Agroind. sci. 15(3): 355-361 (2025)

Agroindustrial Science

Website: http://revistas.unitru.edu.pe/index.php/agroindscience

Escuela de Ingeniería Agroindustrial

Universidad Nacional de Trujillo

Optimizing the flight altitude of the Agras T40 drone for controlling *Spodoptera frugiperda* in maize (*Zea mays L.*) plantations

José Lizardo Reyna-Bowen[1, 2 *]; Leonela Murillo[1]; Heber Cedeño[1]; Lenin Vera Montenegro[1]; María Isabel Delgado-Moreira[3]; Sofía Velásquez Cedeño[1]

[1] Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix López, Campus Politécnico El Limón, Manabí, Ecuador.
[2] Faculty of Forestry, University of Agriculture in Krakow, 29 Listopada 46 Str, 31-425 Kraków, Poland.
[3] Department of Ecology and Silviculture, Faculty of Forestry, University of Agriculture in Krakow, 29 Listopada 46 Str, 31-425 Kraków, Poland.

ORCID de los autores:
J. L. Reyna-Bowen: https://orcid.org/0000-0003-0352-4005
L. Murillo: https://orcid.org/0009-0005-4858-8442
S. Velásquez Cedeño: https://orcid.org/0000-0001-5141-0489
L. Vera Montenegro: https://orcid.org/0000-0002-6885-2002
M. I. Delgado-Moreira: https://orcid.org/0000-0002-3368-7481

ABSTRACT

This study aimed to determine the optimal flight height for controlling *Spodoptera frugiperda* in maize (*Zea mays L.*) plantations using the Agras T40 drone. The research was conducted in Manabí, Ecuador, the experiment compared two UAV-based treatments (5 m and 7 m flight altitudes) with a conventional backpack sprayer control. The Agras T40, equipped with rotary atomizers, applied specific pesticide mixtures on August 30 and June 9, 2024. Plant damage assessments, using GNSS and photogrammetry, were conducted pre and post application. Statistical analyses, including paired t-tests and ANOVA with Tukey HSD post-hoc tests, were performed to evaluate treatment efficacy. Results demonstrated that the 7m UAV treatment significantly reduced fall armyworm infestation compared to the 5m treatment and the conventional control. The 5m treatment showed an increase in infestation, likely due to increased canopy disturbance affecting droplet adherence. The 7 m UAV treatment achieved control comparable to the conventional method, but offered advantages in precision, sustainability and operator safety. This study highlights the potential of UAVs, specifically the Agras T40, for efficient and targeted fall armyworm management in maize, reducing chemical inputs and minimizing environmental impact.

Keywords: pesticides aerial spraying; precision agriculture; spray height; Unmanned Aerial Vehicle.

1. Introduction

The fall armyworm, *Spodoptera frugiperda*, a globally significant polyphagous pest, poses a substantial threat to agricultural productivity, documented to attack over 350 plant species across 76 families (Overton et al., 2021). Its voracious feeding habits and rapid dispersal capabilities result in significant economic losses, particularly in crucial staple crops like maize (*Zea mays L.*), which plays an essential role in global food security, with an annual production of approximately 1147.7 million tonnes (Abbas et al., 2020; Kenis et al., 2023; Kumar et al., 2022; Paredes-Sánchez et al., 2021). The pest's remarkable adaptability, characterized by the emer-gence of distinct biotypes with varying host preferences and increasing resistance to conventional insecticides (Tay et al., 2023), further complicates control efforts. Consequently, the persistent and often excessive reliance on chemical insecticides has raised significant environmental concerns, including soil and water contamination and has contributed to the development of pest resistance, underscoring the urgent need for more targeted and sustainable management strategies (Kenis et al., 2023; Overton et al., 2021; Paredes-Sánchez et al., 2021).

Maize, a cornerstone of agricultural economies, particularly in regions like Latin America and specifically Ecuador, necessitates the maintenance of high yields to support both local and regional economic stability (Albán et al., 2024). However,

Recibido 30 abril 2025
Aceptado 27 septiembre 2025

* Autor correspondiente: jlreyna@espam.edu.ec (J. L. Reyna-Bowen)
DOI: http://doi.org/10.17268/agroind.sci.2025.03.17

the widespread cultivation of maize, especially in irrigated ecosystems and alongside other preferred host crops for *S. frugiperda*, has created conducive environments for pest proliferation, exacerbating the challenges of effective pest management (Paredes-Sánchez et al., 2021; Vivekanandhan et al., 2023). The increasing global demand for maize, coupled with the escalating incidence of fall armyworm infestations, highlights the critical need for innovative and sustainable management strategies to safeguard food security (Tay et al., 2023; Van Den Berg & Du Plessis, 2022).

The application of Unmanned Aerial Vehicles (UAVs) for enhanced precision agriculture, offers a promising opportunity for targeted pest control, optimizing resource utilization and enhancing crop productivity through precise monitoring and application techniques (Ranabhat & Price, 2025; Velusamy et al., 2021). Drone-based pesticide applications have demonstrated significant efficacy in mitigating fall armyworm infestations, achieving high control rates and substantial reductions in pest populations (Bohner et al., 2025; Song et al., 2020). Research further indicates that drone technology enhances overall crop management by reducing monitoring time by up to 50% and improving problem detection accuracy by 30% across various crops, including maize (Ji et al., 2023; Laghari et al., 2023). The Agras T40 drone, utilizing rotary atomizers in place of traditional hydraulic nozzles, represents a novel approach to aerial pesticide application, warranting further investigation into the optimization of flight parameters for enhanced efficacy (Byers et al., 2024).

Flight altitude is a critical parameter in drone-based spraying, as it directly influences droplet drift and deposition. While altitude does not alter initial droplet size, higher altitudes expose droplets to environmental factors such as wind and humidity, increasing drift potential and reducing target deposition (Ozkan, 2023). Therefore, maintaining an ideal flight altitude is crucial for balancing effective targeting and operational safety. This study aims to determine the optimal flight height for controlling *S. frugiperda* in maize (*Zea mays L.*) plantations using the Agras T40 drone. By establishing precise fumigation protocols, this research seeks to minimize chemical residues, reduce input costs, and enhance public health, contributing to the advancement of sustainable and efficient agricultural practices.

2. Methodology

The experiment was conducted from August to October 2024 at Ciudad de la Investigación e Innovación y Desarrollo Agroproductivo (CIIDEA) facilities, located within the Bolívar canton, Manabí province, Ecuador and affiliated with Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix López (ESPAM MFL). The study utilized the ADVANTA 9559 maize variety, planted at a density of 5 plants per linear meter with 0.85 m inter-row spacing, equivalent to 58,000 plants per hectare. The experimental field, measuring approximately 193 m × 141 m, was partitioned into three distinct treatments: Treatment 1 (7,057 m², 40,930 plants), Treatment 2 (7,057 m², 21,889 plants) and a conventional control (3,277 m², 19,006 plants) (Figure 1).

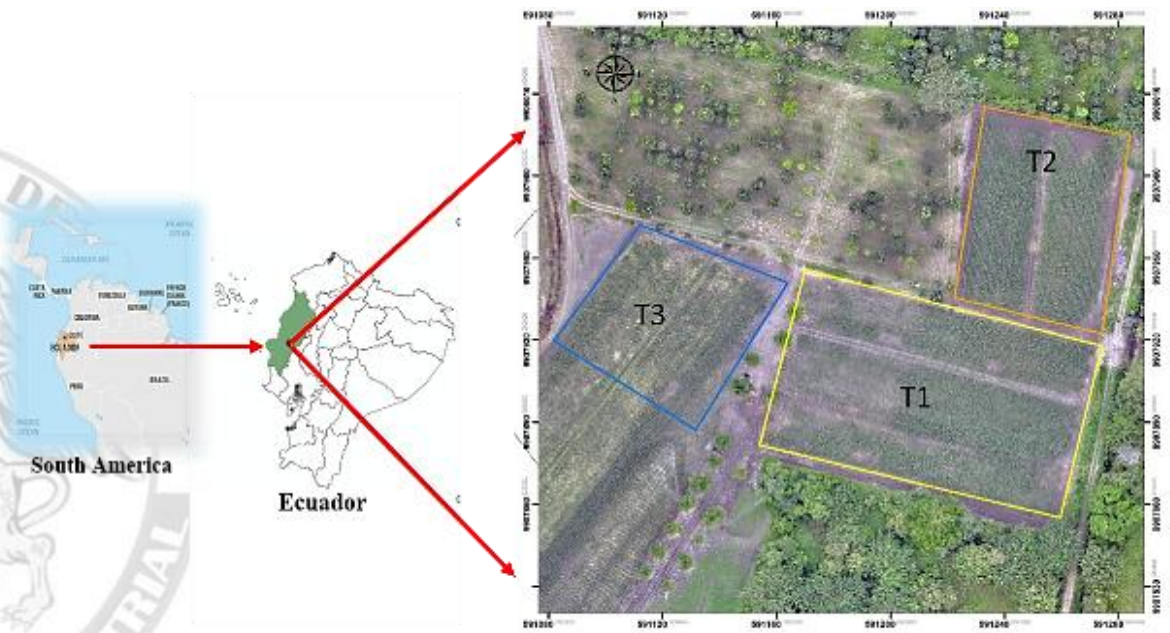

Figure 1. Study area at CIIDEA, of the ESPAM MFL. Study plots: treatment 1 (T1), treatment 2 (T2) and treatment 3 (T3).

This design ensured that each treatment was evaluated under controlled and comparable conditions, facilitating robust data analysis and interpretation.

The AGRAS T40 drone (Figure 2), employed for spraying, features a coaxial twin-rotor design, enabling a 40 kg liquid payload and a 50 kg (70 L) granular payload capacity. Integrated with a dual atomized spraying system, DJI Terra, active phased array radar, and binocular vision, the drone supports diverse agricultural applications, including surveying, mapping, spraying, and spreading. The spraying system is remotely adjustable, allowing operators to configure spray pressure and flow rate to optimize application parameters for specific operational requirements.

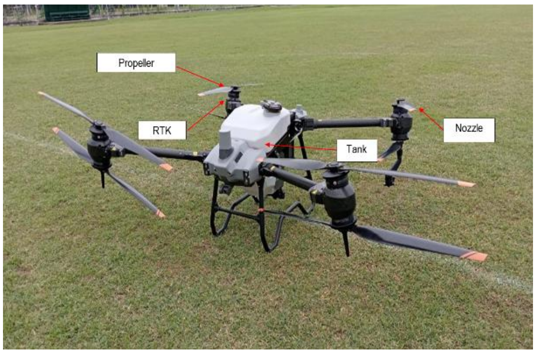

Figure 2. DJI Agras T40 Unmanned Aerial Spraying System (UASS) illustrating the rotary atomization spray mechanism.

Experimental design

An experimental design comprising three treatments was established to assess the efficacy of fall armyworm (*Spodoptera frugiperda*) control in maize using the Agras T40 drone. Treatment 1 involved aerial application of phytosanitary products at a height of 5 m above the crop canopy, while Treatment 2 utilized a height of 7 m. Treatment 3 served as a conventional control, employing backpack sprayer applications following traditional methods.

Figure 3 details the flight parameters for the Agras T40 drone treatments, including altitude, flight path, speed, droplet size, and spray volume. For the execution of designated treatments, the drone underwent thorough calibration and configuration within its flight programming. Treatment 1 was programmed with a flight altitude of 5 m, while Treatment 2 utilized a higher altitude of 7 m. Both treatments were designed to maintain a consistent flight speed of 3.5 m/s, ensuring uniform coverage. The spray system was set to deliver an average droplet size of 310 µm, employing a double-layer spray pattern to maximize target coverage. Furthermore, both treatments were configured to apply a spray volume of 40 liters per hectare, allowing for precise and consistent application rates across the experimental area. Uniform crop management was implemented across all three experimental plots to minimize variability. Soil preparation involved mechanical tillage using a John Deere 6403 tractor equipped with a brush cutter, disc harrow, and rotary tiller. Mechanized sowing was performed at a planting density of 5 plants per linear meter with 0.85 m inter-row spacing, concurrently with the application of basal fertilization at 300 kg/ha of 8-20-20 and 300 kg/ha of urea. Subsequent fertilization at 30 days post-planting included 200 kg/ha of 8-20-20, 200 kg/ha of Yaramila Complex and 200 kg/ha of urea. A final fertilization at 45 days post-planting consisted of 200 kg/ha of urea and 200 kg/ha of potassium chloride.

Weed control was achieved through an initial post-emergence application of a paraquat and 2,4-D amine mixture, followed by nicosulfuron application at 12 days post-planting. Targeted weed control with amine and paraquat was conducted at 50 days post-planting.

Figure 3. For flight programming, the drone was calibrated and configured to execute the designated treatments. Treatment 1 utilized a flight altitude of 5 m (a), while Treatment 2 employed 7 m (b). Both treatments maintained a constant flight speed of 3.5 m/s, an average droplet size of 310 µm, a double-layer spray pattern and a spray volume of 40 L/ha.

Fungicide applications included copper sulfate pentahydrate at 700 L/ha at 30 days post-planting and propiconazole at 700 L/ha at 45 days post-planting. Irrigation was provided via a reel sprinkler system (Rainstar T), ensuring uniform water distribution.
The treatment applications, detailing both aerial and conventional control measures for maize earworm, consisted of two distinct applications. On August 30, 2024, a mixture of Solaris (Spinetoram) at 150 cc, seaweed extract at 1 liter and Cytokinin at 500 cc per 200 liters of water was applied. Subsequently, on June 9, 2024, a combination of Voliam Flex (tiamatoxan + chlorantraniliprole) at 200 cc and Future (thiodicard) at 150 cc per 200 liters of water was utilized.

Data collection

Pre-application assessment of fall armyworm infestation was conducted using high-precision base and mobile GNSS (RTK) equipment to quantify the number of affected plants. A point-based survey was performed, geo-referencing each infested plant to determine the initial damage percentage. Additionally, photogrammetric analysis was employed to visualize the spatial distribution of infested areas. Four days' post-application, the survey and photogrammetric analysis were repeated to evaluate application efficacy.
For conventional control, a parallel assessment was carried out using GNSS to identify and geo-reference affected plants. This process was also repeated four days' post-application to determine the efficacy of the conventional control method.
The percentage of fall armyworm damage was calculated using the following equation 1:

$$\text{Affected percentage} = \left(\frac{\text{Number of affected plants}}{\text{Total number of plants}}\right) * 100 \quad (1)$$

Statistical analysis

The efficacy of fall armyworm (*Spodoptera frugiperda*) control across treatments was evaluated through a descriptive analysis of pre and post-treatment infestation percentages. To account for inherent variability in affected plant counts, a simulated dataset, assuming a normal distribution, was generated from the observed percentage data. Paired t-tests were subsequently employed to compare infestation percentages within each treatment, assessing the significance of reductions.

Inter-treatment differences in fall armyworm control were assessed using a one-way analysis of variance (ANOVA). Where significant ANOVA results were observed, a post-hoc Tukey test was conducted to determine specific treatment-pair differences. The ANOVA compared percentage infestation reductions among Treatment 1 (5 meters), Treatment 2 (7 meters), and the conventional control. All statistical analyses were performed using Python (version 3.10) within the Google Colab environment, utilizing the SciPy and Pandas libraries for statistical testing and data manipulation, respectively. Statistical significance was determined at a 95% confidence level ($p < 0.05$).

3. Results and discussion

Application efficiency of treatments

Descriptive analysis revealed initial fall armyworm infestation rates of 0.19% for Treatment 1 (T1) and 0.27% for Treatment 2 (T2) prior to application. Post-application, infestation rates decreased to 0.05% in T1 and 0.04% in T2, representing reductions of 73.68% and 85.19%, respectively. These results indicate significant control efficacy for both treatments, with T2, utilizing a 7-meter flight altitude, demonstrating superior performance (Figure 4). This enhanced control suggests improved agrochemical distribution and fall armyworm suppression, consistent with (Onler et al., 2023), who reported that increased flight altitudes resulted in more uniform droplet distribution and canopy penetration, reducing localized concentration gradients. Furthermore, the drone's high flight capacity, generating significant turbulence at lower altitudes, may contribute to unintended liquid dispersal, potentially reducing product efficacy. Conversely, the 7-meter altitude in T2 likely facilitated a more dispersed and effective agrochemical application.

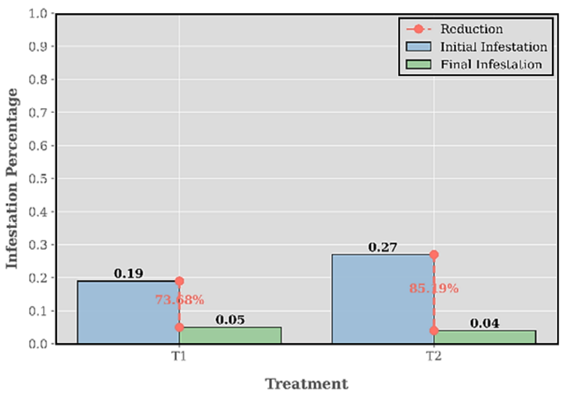

Figure 4. Comparative analysis of plant damage percentages before and after Agras T40 drone-mediated phytosanitary treatment.

As shown in Table 1, paired t-tests revealed statistically significant reductions in fall armyworm infestation for both Treatment 1 (T1) ($t = 38.74$, $p < 0.001$) and Treatment 2 (T2) ($t = 39.06$, $p < 0.001$). While both treatments demonstrated significant efficacy in pest control, the results suggest a superior control effect with Treatment 2.

Drone vs. conventional application

Pre-treatment fall armyworm infestation rates were 0.24% for Treatment 1 (T1), 0.22% for Treatment 2 (T2), and 0.37% for the conventional control. Post-treatment, infestation rates were recorded as 0.43% for T1, 0.07% for T2, and 0.07% for the control, resulting in percentage changes of -79.17% (increased infestation) for T1, a 68.18% reduction for T2, and an 81.08% reduction for the control (Figure 5).

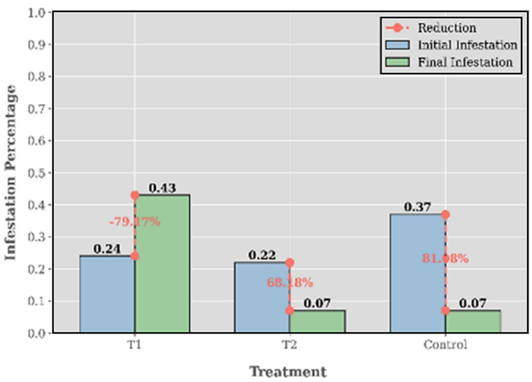

Figure 5. Evaluation of plant damage reduction resulting from Agras T40 drone-delivered aerial phytosanitary applications.

The reduced efficacy observed in Treatment 1 (5 m) may be attributed to increased canopy disturbance at lower flight altitudes. This turbulence likely resulted in enhanced droplet movement within the leaf pore spaces, hindering effective adherence to target surfaces and consequently reducing insecticide distribution efficiency (Pandiselvam et al., 2024). Moreover, effective fall armyworm control necessitates insecticide penetration into the whorls, where larvae are concentrated (Matova et al., 2020).

Paired t-tests revealed significant changes in fall armyworm infestation for all treatments: Treatment 1 (T1) ($t = -42.62$, $p < 0.001$), Treatment 2 (T2) ($t = 35.88$, $p < 0.001$) and the conventional control ($t = 65.70$, $p < 0.001$). However, while T2 and the conventional control demonstrated significant reductions in infestation, T1 exhibited a significant increase, indicating ineffectiveness (Table 2).

As described in Table 3, analysis of variance (ANOVA) revealed statistically significant differences in fall armyworm control efficacy among treatments. Subsequent Tukey HSD post-hoc analysis indicated that Treatment 1 (5 m) exhibited significantly lower efficacy compared to Treatment 2 (7 m), with a mean difference of 0.3418 ($p < 0.0001$). Similarly, Treatment 1 demonstrated significantly lower efficacy than the conventional control, with a mean difference of 0.3367 ($p < 0.0001$). Conversely, no statistically significant difference was observed between Treatment 2 (7 m) and the conventional control (mean difference = -0.0051, $p = 0.6866$).

Table 1

Summary of results, including flight height, initial and final infestation percentages, percentage reduction, and t-statistic values and p-value for each treatment

Treatment	Height (m)	Initial Infestation (%)	Final Infestation (%)	Reduction (%)	Statistic t	p-value
T1 (5 m)	5	0.19	0.05	73.68	38.74	<0.001
T2 (7 m)	7	0.27	0.04	85.19	39.06	<0.001

Table 2

Second Control Results: Flight Height, Infestation Percentages, Reduction, and Paired T-Test Statistics

Treatment	Height (m)	Initial Infestation (%)	Final Infestation (%)	Reduction (%)	Statistic t	p-value
T1 (5 m)	5	0.24	0.43	-79.17	-42.62	<0.001
T2 (7 m)	7	0.22	0.07	68.18	35.88	<0.001
Control	-	0.37	0.07	81.08	65.70	<0.001

Table 3

Tukey HSD post-hoc analysis of treatment means for fall armyworm control (α = 0.05)

Comparison	Average Difference	p-value (Tukey)	Significant (p < 0.05)
T1 (5 m) vs T2 (7 m)	0.3418	< 0.0001	*
T1 (5 m) vs Control	0.3367	< 0.0001	*
T2 (7 m) vs Control	-0.0051	0.6866	

Treatment 2, using the Agras T40, demonstrated fall armyworm control efficacy comparable to conventional methods while offering superior precision, sustainability, and operator safety. UAV application in maize reduces spraying time and minimizes pest damage compared to high-volume sprayers (Shanmugam et al., 2024). Enhanced targeting capabilities optimize pesticide and herbicide use, lowering chemical inputs and mitigating public health risks (Mourya et al., 2024). This precision improves crop yields and product quality while promoting environmental sustainability by minimizing chemical runoff and preserving biodiversity (Saini et al., 2024).

Additionally, UAVs reduce direct chemical exposure for field personnel, providing long-term health benefits. Studies show drones can cut pesticide and herbicide use by 40% to 80% compared to conventional methods while increasing application speed up to fivefold (Guebsi et al., 2024). Drone-based spraying offers an efficient, precise, and safer alternative to manual methods, reducing environmental pollution and health risks (Mahamuni et al., 2024). UAVs are also increasingly used for irrigation, fertilization, phytosanitary treatments, and integrated pest management (Toscano et al., 2024). Moreover, drone operating parameters such as flight height and speed significantly influence product application efficacy and field airflow distribution (Bautista et al., 2024).

When using drones for agricultural pesticide spraying, it is essential to consider both current limitations and future research directions. Key challenges include battery life, payload capacity, and regulatory constraints. Future research should focus on optimizing drone flight parameters for different crop types and environmental conditions, as these factors significantly impact pesticide efficacy. Advancements in navigation, obstacle avoidance, and sensor technology for real-time pest and disease detection are also crucial. Additionally, studies should assess the long-term environmental impact of drone-based pesticide applications and establish standardized data collection protocols to ensure consistency and comparability across research.

4. Conclusions

A comprehensive evaluation of the Agras T40 drone's application for *Spodoptera frugiperda* control in maize was conducted, focusing on the optimization of flight parameters for effective agrochemical delivery. The study revealed that a 7-meter flight altitude yielded optimal droplet distribution and canopy penetration, resulting in significantly enhanced pest management compared to a 5-meter altitude and conventional control methods. Specifically, the 7-meter treatment demonstrated a substantial reduction in fall armyworm infestation, attributed to improved agrochemical coverage and penetration into the maize whorls where larvae reside. While conventional control demonstrated efficacy, aerial application via the Agras T40 exhibited significant advantages in precision, including targeted application and minimized drift, and sustainability through reduced chemical input and environmental impact. Furthermore, the UAV-based approach offered improved operator safety by minimizing direct chemical exposure. These findings suggest the potential of drones, particularly the Agras T40, to refine phytosanitary operations for enhanced agricultural outcomes, promoting both economic viability and environmental stewardship in maize production.

Acknowledgments

To the technical team of Ciudad de la Investigación e Innovación y Desarrollo Agroproductivo (CIIDEA) and ESPAM MFLstudents, and Funding acknowledgment statement: Supported by funding from the ESPAM MFL with the research Smart Land Project CUP: 91880000.0000.389947 SEMPLADES, Ecuador.

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