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Physical Barriers in the Control of *Sagalassa valida* in Interspecific Oil Palm Hybrids

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Abstract | *Sagalassa valida* is a pest that restricts the oil palm root system growth, causing damage that reaches as much as 80% of it, consequently reducing the oil palm yield between 50% and 83%, depending on how the plant is managed. The present study aimed to evaluate the influence of physical barriers (mulching) using different parts of oil palm plants on controlling root borer (*S. valida*) in the interspecific oil palm hybrid OxG. The study was conducted at the Palesema plantation, situated in Mataje Parish, San Lorenzo Canton, Esmeraldas Province, Ecuador, located at 1°17'18" N and 78°50'13" E and 100 m above sea level. 10-year plants from the OxG Coari x La Mé hybrid were used in the study. Parts of oil palm were used as mulching (physical barriers) under the crown of the plant as follows: 200 kg of fruitless bunches, 160 kg of palm fiber, 20 kg of around weeds, 40 kg of pruned palm leaves, also, there was a treatment with insecticide, applying 150 ml of thiamethoxam+lambda-cyhalothrin (in 200 L in water), and one control treatment, without mulching or insecticide (clean area). A completely randomized block design was used. Our results showed that the number of *S. valida* larvae, the percentage of fresh damaged roots, and leaf emission were assessed. There were fewer *S. valida* larvae and damaged roots in the treatments with fruitless bunches and fiber at 180 days and with leaves at 90 days after beginning the treatments, while in absolute control, the larval population rose over time. The application of physical barriers reduced the incidence of root borer attacks by 40% compared to areas where these measures were not implemented. The pruned leaves placed on the plate proved to be a suitable alternative for pest control and showed one of the lowest application costs, that make it the best alternative for the integrated management of *Sagalassa valida*.

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Introduction

The oil palm, *Elaeis guineensis*, is the most productive oilseed, surpassing crops such as soybean, canola, corn, and others (Corley and Tinker, 2016). Due to its high efficiency, it is estimated that oil palm produces 30% of the world's oil production in approximately 6% of the area used to produce vegetable oils; in comparison, soybean produces 22% of the world's oil in an area corresponding to 40% of the total land used to grow oilseeds (Meijaard *et al*., 2018).

Ecuador is the third-largest palm oil producer in Latin America, after Colombia and Guatemala (Folleco *et al*., 2020). Oil palm plantations have been renewed by 40% with OxG hybrid cultivars (Avila *et al*., 2016). The 2017 National Palm Census recorded 46,077 ha cultivated with OxG hybrid in Ecuador, representing 18% of the national area cultivated with oil palm. In the province of Esmeraldas, there were 24,452 hectares with this hybrid (Flores *et al*., 2018).

Root borer (*Sagalassa valida* Lepidoptera: Brachodidae) is currently becoming the most important pest of oil palm in the Pacific plain of Colombia and Ecuador and is present with high incidence in the San Lorenzo (Esmeraldas Province) and eastern (Orellana and Sucumbíos Provinces) blocks (Poveda and Figari, 2008). The larvae bore into the roots of the oil palm, and their damage can reach up to 80% of the entire root system (Aldana *et al*., 2010) and up to 70% of yield losses (Egonuy *et al*., 2022). Adults are located in shaded areas, predominantly in areas bordering jungle or forest, adult palms, and water sources. Larvae mainly affect crops less than four years old and are found in roots up to 1.5 m from the base of the stem (Chávez *et al*., 2000; Sáenz and Olivares, 2008).

In the OxG hybrid, even at the age of 10 years, the damage can be very important. Consequently, young palms show problems with anchorage, in addition to slow physiological development and generalized chlorosis. In adult palms, there is a continuous emission of male inflorescences and low yield (Calvache *et al*., 2000; Sáenz and Olivares, 2008), and in the OxG cultivar Coari X La Me, it generates androgyny, which severely reduces the yield of the crop since this type of reproductive male structure does not produce pollen neither oil but does consume nutrients as if it were a normal bunch (Forero *et al*., 2012).

The management of this pest should always be related to the critical index of root damage, which is 5%; higher values indicate the need to control it. Traditionally, this has been carried out in two ways: The first corresponds to the application of insecticides, which normally have high levels of toxicity and residuality (Bernal *et al*., 2015), and the second corresponds to cultural practices that allow the establishment of nectariferous plants, as well as the use of physical barriers, with which its damage can be kept low (Casanova, 2003; Corredor *et al*., 2016). These barriers also guarantee a supply of nutrients and organic matter to the soil that facilitate the recovery of the palm's root system (Sáenz *et al*., 2006) since the leaflets contain 2.33% nitrogen and 0.13% phosphorus, and the fruitless bunches contain 0.87% N and 0.05% P (Maddison *et al*., 2016), which, when reincorporated into the soil, can favor a greater emission of new roots. On the other hand, it increases biodiversity in the rhizosphere, as the presence of arthropods of the Formicidae family has been found in plants with fiber mulch and insects of the order Dermaptera, Carabidae, Staphylinidae, Coleoptera, and Hymenoptera, with the predatory genera *Ectatomma* and *Pachycondyla* in areas with bunches (Coral *et al*., 2004; Löhr and Narváez, 2021).

In this way, the Integrated Management of Pests (IMP) contributes to the sustainability of the environment with minimal impact (Kabir and Rainis, 2015). However, all the benefits of these practices for the management of *Sagalassa* are known. Still, there is little updated information on their effective control on a commercial scale, mainly in the percentage of fresh damage in the root, since only yield has been monitored but not the effect on the pest (Corredor *et al*., 2016). The present study aimed to evaluate the influence of physical barriers (mulching) using different parts of oil palm plants on controlling root borer in the interspecific oil palm hybrid OxG and contribute to the integrated management of this pest and improve the root system growth and reduce the hydric stress (Sharma, 2013).

Materials and Methods

The study was carried out between June and December 2022 in the plantation of the company Palesema S.A., located in the Province of Esmeraldas, canton San Lorenzo, parish Mataje, at coordinates 1°17'18" N. 78°50'13" W, at 100 m above sea level. The region's climatic conditions are 26.2 °C average temperature, 3412 mm of precipitation, 956.2 hours of light per year, and between 80 and 90% relative humidity (Weather Station of the company Palesema) with a clay-loam soil with regular topography. The plantation has a total area of 8000 ha, and the experiment was developed in lot I2-23 (Figure 1), corresponding to an area of 22 ha, in which 5 ha were used for the study. The genotype corresponds to 10-year-old Coari x La Mé.

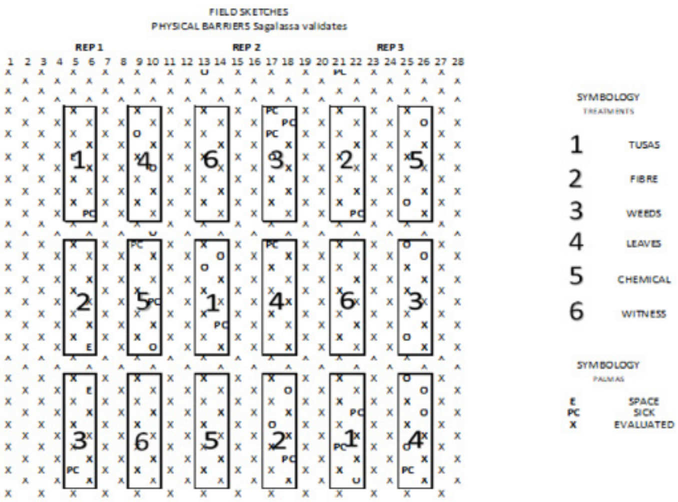

Figure 1: *Map of the experiments.*

A completely randomized block design (CRBD) was used, with six treatments and three replications, for a total of 18 experimental units. Each unit consisted of ten plants, of which five were evaluated randomly. The treatments used were: T1. Palm fruitless bunches (200 kg palm^{-1}); T2. Palm fiber (160 kg palm^{-1}); T3. Weeds (20 kg palm^{-1}); T4. Palm leaves (40 kg palm^{-1}); T5. Chemical control (thiamethoxam + lambda-cyhalothrin, 150 ml in 200 L water); T6. Control (clean area). The treatments were placed in vegetative cover on the plant base so that the weeds and fiber were placed in a fresh state, taken directly from the oil extraction plant, and arranged under the crown of the plant; the weeds were obtained from the surroundings with the backpack brushcutter and from the epiphytic plants that develop in the stipe, and subsequently placed around the plant with the help of a rake; the leaves were pruned from the plant and cut into four pieces, from which the fragment containing thorns was placed to one side, and the remaining fragments of the leaf were placed surrounding the plant. These coverings were distributed in the entire area under the crown, avoiding crowding from the base of the stipe outward. The chemical control was used on two occasions: during the establishment of the study and 90 days later. A knapsack sprayer was used for its application, and 1.3 L of solution were sprayed, covering the entire area under the crown up 2 m from the base of the stipe covering the entire clean area around the palm. The specialized Infostat software was used for data analysis, and the Tukey test at 5% probability was used to compare the means.

The Palesema S.A. plantation has an agronomic management program in which pruning is performed every eight months, maintaining between 35 and 40 functional leaves on the plant and eliminating excess leaves, which will be distributed in the areas around the plant. Weeds are removed with the help of a machete, cleaning the harvesting paths in 90 days, and glyphosate herbicide is applied under the crowns. Fertilization is carried out using a nutritional management plan that calculates the specific requirements of the plant based on the results of the foliar analysis so that the amount of fertilizer is divided into three soil applications per year. Phytosanitary control was taken through a census of pests or diseases in each lot so that immediate control measures are taken when a problem is detected.

The following variables were recorded in each plant: number of *S. valida* larvae and percentage of roots with fresh damage caused by *S. valida*, for which an inspection was made at the base of the stipe (stem) of the palm, cleaning the site before. Immediately, using a spade, two longitudinal cuts were made 1 m from the base of the stipe (Figure 2a), with dimensions of 30 cm wide x 25 cm deep and 1 meter long, according to Aldana *et al.* (2000); Chávez *et al.* (2000). In addition, leaf emission was recorded by marking leaf N° 1 with indelible paint at the beginning of the study and counting the number of leaves emitted by the plant each month. To determine the type of root, the coloration and aspect of the roots were verified, being the functional ones dark brown (Figure 2b), the new ones white (Figure 2c), and the roots with fresh damage (Figure 2d) generally normal in appearance on the outside but brittle when touched, and when they are opened, the presence of dejections (sawdust type) is observed. They are light pink in color and moist in appearance. They are light pink and moist inside, with the presence of larvae (Figure 3). If this damage is dry and dark, it is verified that they are roots with old damage.

The percentage of fresh damage was determined using the formula adapted from Chávez *et al.* (2000):

$$\text{Fresh damage \%} = \frac{\text{\# fresh damaged roots}}{\text{\#total de roots *}} x100$$

*The total number of roots refers to the sum of functional, new, and roots with fresh damage.

Figure 2: *Root survey for the evaluation of S. valida (a) preparation of the survey; (b) functional roots; (c) new roots (white color); (d) fresh damage (reddish dejections) of S. valida; (e) new roots (white color); and (f) new roots (reddish dejections).*

Figure 3: *Larva of S. valida and its damage to a primary root of the oil palm.*

Results and Discussion

Number of larvae of S. valida

There were significant statistical differences in the effect of treatments on the number of *S. valida* larvae per root for the four evaluations (0, 90, 180, and 270 days). According to the Tukey test, the treatments with fruitless bunches and fiber stood out significantly at 90, 180, and 270 days after the treatments were applied, presenting values of zero larvae compared to the initial values of the population, which were presented in averages of 3.3 and 1.3 larvae in the roots.

Similarly, the treatment with leaves achieved the lowest values at 90 and 270 days. In contrast with the weed treatment, which did not cause any reduction in the population of this pest, it maintained close values on average in the three evaluations. There was also no response to the chemical treatment, with a significant increase in populations between 90 and 180 days. The control showed a sustained increase in the larval population (Figure 4).

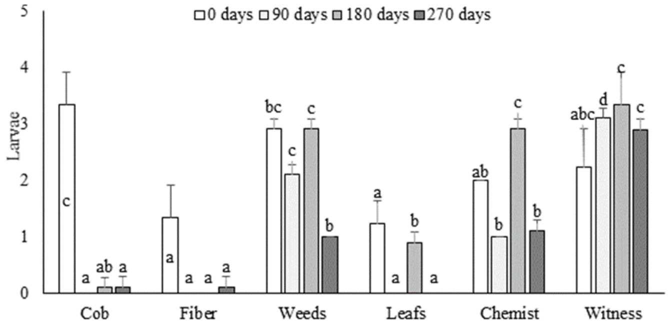

Figure 4: *Number of S. valida larvae per plant according to the treatments under study in the four evaluations carried out in an oil palm plantation in esmeraldas, ecuador.*

The cover offered by plant debris prevents *S. valida* adults from reaching the area under the plant's crown and depositing eggs there for future larvae hatching (Aldana *et al*., 2015), and their ability of decompose over time determines their protection against pests. In this regard, studies on oil palm *Elaeis guineensis* material conducted by Casanova (2003) showed that rice husks showed less damage during 270 days, while the covering with weeds did not reduce damage, showing results similar to the control treatment at 180 days. In the case of the present study, the number of larvae found decreased to 0 in the treatments with fruitless bunches, fiber, and leaves at 90 days, while the slow decomposition of fiber and fruitless bunches allowed the values to remain low until 270 days. In contrast, the covering with weeds did not guarantee a pest reduction; the opposite occurred, and populations were sustained throughout the 90 and 180 days of evaluation.

In addition, the vegetation cover generates a microhabitat in which the biodiversity of macro- and meso-fauna increases (Ashton-Butt *et al*., 2018), represented by the presence of predators organisms, that causes the biological control of *S. valida* larvae, like ants from the genus *Pachycondyla* spp. that were favored by these conditions with a high quantity of organic matter. Additionally, it has been determined that *Ectatomma ruidum* is a predator of the pest and represents 94.6% of the ant population collected in 7-year-old OxG hybrid crops (Löhr and Narvaez, 2021). For this reason, the establishment of vegetative covers increases the beneficial fauna under the palm crown and is capable of biological control that favors the decrease in the number of *S. valida* larvae found in the study.

Fresh damage caused by S. valida in roots of oil palm

There was a significant effect of the treatments under study on the fresh damage caused by *S. valida* in the roots at 90, 180, and 270 days after the application of the treatments. According to Tukey's significance test, the most important treatments were fiber, fruitless bunches, and leaf of oil palm, which showed the greatest reduction in fresh damage caused by *S. valida* in the roots at 90, 180, and 270 days. Chemical control was inefficient in reducing this pest's damage, showing a slight increase between the initial evaluation and 180 days. These results are corroborated by the control treatment (without mulch), where the damage caused by *S. valida* increased significantly 90 days after the start of the test, differing statistically from the other treatments (Figure 5).

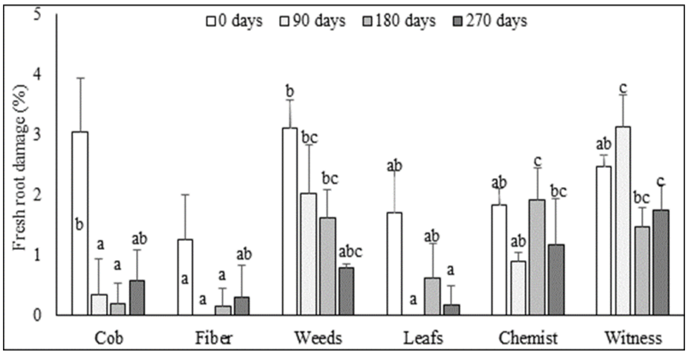

Figure 5: *Percentage of fresh damage caused by S. valida in the roots of oil plants according to the treatments under study in the four evaluations carried out in an oil palm plantation in Esmeraldas, Ecuador.*

The decomposition capacity of the mulches over time is fundamental to avoiding the oviposition of *S. valida* females in the soil near the roots, from where the larvae hatch and cause damage to the root system of the plant (Sáenz and Olivares, 2008). For this reason, the treatments with fruitless bunches, fiber, and leaves reached the lowest percentages throughout all evaluations, while the weed was not able to achieve the same results. In the evaluations carried out in this study, it was possible to observe the decomposition of the different mulches, where it was found that after nine months, the treatments with fruitless bunches, fiber, and leaves placed under the crown of the plants remained, generating a physical barrier, while the weeds disappeared completely from the site where they were initially placed (Figure 6). Chee and Chiu found that fruitless bunches descomposes between 8 and 10 months due to its C/N relation (Chee and Chiu, 2000).

The positive results obtained in this research are consistent with those reported by Muñoz (2016), who determined that, from 90 days after the application of mulches with fruitless bunches and fiber of oil palm, fresh damage caused by *S. valida* decreased, and this protection was maintained until 360 days. Regarding chemical control, the results of Bernal *et al*. (2015) are also consistent with the present study since at 180 days, the percentage of fresh damage in the roots increased in the chemical treatment (Thiamethoxam + Lambda-cyhalothrin), being similar to the control treatment.

Figure 6: *Evolution of the decomposition of the mulches used in the treatments in the study carried out in an oil palm plantation in Esmeraldas, Ecuador. (a) fresh fruitless bunches; (b) fruitless bunches after 90 days; (c) fresh fiber; (d) fiber after 90 days; (e) fresh weeds; (f) weeds after 90 days; (g) fresh leaves; (h) leaves after 90 days.*

Finally, it is important to highlight that, the percentage of damage did not exceed the critical index of 5% of roots affected by *S. valida*, established as an economic threshold (Chávez *et al*., 2000; Bernal *et al*., 2015); however, the behavior of the treatments during the three evaluations allowed observing that the data obtained by the fruitless bunches, fiber, and leaf covers formed a group that presented the lowest values, while the weed, chemical, and absolute control treatments always showed higher values (Figure 7). This information is comparable to that of Bernal *et al.* (2015), who found that the absolute control differed from the cluster formed by the insecticide treatments for the control of *S. valida* in hybrid OxG.

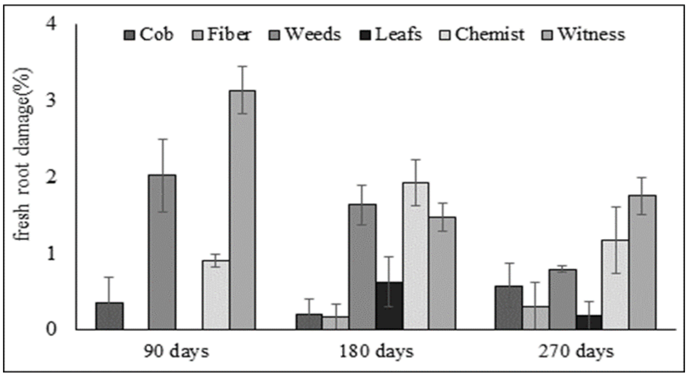

Figure 7: *Percentage of fresh damage caused by S. valida in the roots of oil palm plant according to the treatments under study in the three evaluations carried out in an oil palm plantation in Esmeraldas, Ecuador.*

Leaf emission

The treatments did not influence the leaf emission at 90 and 180 days after the beginning of the experiment.

The evaluations executed at 90 and 180 days after the establishment of the study show that there are no significant statistical differences in leaf emission in any of the periods, presenting similar values among the different treatments compared to the control (Figure 6). Intriago (2016) found no differences in leaf emission when using chemical control of *S. valida*, agreeing with our data. The decrease in leaf emission found in this study may be due to the climatic conditions observed in the fourth quarter of the year since it was found that leaf emission was higher in the first 90 days of evaluation during the June-September period compared to the data at 180 days in the October-December period (Figure 7).The lower leaf emission is related a water deficit, where the plant's physiological response with delayed opening of the leaves. This deficit is reach out below 100 mm month^{-1} (Paramananthan *et al*., 2012) The results found in the 180 days evaluation was related to rainfall in the evaluation area (Figure 8) shows that between October and December, the average rainfall was less of 100 mm.

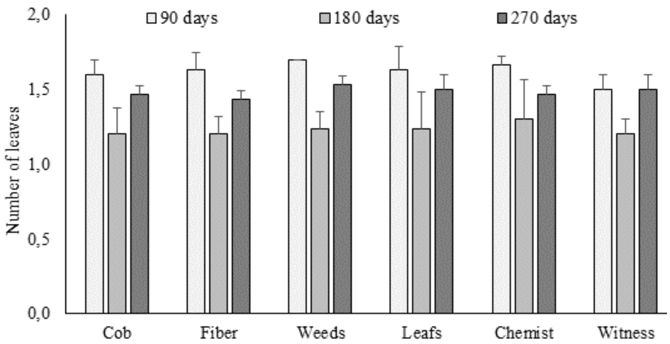

Figure 8: *Leaf emission of oil palm plants according to the treatments under study in the three evaluations carried out in an oil palm plantation in Esmeraldas, Ecuador.*

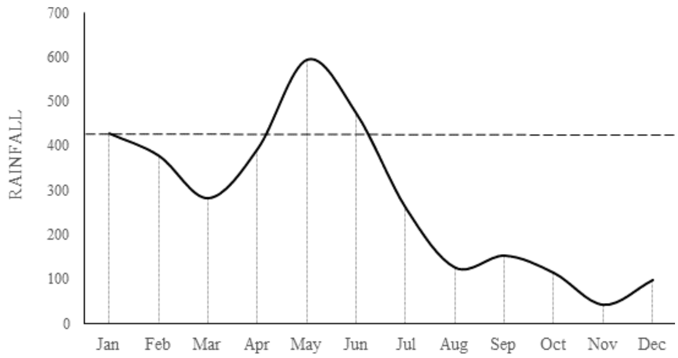

Figure 9: *Rainfall during the experiment in an oil palm plantation in Esmeraldas, Ecuador. The dashed line indicates the water deficit for the crop.*

Conclusions and Recommendations

- The application of physical barriers is a path to more sustainable and eco-friendly pest management in the oil palm world. The results indicates that physical barriers, when implemented correctly, can be an effective tool in reducing the damage caused by the root borer, which in turn contributes to the health and productivity of the palms, its application reduced the incidence of root borer attacks by 40% compared to areas where these measures were not implemented. This result not only highlights the effectiveness of physical barriers as a method of control, but also underscores the importance of integrating sustainable management practices into commercial agriculture.
- The application of physical barriers (tusa and fiber) provided the greatest protection to the palm roots, as the lowest number of larvae of *Sagalassa valida* was found in the roots, but the cost of labor was the highest, which is fundamental at the time of evaluation for the implementation of any agricultural practice on a commercial scale.

- The pruned leaves placed on the plate proved to be a suitable alternative for pest control, which showed one of the lowest application costs among the different covers, and for this reason make it the best alternative for the integrated management of *Sagalassa valida*, which additionally favors the reincorporation of nutrients and organic matter into the soil, and the formation of suitable niches for the proliferation of beneficial fauna. To ensure proper performance, the location of the leaves must be renewed every 90 days.

Novelty Statement

The study suggests that the excessive use of agrochemicals for the control of Sagalassa valida in several cases has made the pest resistant to these products and this only repels it, while the use of physical barriers in addition to breaking the cycle of the pest and controlling it stimulates the formation of roots and improves the microfauna of the soil in addition to its structure.

Author's Contribution

Cristian Mendoza: Conceptualization.
Adriana Celi-Soto: Funding acquisition, investigation, supervisión, writing review and editing
Ernesto Cañarte: Data curation, Supervision, writing review and editing.
George Cedeño-García: Data curation, formal análisis, supervisión, writing review and editing.

Conflict of interest
The authors have declared no conflict of interest.

References

Aldana, R.C., J.A. Aldana, H. Calvache and P.N. Franco. 2010. Manual of oil palm pests in Colombia. Fourth edition. Sena Cenipalma Agreement. pp. 198. https://es.slideshare.net/YulyFlorez/aldana-2010oilpalmpestmanual-de-plagas

Aldana, R., J. Aldana, H. Calvache and P. Franco. 2009. Manual of oil palm pests in Colombia. Bogotá: Cenipalma.

Aldana, R., H. Calvache and J. Zambrano. 2000. Determination of the damage of *Sagalassa valida* (Lepidoptera: Glyphipterigidae) in the oil palm root system. Rev. Palmas, 21(1): 175-179. https://publicaciones.fedepalma.org/index.php/palmas/article/view/780.

Aldana, R., C. Sendoya and A. Bustillo. 2015. Control of the root borer *Sagalassa valida* in oil palm. Poster XVIII International Conference on Oil Palm. Cenipalma. Colombia. https://www.researchgate.net/publication/319645537_Control_del_barrenador_de_las_raices_Sagalassa_valida_en_palma_de_aceite_Control_of_oil_palm_root_borer_Sagalassa_valida

Ashton-Butt, A., A.A. Aryawan, A.S. Hood, M. Naim, D. Purnomo, Suhardi and J.L. Snaddon. 2018. Understory vegetation in oil palm plantations benefits soil biodiversity and decomposition rates. Front. For. Glob. Change, 1, 10.

Avila, R., E. Daza, E. Navia and H. Romero. 2016. Response of various oil palm materials (*Elaeis guineensis* and *Elaeis oleifera* × *Elaeis guineensis* interspecific hybrids) to bud rot disease in the southwestern oil palm-growing area of Colombia. Agron. Colombiana, 34(1): 74-81.

Bernal, G., V. Bravo, C. Vega, P. Quirola, F. Chiriboga and R. Intriago. 2015. New chemical alternatives for the control of the Root Borer (*Sagalassa valida*) of oil palm. Tech. Bull. 12. ANCUPA. Quito-Ecuador. pp. 20.

Calvache, H., P. Franco and J. Aldana. 2000. Oil palm pests in Colombia. Cenipalma, pp. 51-55.

Casanova, J., 2003. Evaluation of physical barriers from organic wastes in the fight against the root borer (*Sagalassa valida* Walker) in African Palm. Thesis for the degree of agronomist engineer. Technical University of Manabí. https://www.bing.com/search?q=Casanova%2C+J.+(2003).

Chávez, C., L. Ortíz, J. Salamancas and E. Peña. 2000. Sampling of *Sagalassa valida* in oil palm plantations in the Tumaco area (Nariño), Colombia. Palmas Magazine, 21(1): 181-184.

Chee, K.H. and S.B. Chiu. 2000. Fruit waste reciclyng by mulching with empty fruit bunches. Rev. Palmas, 21(3): 65-71.

Coral, J., H. Calvache, J. Salamanca, R. Aldana and C. Chávez. 2004. Recognition of insect predators of the root borer *Sagalassa valida* Walker in oil palm. Rev. Palmas, 25(II): 232-239.

Corley, R.H.V. and P.B. Tinker. 2016. The oil palm (Fifth Edition). Wiley Blackwell. https://doi.org/10.1002/9781118953297

Corredor, J., M. Mosquera, C. Fontanilla and E. Álvarez. 2016. *Sagalassa valida* Walker and the clean plate paradigm scientific article. https://agris.fao.org/agris-search/search.do?recordID=CO2021F01372.

Egonyu, J.P., J. Baguma, L.C. Martínez, H. Priwiratama, S. Subramanian, C.M. Tanga, J.P. Anankware, N., Roos and S. Niassy. 2022. Global advances on insect pest management research in oil palm. Sustainability, 14: 16288. https://doi.org/10.3390/su142316288

Fedepalma, Bogotá and D. Firestone. 2006. Physical and chemical characteristics of oils, fats, and waxes. 2nd ed. Urbana, IL: AOC. https://web.fedepalma.org/international/wp-content/uploads/2020/06/The_Oil_Palm_Agribusiness_in_Colombia_2020.pdf

Flores, R., A. Álvarez, C. Loaiza, R. Vargas, W. Acosta, O. Mantilla and J. Malo. 2018. Memoria técnica inventario de plantaciones de palma aceitera en el Ecuador. Quito: Ministry of Agriculture and Livestock, ANCUPA, FEDAPAL and APROGRASEC.

Folleco, A.M.S., L.V.H. Parra and W.S.C. Aldana. 2020. Organización de las naciones unidas para la alimentación y la agricultura (FAO 1).

Forero, D., P. Hormaza, L. Moreno and R. Ruiz. 2012. Generalidades sobre la morfología y fenología de la palma de aceite. Centro de Investigación en Palma de Aceite (Cenipalma). Bogotá, Colombia. https://repositorio.fedepalma.org/handle/123456789/108001

Intriago, R., 2016. Chemical control of root borer *(Sagalassa valida* Walker), in Hybrid (*Elaeis oleifera* x *Elaeis guineensis* Jacq.). Thesis prior to obtaining the degree of agronomist engineer. University of Guayaquil. pp. 96. http://repositorio.ug.edu.ec/handle/redug/9218?mode=full

Kabir, M.H. and R. Rainis. 2015. Adoption and intensity of integrated pest management (IPM) vegetable farming in Bangladesh: an approach to sustainable agricultural development. Environ. Dev. Sustain., 17: 1413-1429. https://doi.org/10.1007/s10668-014-9613-y

Löhr, B. and A. Nárvaez. 2021. Land use and terrestrial arthropods at the Colombian Pacific coast. Rev. Colomb. Entomol., 47(1): et7640. https://doi.org/10.25100/socolen.v47i1.7640

Maddison, C.J., A. Mnih and Y.W. Teh. 2016. The concrete distribution: A continuous relaxation of discrete random variables. arXiv preprint arXiv:1611.00712.

Meijaard, E., J. Garcia-Ulloa, D. Sheil, S. Wich, K. Carlson, D. Juffe-Bignoli and T. Brooks. 2018. Oil palm and biodiversity. A situation analysis by the IUCN oil palm task force. IUCN oil palm task force Gland, Switzerland. pp. 134. https://www.semanticscholar.org/paper/Oil-palm-and-biodiversity%3A-a-situation-analysis-by-Meijaard-Garc%C3%ADa-Ulloa/6001879f90736343afe9034c18a787a2aa8aeb2d

Muñoz, D. 2016. Residuos de cosecha para controlar el barrenador de raíces (*Sagalassa valida* Walker) en palma aceitera, en el cantón la Concordia. Tesis de titulación previo a la obtención del título de ingeniero agropecuario. ESPE. 53 p.

National Federation of Oil Palm Growers-Fedepalma, 2015. Statistical yearbook 2015: The oil palm agroindustry in Colombia and the world 2010 - 2014.

Paramanathan, T., I. Vladescu, M.J. McCauley, I. Rouzina and M.C. Williams. 2012. Force spectroscopy reveals the DNA structural dynamics that govern the slow binding of Actinomycin D. Nucleic Acids Res., 40(11): 4925-4932.

Poveda, W. and A. Figari. 2008. Inventory of oil palm (*Elaeis guineensis* Jacq) pests in Ecuador. ANCUPA, MAGAP and SESA. Quito, Ecuador. pp. 95. https://repositorio.uasb.edu.ec/bitstream/10644/8922/1/T3891-MCCSD-Angel-Los%20impactos.pdf

PROPALMA, 2023. La palma in figures. https://propalmaec.com/.

Romero, H. and I. Ayala. 2021. How to reach 10 tons of oil per hectare: management technologies of OxG interspecific hybrids towards highly efficient production. https://publicaciones.fedepalma.org/index.php/palmas/article/view/13449.

Sáenz, A., M. Mosquera, L. Fajardo and H.D. Pulido. 2006. Comparación de costos para el manejo de Sagalassa valida Walker en la zona occidental de Colombia. Palmas, 27(4): 47-51.

Sáenz, A. and W. Olivares. 2008. Movement speed of the first instar of *Sagalassa valida* (Lepidoptera: Glyphipterigidae). Colombian Rev. Entomol., 34(1): 57-61.

Sharma, M., 2013. Sustainability in the cultivation of oil palm. Issues and prospects for the industry. J. Oil Palm Environ., 4: 47-68.