$) for either the LAI or the yield. Therefore, there is no simple linear relation between the regressor (independent variable) and the leaf area index or the yield an aspect that is corroborated by the value of the determination coefficient (0). This research does not intend to determine which of these variables best fits the various types of non-linear regressions.

Opposite results were found when the amount of plants with 4th to 5th degree damage was used as regressor variable: the value of p (<0.05) was significative for both the LAI and the yield. This proves the existence of a linear, inverse relation, as a result of the negative sign of the estimate value. In other words, as the pest attack intensifies and reaches the

Table 1. Statistic values of the simple linear regression for the number of plants with 1st to 3rd degree damage and the number of plants with 4th to 5th degree as regressor variables and LAI (IAF) and dry grain yield (Rend) as dependent variables. Significance level: p<0.05.

	Number of plants between damages 1-3					Number of plants between damages 4-5				
	R^2Adj	Est	SE	p	Mallow	R^2Adj	Est	SE	p	Mallow
LAI	0,00	−0,62	1,66	0,72	1,14	0,80	−7,87	2,26	0,01	13,1
Yield	0,00	0,37	1,24	0,77	1,09	0,94	−6,63	0,89	0,01	56,55

4th and 5th degrees in the damage scale caused to corn plants, the linear form of the Leaf Area Index and the crop yield diminish. The relation between yield and the LAI is more linear and inverse as a result of a greater adjusted coefficient of determination (from 0.80 to 0.94), a lower standard estimation error (from 2.26 to 0.89), and a greater Mallow's Cp coefficient (from 13.1 to 56.55). Therefore, yield fits better a linear regression model than the Leaf Area Index, when the regressor variable is the amount of plants with 4th and 5th degree damage.

To a great extent, this inverse linear relation is linked with the following phenomena: the pest worm mainly feeds on the plant's growth area (apical meristem), damaging the tissues in charge of growth and development —*i.e.*, the growth of the corncob (Cruz, 2009) and the development of new leaves.

CONCLUSIONS

The soil cover treatment with a 9:1 ratio of corn waste and neem plus two applications of neem extracts, 10 and 20 days after germination, resulted in a 15.0% decrease of the percentage of plants that suffer 4th and 5th degree damages as a consequence of the attacks of *Spodoptera frugiperda*. Likewise, it increases the Leaf Area Index (>5 values); meanwhile, the agricultural yield (grains) exceeds 7 t ha^{-1}, perhaps as a result of the control it has over the pest and the beneficial effects of harvest waste cover on the soil, which could be a potentially sustainable alternative for maize production. However, if pests cause 4th and 5th degree damages, there is a significative linear and inverse reduction in LAI and agricultural yield.

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