NARDI FUNDULEA, ROMANIA ROMANIAN AGRICULTURAL RESEARCH, NO. 42, 2025
www.incda-fundulea.ro; doi.org/10.59665/rar4277 First Online: July, 2025. DII 2067-5720 RAR 2025-200

Effectiveness of Drone-Based Herbicide Applications in Silage Corn Production

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ABSTRACT

Drone technology has emerged as a transformative tool in precision agriculture, offering targeted and efficient solutions for herbicide application. This study evaluates the impact of drone-based herbicide spraying on plant growth and yield parameters in silage corn production compared to conventional tractor-based applications. Among the treatments, the 4 L/2 m and 4 L/3 m drone applications resulted in the highest plant heights of 240.5 cm and 258.0 cm, respectively, significantly surpassing the control (194.9 cm) and tractor (196.7 cm) treatments. In terms of cob weight, the 4 L/3 m treatment demonstrated the most substantial increase, whereas the 2 L/2 m treatment yielded the lowest cob weight. The 4 L/2 m treatment also exhibited superior performance in cob length, kernel row number, and total kernel count, recording the highest value of 605.6 kernels per cob. Statistical analyses revealed that higher herbicide dosages applied via drone significantly influenced grain yield and plant growth, with high-dose treatments (4 L/2 m and 4 L/3 m) achieving the greatest impact on key agronomic traits. Total stem weight, a critical factor in silage corn production, was notably enhanced under high-dose applications, with the 4 L/2 m treatment achieving the highest stem weight of 4.234 kg. Similarly, total ear weight followed the same trend, confirming the efficacy of high-dose drone applications. The statistical grouping of treatments indicated that high-dose applications (4 L/3 m and 3 L/3 m) consistently outperformed lower-dose and control treatments across multiple plant parameters. These findings underscore the potential of drone-based herbicide application as a precision-driven alternative to traditional methods, optimizing crop yield while reducing environmental impact and operational costs. The study suggests that drone-based application systems can be effectively implemented in silage corn and potentially adapted for use in various agro-ecological regions.

Keywords: drone herbicide application, silage corn, sustainable agriculture, precision farming, weed control.

INTRODUCTION

Drone-based herbicide application is an advanced and innovative method of modern agriculture that is changing the way growers manage crop protection. This technology uses unmanned aerial vehicles (UAVs), commonly referred to as drones, to apply herbicides and other crop protection products with remarkable efficiency (Garre and Harish, 2018). The use of drones in agriculture has rapidly gained popularity due to their many advantages, including their ability to provide high levels of precision, reduce labor costs and significantly speed up the process of applying herbicides over large areas of land (Nobre et al., 2023; Kavya et al., 2024). Traditional methods of herbicide application often involve ground-based machines that can be slow, labor-intensive and prone to inefficiencies such as over-application. Drones, on the other hand, can cover large areas much more quickly and accurately, allowing growers to address problems such as weed infestations with minimal resources. One of the key benefits of using drones for herbicide application is their exceptional targeting capabilities. Equipped with advanced sensors and GPS technology, drones can identify and apply herbicides directly to specific areas of a field that need treatment (Rani et al., 2019). This is particularly useful when dealing with problem areas such as weed patches or areas of the field that are suffering from pest damage. Instead of spraying the entire field with herbicides, which can result in wasted chemicals and potential harm to the surrounding environment, drones can deliver targeted treatments to the exact areas that need attention. By reducing the unnecessary

Received 2 June 2025; accepted 29 July 2025.

application of herbicides to areas that do not need treatment, drones help minimize chemical waste, lower costs and reduce the overall environmental impact of herbicide use. Reducing herbicide overuse is a major concern in traditional farming practices, as over-application of chemicals can lead to soil degradation, water contamination, and harm to non-target species (Fernández-Quintanilla et al., 2018). With drone technology, farmers can address these concerns by ensuring that only the necessary areas receive chemical treatments. This precision application results in a significant reduction in chemical overuse, contributing to the long-term sustainability of agricultural practices. For instance by drone applications the pesticide use is reduced up to 30% (García-Munguía et al., 2024). By improving the efficiency and effectiveness of herbicide application, drones play a critical role in ensuring that farmers can protect their crops while preserving the environment and natural resources (Meesaragandla et al., 2024).

In addition, the environmental benefits of drone-based herbicide application cannot be overstated. The ability to apply herbicides with pinpoint accuracy means that only the specific areas that need treatment are targeted, helping to reduce the risk of chemical runoff into surrounding ecosystems. Chemical runoff is a significant environmental concern with traditional agricultural practices, as excess chemicals can flow into nearby waterways, affecting aquatic life and contaminating drinking water supplies. Drone technology helps mitigate this problem by ensuring that herbicides are applied in a controlled manner, reducing the likelihood of runoff and preventing damage to ecosystems beyond the farm. In addition, drones can minimize the risk of harming beneficial organisms in the soil, such as earthworms and beneficial insects, which are essential to maintaining healthy agricultural ecosystems. By applying herbicides directly to the areas that need treatment, drones contribute to more sustainable farming practices that protect biodiversity and reduce the overall environmental footprint of agriculture. For example, in Brazil, one of the world's largest agricultural producers, farmers have embraced drone technology to spray herbicides and pesticides across their vast fields. With Brazil's rich and diverse ecosystems, including fragile forests and rivers, the ability to reduce pesticide drift into these areas is a significant benefit. By using drones, farmers can ensure that herbicides are applied accurately and in a controlled manner, helping to minimize pesticide drift and reduce the environmental impact on surrounding forests, rivers, and other sensitive habitats (Nobre et al., 2023). In addition to the speed and efficiency of herbicide application, drones can also provide real-time monitoring of crop health. Many drones are equipped with advanced cameras and sensors that can detect crop stress, weed infestations or pest problems. This data can be used to monitor overall crop health, track the effectiveness of herbicide treatments, and identify areas that may need additional attention. By providing real-time insights into crop health, drones enable farmers to make informed decisions about where and when to apply herbicides, ensuring that resources are used efficiently and effectively. For example, in China, where marigold and rice fields are often plagued by both weeds and pests, drones are used to collect data on crop conditions and determine the optimal times to apply herbicides. This real-time monitoring capability allows farmers to be proactive and address problems before they become widespread and cause significant damage to crops (Zou et al., 2021; Yu et al., 2022).

Overall, drone-based herbicide application offers a wide range of benefits to modern agriculture, from improving precision and reducing chemical waste to increasing sustainability and operational efficiency. By adopting drone technology, farmers can apply herbicides more precisely, reducing the environmental impact of agriculture while increasing productivity and profitability. As drone technology continues to evolve and improve, its use in agriculture is expected to become even more widespread, helping to solve some of the most pressing challenges in food production, resource management and environmental protection.

MATERIAL AND METHODS

Location of the Experiment, Sowing Method, Corn Variety, and Its Characteristics

This experiment was conducted in a corn silage field located in the Cumhuriyet neighborhood of Serdivan district, Sakarya province.

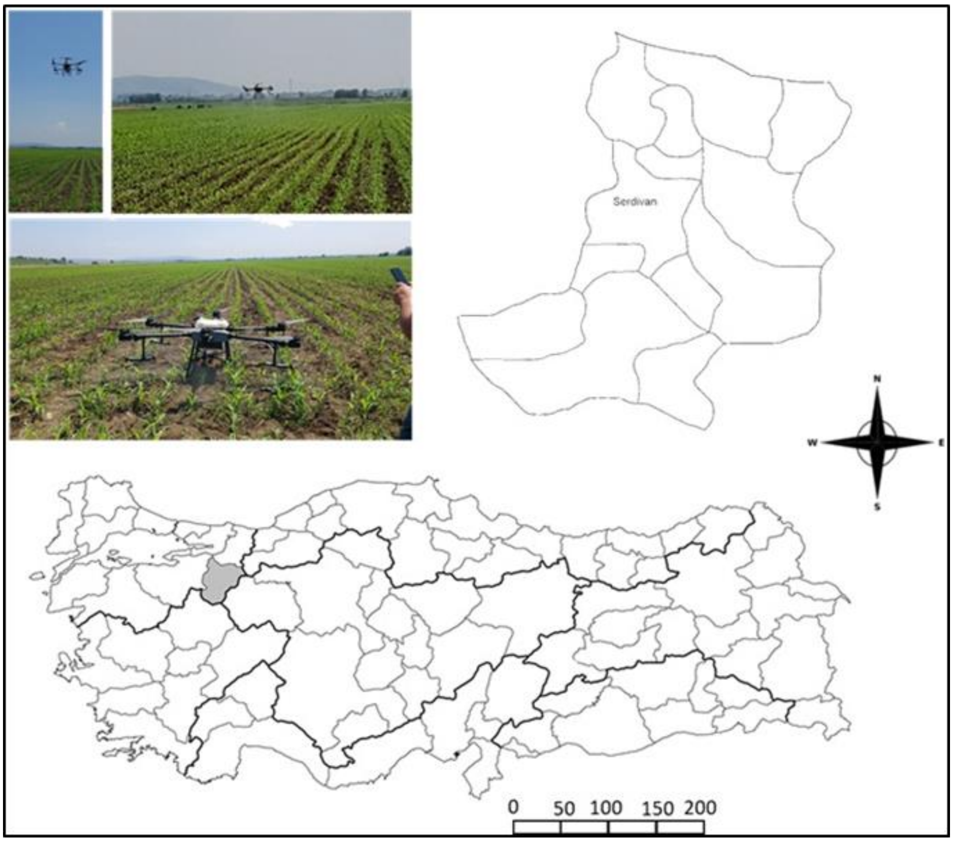

Figure 1. Study area map and image of experimental field

Figure 1 illustrates herbicide application in a corn field using a multi-rotor agricultural drone. The drone is shown both in action and on the ground, demonstrating its capability to efficiently spray herbicides over uniformly planted corn rows with minimal human intervention. As seen in the field images the herbicides were applied when plant were at approximately at four leaves stage.

A drip irrigation system was employed to irrigate the corn field efficiently. The corn variety used in the experiment was DKC6664, a variety from the Dekalp brand. This variety is excellently adapted to dense planting conditions. It features a strong root and stalk structure and is resistant to plant diseases. The grain quality is very high, with large grains that are rich in nutritional value. The corn was planted using traditional methods. During planting, the distance between rows was set at 75 cm, while the distance between plants within each row was set at 20 cm. These planting distances were selected to promote healthier growth of the corn and to make optimal use of the available space.

Herbicide Application and Active Ingredients

The herbicide used in the trial was a mixture of 37.5 g/l Mesotrione and 15 g/l Nicosulfuron (Monet-Hektaş). During the trial, a DJI T30 model spraying drone with a 30-liter capacity was employed for herbicide applications. This drone is designed to provide an efficient solution for agricultural spraying and offers significant advantages in terms of time and labor. By using the drone, the goal was to achieve a more uniform distribution of herbicides across the area, thus enhancing their effectiveness. Additionally, a system with a fan beam nozzle structure was used during the spraying process to accurately apply the herbicides to the plants.

The amount of medicated water mixture used in the experiment was set at 15 liters per hectare, with three different doses applied: 2 lt/ha, 3 lt/ha, and 4 lt/ha. These varying doses were used to assess their effects on plant health and yield, aiming to determine the most effective dosage for optimal results. To evaluate the impact of flight height on spraying efficiency, two different flight heights were tested: 2 meters and 3 meters. For comparison, standard tractor spraying was also included in the trial. The tractor application used a dose of 3 lt/ha, and its effectiveness was compared to the drone application to determine which method offered better efficiency in terms of herbicide distribution and overall results. Additionally, a control plot was included in the trial that received no spraying, remaining under natural conditions. The design of the experiment followed a split plot design with randomized blocks. Each treatment area was 200 meters long and 15 meters wide, with a 3-meter safety strip between adjacent treatments. The trial was established on June 23, 2024, and three different observation periods were scheduled during the trial: Day 7, Day 14, and Day 21. During these periods, field checks were conducted to monitor the effects of spraying on plant growth, diseases, and pests. The experiment ended on October 7, 2024, and the collected data was thoroughly analyzed to assess the impact of the different spraying methods on various yield parameters.

At the conclusion of the experiment, several corn plant parameters were measured to assess the effects of the treatments. These parameters included plant height, cob weight, cob length, cob diameter, row grain number, length grain number, total cob grain number, cob dry weight, cob thousand grain weight, cob weight, and stem weight (Beagle, 1985). The data collected from these measurements were subjected to statistical analysis using the SPSS package program. To determine whether there were significant differences between the different treatments for each parameter, the Duncan test was applied.

RESULTS AND DISCUSSION

Drone spraying was employed in corn fields to apply herbicides, and its effects on various plant parameters were assessed. It was found that 4 L/2 m and 4 L/3m treatments produced highest average plant height of 240.5 cm and 258 cm, respectively. These values significantly exceeded those of the control (194.9 cm) and tractor (196.7 cm) groups, which had significantly lower averages. In terms of cob weight, the 4 L/3 m treatment stood out as the most effective, giving the highest increase in cob weight. Conversely, the 2 L/2 m treatment had the lowest cob weight among all groups. When evaluating cob length, number of kernel rows per cob and number of kernels per cob, the 4 L/2 m treatment showed superior performance. This treatment was statistically determined to be the most ideal, with results closely followed by those of the 3 L/3 m treatment. The analysis revealed significant differences in the total number of kernels on the cob among the treatments. In the control group and the applications performed with a tractor, the total kernel counts were 470.6 and 535.0, respectively. For drone applications, the lowest kernel count was observed in the 2 L/2 m application, with 334.8 kernels. Conversely, the highest kernel count was achieved with the 4 L/2 m application, reaching 605.6 kernels, followed closely by the 4 L/3 m application, which yielded 592.0 kernels. Herbicide dosage and application height significantly influenced grain yield in corn, particularly at higher dosages. High-dose applications were notably more effective, with plant height playing a critical role in maximizing yield. In terms of total stem weight, a key factor in silage corn production, notable differences were observed among treatments. The control and tractor applications yielded relatively low total stem weights of 2.754 kg and 2.760 kg, respectively. In contrast, significant increases in stem weight were recorded in the 4-liter applications. For the 4 L/3 meters treatment, stem weight reached 3.854 kg, while increasing the application density to 4 L/2 meters further raised the stem weight to 4.234 kg. These findings indicate that the 4 L applications had the most substantial impact on stem weight. Similarly, the highest total ear weights were also achieved with the 4 L treatments.

The statistical analyses provided significant insights into the effects of different treatments on plant parameters. Statistically distinct groups are indicated by letters, and the treatment effects have been evaluated based on these groupings. In terms of plant height, the "3 L/3m" and "4 L/3m" treatments achieved the highest values, placing them in the "a" group. In contrast, "Control," "Tractor," and "2 L/2m" groups exhibited lower values, falling into the "d" or "c" groups. This indicates that high-dose treatments result in a statistically significant increase in plant height. Similarly, for parameters such as cob diameter and cob dry weight, the "4 L/3m" treatment produced the highest values and was statistically significant compared to the other treatments. On the other hand, "2 L/2m" and "Tractor" treatments showed significantly lower values. For example, in terms of total kernel count, the "4 L/3m" and "3 L/3m" treatments were classified in the "a" group, while the "2 L/2m" treatment was placed in the "e" group. Regarding the 1000-kernel weight, the "4 L/3m" treatment achieved the highest values, statistically separating it from the other groups. Conversely, the "2 L/2m" and "Control" treatments displayed lower weights, highlighting the significant impact of treatment dose on kernel weight. Overall, the statistical analyses reveal that high-dose treatments, such as "3 L/3m" and "4 L/3m", have a positive and statistically significant impact on plant growth parameters. In contrast, low-dose treatments and control groups generally showed lower performance (Table 1, Figure 2).

Table 1. Plant height, cob weight, and cob length results in all treatments

	Plant height (cm)	Cob weight (grainless) (g)	Cob dry weight (Grainless) (g)	Cob length (cm)	Kernel rows per cob (unit)	Total stem weight (kg)
Control	196.3±14.8 d	208.2±2 cb	334.0±29.1 b	17.5±1.6 b	17.1±0.9 cb	2.7
Tractor	196.7±14.7 d	230.0±3 cb	364.1±38.8 ba	18.9±2.0 ba	18.2±1.3 cba	2.7
2 L/2m	194.9±31.3 d	138.8±3 d	299.7±33.9 c	15.1±1.7 c	16.8±2.0 c	2.8
2 L/3m	222.5±6.8 c	243.0±3 b	377.3±24.1 a	19.3±1.0 a	18.2±1.3 cba	2.7
3 L/2m	215.8±9.1 c	215.0±8 cb	339.7±32.2 b	17.6±2.1 b	17.7±1.7 cba	3.1
3 L/3m	265.5±18.1 a	199.8±2 c	333.1±43.5 b	19.6±1.8 a	17.9±1.2 cba	3.6
4 L/2m	240.5±13.1 b	237.0±2 cb	336.2±36.7 b	19.8±0.9 a	18.8±1.3 a	4.2
4 L/3m	258.0±14.8 a	289.0±1 a	393.4±10.4 a	19.1±1.2 ba	18.4±1.5 bc	3.8

	Cob diameter (cm)	Cob length grain (unit)	Thousand grain weight (g)	Total grain per cob (unit)	Cob dry weight (Grainless) (g)
Tractor	47.5±2.3 b	29.7±3.0 ba	470.6±47.9 d	180.8±20.9 d	334.0±29.1 b
2 L/2m	48.8±2.0 b	29.1±4.5 b	535.0±75.1 c	194.6±41.8 dc	364.1±38.8 ba
2 L/3m	44.7±3.7 c	18.9±2.4 c	334.8±78.9 e	95.2±14.1 e	299.7±33.9 c
3 L/2m	49.8±1.2 ba	31.7±3.1 ba	569.4±45.3 cba	211.6±19.7 cb	377.3±24.1 a
3 L/3m	48.3±2.0 b	30.6±3.3 ba	540.9±32.5 c	181.7±24.2 d	339.7±32.2 b
4 L/2m	47.5±2.7 b	32.1±2.3 a	548.4±49.6 cb	200.0±10.5 dc	333.1±43.5 b
4 L/3m	49.7±2.7 ba	32.3±1.8 a	605.6±27.7 a	230.3±15.8 ba	336.2±36.7 b
Control	51.4±1.5 a	31.3±2.0 ba	592.0±32.4 ba	235.6±18.1 a	393.4±10.4 a

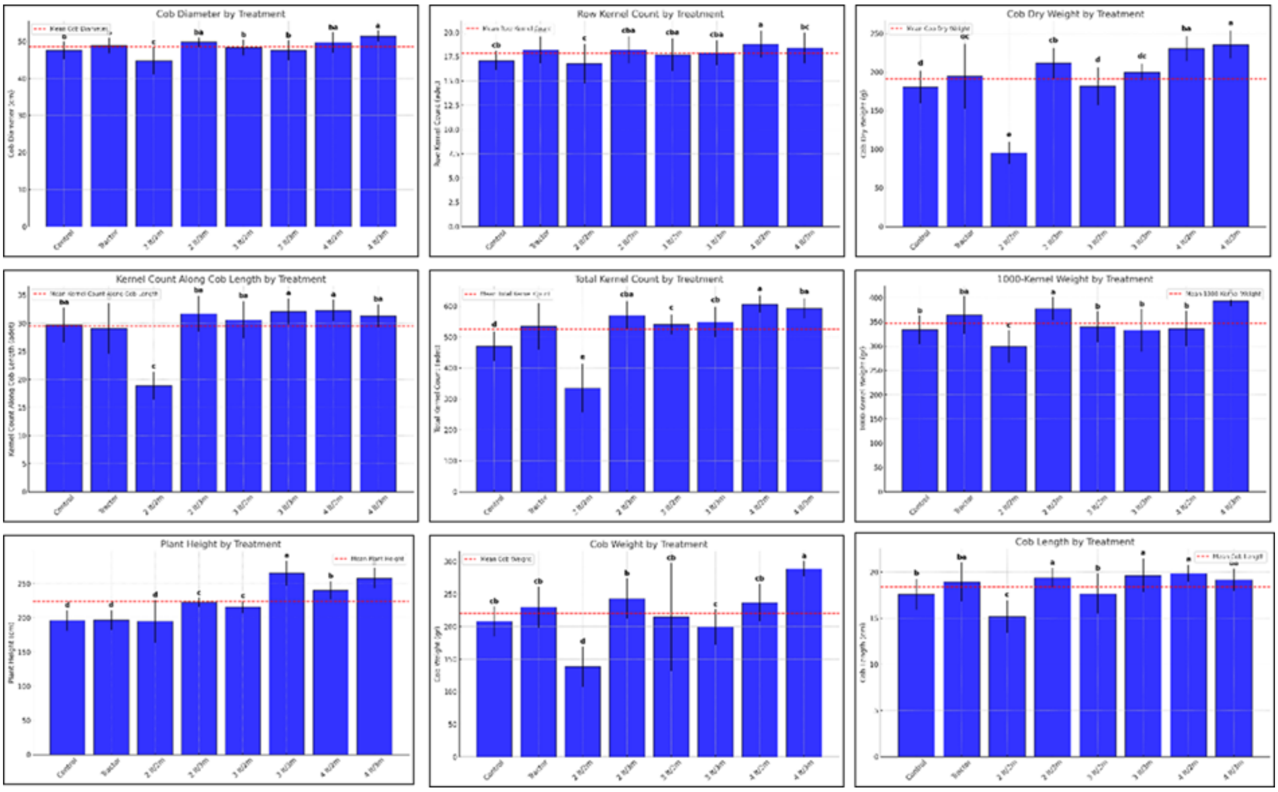

Figure 2. Duncan test comparisons of all applications

Weed infestation is one of the most significant obstacles to maize production in Türkiye and worldwide, leading to substantial economic losses due to ineffective weed control practices, low soil fertility, and labor shortages. The reliance on manual methods such as hand hoeing, particularly in regions with limited access to mechanized equipment, exacerbates the problem. Maize is particularly susceptible to weed competition during its early growth stages, with yield losses ranging from 51% to 100%, and 60-81% typically reported when weed control is insufficient (Imoloame and Omolaiye, 2017). In other studies yield losses of 33-70%, 58-62%, 67-79%, and 33-50% were observed (Sharma et al., 2000; Massinga et al., 2003; Malviya and Singh, 2007; Mukhtar et al., 2007; Page et al., 2012). Extended weed interference reduces the number of cobs per plant and decreases 100-seed weight, with seed number per cob being the most significantly affected component. These issues highlight the urgent need for effective and sustainable weed management to optimize maize yields and ensure food security, especially in regions that heavily rely on maize production (Evans et al., 2003). In this context, Hossain et al. (2020) emphasized that integrated chemical weed control strategies implemented under conservation agriculture systems can effectively reduce weed pressure and enhance maize productivity.

Drone technology has introduced a revolutionary shift in agricultural practices, particularly in herbicide application, by offering precision and uniformity that traditional methods lack. Drones ensure the even distribution of herbicides, reducing weed competition while minimizing chemical wastage. This targeted application is especially beneficial in areas severely affected by weeds, optimizing crop growth while preventing overuse of chemicals that could harm the environment or non-target plants. The growing use of drones for weed management across various crops underscores their effectiveness. Palacios-Zuñiga et al. (2024) found that drones achieved superior control of weeds like ryegrass and oilseed radish with glyphosate, and produced comparable results with glufosinate, even at low spray volumes. This efficiency, along with low chemical usage, demonstrates drones' potential to enhance weed control without compromising the effectiveness of herbicide applications.

The study further explored the impact of drone spraying on corn plant growth and yield, showing that drone applications can significantly outperform traditional methods when higher spray volumes are used. Treatments with 4 L/2 m and 4 L/3 m achieved superior results compared to control and tractor-based treatments, with plants growing to an average height of 258 cm and 240.55 cm, respectively. This was considerably taller than the control group (194.9 cm) and those treated with tractor-based applications (196.7 cm). Meesaragandla et al. (2024) noted that drone applications improve the uniformity and penetration of spray droplets, effectively reducing weed competition and enhancing plant growth. These findings align with the results from this study, highlighting the substantial benefits of drone spraying in improving crop health.

Drone spraying height and speed play crucial roles in application efficiency. Qin et al. (2016) showed that flying at a height of 1.5 m with a speed of 5 m/s resulted in superior droplet uniformity compared to conventional sprayers. Similarly, Kumar et al. (2022) demonstrated that UAV sprayers significantly improved droplet distribution and weed control efficacy in wheat, highlighting their potential for precise herbicide delivery in cereal crops. Furthermore, Paul et al. (2024) reported that droplet density increased with higher flow rates at a constant height (2 m), but decreased with increasing height and speed at a fixed flow rate (1.08 L/min). These findings emphasize the importance of optimizing drone parameters such as flying height, speed, and flow rate to ensure even coverage and maximize pesticide application efficiency.

In terms of yield, the 4 L/3 m treatment resulted in the highest cob weights, while the 2 L/2 m treatment, which used a lower volume, produced the lowest cob weights. This result corroborates Maqbool et al. (2006), who found that optimized herbicide applications reduce weed competition and allow plants to allocate more resources to reproductive organs like cobs. Moreover, for kernel-related parameters, such as cob length, the number of kernel rows per cob, and total kernel count, the 4 L/2 m treatment was the most effective, followed closely by the 3 L/3 m treatment. The study revealed significant differences in kernel count across treatments. The control and tractor treatments yielded 470.6 and 535.0 kernels, respectively, while the 2 L/2 m treatment resulted in the lowest kernel count (334.800). In contrast, the 4 L/2 m and 4 L/3 m treatments produced 605.6 and 592.0 kernels, respectively, demonstrating the significant impact of drone spraying on maize yield.

Drone applications provide several additional benefits beyond improving maize yield. They offer uniform herbicide coverage, reduce soil compaction, a common issue with tractor applications, and allow for site-specific treatments that minimize environmental impact. Furthermore, drones are adaptable to various field conditions, making them a valuable tool in areas with challenging terrain or where access to mechanized equipment is limited.

CONCLUSIONS

The results of this study highlight the potential of drone-based herbicide applications as an effective and sustainable tool for modern maize production. High-volume drone treatments significantly improved key agronomic traits, including plant height, cob characteristics, kernel count, and stem weight, compared to conventional methods. These findings emphasize the value of optimizing both herbicide dosage and application parameters, such as flight height, to enhance crop performance. Overall, UAV spraying offers a promising alternative for precision weed management, particularly in areas where uniform application, environmental protection, and operational efficiency are priorities.

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