

Effect of the AgroPlus® adjuvant on the desiccation of hard-to-control weeds using ground and aerial applications

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Abstract

The desiccation of hard-to-control weeds represents a major challenge in agricultural production systems, particularly in areas with high infestations of perennial species and weeds at advanced growth stages. In this context, adjuvants have been widely used to enhance herbicide performance and optimize application quality. This study aimed to evaluate the influence of the AgroPlus® adjuvant on weed desiccation efficiency by comparing ground and aerial application systems. The experiments were conducted in an experimental area at the Goiano Federal Institute – Rio Verde Campus, under six months of fallow conditions with the predominance of several hard-to-control weed species. The experimental design consisted of randomized blocks with five treatments and four replications, involving different adjuvants associated with standard herbicides. Weed control efficiency was assessed at 7, 14, 21, and 28 days after application, in addition to spray quality parameters. The results demonstrated that the use of adjuvants increased desiccation efficiency compared with treatments without adjuvants. AgroPlus® showed superior performance, particularly in ground applications, providing greater weed control efficiency and more consistent results throughout the evaluation period. In aerial applications, although improvements in droplet quality were observed, no substantial differences among treatments were detected regarding weed control efficiency. It can be concluded that AgroPlus® improves application quality and enhances desiccation efficiency, with more pronounced effects under ground application systems.

Keywords: application technology, agricultural adjuvants, herbicides, weed management, spraying.

Efeito do adjuvante AgroPlus® na dessecação de plantas daninhas de difícil controle por aplicações terrestres e aéreas

Resumo

A dessecação de plantas daninhas de difícil controle representa um importante desafio para os sistemas de produção agrícola, especialmente em áreas com elevada infestação de espécies perenizadas e em estádios avançados de desenvolvimento. Nesse contexto, a utilização de adjuvantes tem sido amplamente empregada com o objetivo de aumentar a eficiência dos herbicidas e otimizar a qualidade das aplicações. O presente estudo teve como objetivo avaliar a influência do adjuvante AgroPlus® na eficiência da dessecação de plantas daninhas, comparando os sistemas de aplicação terrestre e aérea. Os experimentos foram conduzidos em área experimental do Instituto Federal Goiano – Campus Rio Verde, em condição de pousio por seis meses, com predominância de diferentes espécies de plantas daninhas de difícil controle. O delineamento experimental adotado foi em blocos casualizados, composto por cinco tratamentos e quatro repetições, envolvendo diferentes adjuvantes associados a herbicidas padrão. Foram avaliados a eficiência de controle das plantas daninhas aos 7, 14, 21 e 28 dias após a aplicação, bem como parâmetros relacionados à qualidade da pulverização. Os resultados demonstraram que a utilização de adjuvantes proporcionou incremento na eficiência da dessecação em comparação à ausência desses produtos. O AgroPlus® apresentou desempenho superior, especialmente nas aplicações terrestres, promovendo

maior eficiência de controle e maior estabilidade dos resultados ao longo das avaliações. Nas aplicações aéreas, embora tenham contribuído para melhorias na qualidade das gotas pulverizadas, não foram observadas diferenças expressivas entre os tratamentos quanto ao controle das plantas daninhas. Conclui-se que o adjuvante AgroPlus® favorece a qualidade da aplicação e potencializa a eficiência da dessecação, com resultados mais evidentes em sistemas de aplicação terrestre.

Palavras-chave: tecnologia de aplicação, adjuvantes agrícolas, herbicidas, manejo de plantas daninhas, pulverização.

1. Introduction

Weed management represents one of the major challenges of modern agriculture, particularly in intensive production systems, where the selection pressure imposed by the continuous use of herbicides has favored the emergence of resistant or tolerant populations. In the Brazilian Cerrado, especially in the state of Goiás, species such as sourgrass (*Digitaria insularis*), fleabane (*Conyza* spp.), Benghal dayflower (*Commelina benghalensis*), goosegrass (*Eleusine indica*), and pigweed (*Amaranthus* spp.) are among the most important weeds responsible for yield losses and increased production costs (Alcantara-de la Cruz et al., 2026; Gomes et al., 2025; Santos et al., 2018). Sourgrass and fleabane are particularly problematic due to the widespread occurrence of Glyphosate-resistant® biotypes, making their management increasingly difficult (Guimarães et al., 2019; Piasecki et al., 2020).

Pre-sowing desiccation is an essential practice for the success of no-tillage systems, as it promotes the elimination of existing vegetation and reduces early weed competition with crops (Andrade et al., 2025; Cordeau, 2022). However, the effectiveness of this practice depends on several factors, including the target species, plant growth stage, weather conditions during application, and the spraying technology employed. Perennial weeds or plants at advanced reproductive stages generally exhibit greater tolerance to herbicides due to their more developed structures and reduced translocation of active ingredients (Piasecki et al., 2020; Zanin et al., 2022; Zheng; Xu, 2023).

Among the herbicides most commonly used in desiccation programs are Glyphosate®, 2,4-D®, Ammonium glufosinate®, and Saflufenacil®, applied either alone or in mixtures (Neto et al., 2020). Recent studies have demonstrated that combinations of Glyphosate® and Saflufenacil® provide superior control of *Conyza* species, including glyphosate-resistant populations, due to the complementary action of different mechanisms of action. Likewise, management programs integrating herbicides with distinct mechanisms of action have shown improved control of perennial sourgrass, one of the most troublesome weeds in the Brazilian Midwest region (Guimarães et al., 2019; Piasecki et al., 2020).

In addition to selecting the appropriate herbicide, spray solution quality has a direct influence on weed control efficiency (Daramola et al., 2022). Factors such as water pH, hardness, product compatibility, surface tension, droplet size, and spray uniformity can significantly affect herbicide deposition and absorption by target weeds. Therefore, deficiencies in spray mixture preparation may compromise herbicide performance, even when highly effective products are used (Castro et al., 2018).

In this context, adjuvants play a fundamental role in spray application technology by modifying the physicochemical properties of the spray solution. They can reduce surface tension, increase droplet spreading and retention on leaf surfaces, and minimize losses caused by evaporation and drift (Ma et al., 2022; Wang et al., 2023). Previous studies have demonstrated that the appropriate use of adjuvants can improve herbicide deposition on the target and enhance weed control efficiency, particularly under less favorable environmental conditions (Basilio et al., 2024; Castro et al., 2018).

Among the commercially available adjuvants, AgroPlus® has attracted considerable interest due to its potential to optimize spray application performance. Its formulation is designed to improve droplet uniformity, enhance adhesion and retention on plant surfaces, and reduce drift-related losses. These characteristics may improve target coverage and increase herbicide availability for absorption by weeds, thereby enhancing both operational and agronomic efficiency. However, the effectiveness of adjuvants may vary according to the application system employed, especially when comparing ground and aerial applications, which differ substantially in spray volume, droplet spectrum, and susceptibility to environmental conditions.

Therefore, the objective of this study was to evaluate the effect of the AgroPlus® adjuvant on the desiccation of hard-to-control weeds, comparing its performance under ground and aerial application systems, as well as its effects on spray quality and chemical weed control efficiency.

2. Materials and Methods

2.1 Experimental area

The experiment was conducted at the Federal Institute Goiano – Rio Verde Campus, located in the municipality of Rio Verde, Goiás State, Brazil, at the coordinates 17°48'27.9"S and 50°53'57.5"W. The region is characterized by a tropical savanna climate (Aw), according to the Köppen classification, with a dry winter season and a rainy summer season (Chen; Chen, 2013). The experimental area remained fallow for six months before the establishment of the experiment during the first semester of 2025, favoring the development of a diverse weed community, predominantly composed of perennial and hard-to-control species. At the time of application, the weeds were predominantly at the reproductive stage, with a high occurrence of both grass and broadleaf species.

2.2 Weed plants in the study area

The weed species present in the experimental area were predominantly sourgrass (*Digitaria insularis*), goosegrass (*Eleusine indica*), southern sandbur (*Cenchrus echinatus*), signal grass (*Urochloa decumbens*), Jamaican crabgrass (*Digitaria horizontalis*), Benghal dayflower (*Commelina benghalensis*), asthma weed (*Euphorbia hirta*), morning glory (*Ipomoea grandifolia*), and smooth pigweed (*Amaranthus hybridus*). These species were found at different developmental stages, with a predominance of plants in the reproductive phase, characterizing a diverse weed community representative of the main difficult-to-control weed species commonly found in agricultural areas of the Brazilian Cerrado.

2.3 Experimental design and treatments

The experimental design was a randomized complete block design consisting of five treatments and four replications, totaling 20 experimental plots. The plots were sized to allow proper assessment of spray deposition and weed control efficiency, with buffer zones maintained between experimental units to minimize potential interference among treatments. The evaluated treatments were (Untreated control, Herbicide (Roudup 720 WG (Glyphosate®) 2.5 L ha⁻¹) without adjuvant, Herbicide (Prend-D 806 (2,4-D®) 0 L ha⁻¹) + DNA Aderence®, Herbicide (Poquer 240 (Cletodin®) 1 L ha⁻¹) + Action Sil®, and Herbicide (Roudup 720 WG (Glyphosate®) 2.5 L ha⁻¹) + AgroPlus®. The herbicides were applied according to the manufacturers' technical recommendations, respecting the recommended application rates, weed growth stage, and suitable environmental conditions at the time of application. The adjuvants were added directly to the spray tank, ensuring proper homogenization of the spray solution before application.

2.4 Application type

2.4.1 Ground application

The soil application was carried out using a CO₂-pressurized backpack sprayer equipped with a flat jet hydraulic nozzle and a JCV 11002 type tip. A spray volume of 100 L ha⁻¹ was used, with the operating pressure adjusted to produce a droplet spectrum suitable for herbicide applications. The droplet size was selected according to technical recommendations to maximize target coverage and minimize drift losses, since the droplet spectrum directly influences spray deposition and application efficiency. The ground application was carried out on February 6, 2026.

2.4.2 Aerial application

Aerial application was carried out using a spray volume of 10 L ha⁻¹, which is commonly adopted in this application system due to the high operational capacity provided by low-volume spraying. Applications were performed at 10:30 a.m., under an average air temperature of 26 °C and wind speed of 8.7 km h⁻¹. Droplet size was classified using the Volumetric Median Diameter (VMD), which ranged from 350 to 450 µm and corresponded to the coarse droplet size class. This droplet spectrum was selected to reduce the potential for drift while maintaining an adequate deposition on the target. The aerial application was carried out on April 3, 2026.

2.5 Environmental and operational conditions during application

Meteorological conditions were monitored during herbicide applications to ensure compliance with the

recommended standards for pesticide spraying. Air temperature, relative humidity, wind speed, spray volume, and droplet spectrum characteristics were recorded for both ground and aerial applications. These parameters were used to characterize the environmental and operational conditions under which the treatments were applied and to support the interpretation of spray quality and weed control results (Table 1).

Table 1. Environmental and operational conditions during herbicide application.

Parameter	Ground application	Aerial application
Air temperature (°C)	32	30
Relative humidity (%)	68	78
Wind speed (km h ⁻¹)	9.5	8.7
Spray volume (L ha ⁻¹)	100	10
VMD (µm)	350-450	350-450
Droplet class	Very Coarse	Medium/ Extremely Coarse

Source: Authors, 2026.

2.6 Evaluations

Evaluations were conducted at 7, 14, 21, and 28 days after application (DAA) between February and June 2026. These assessment intervals were established to determine the temporal response of weeds to the treatments and to quantify control efficiency throughout the experimental period. The assessed variables included weed mortality (%), spray deposition volume on water-sensitive paper (µL cm⁻²), droplet density (droplets cm⁻²), Relative Span, drift risk potential(%), and Volumetric Median Diameter (VMD) (µm).

Weed mortality was visually estimated using a percentage scale ranging from 0 to 100%, where 0% represented the absence of control and 100% indicated complete mortality of the weeds present within the experimental plot. Evaluations were performed considering the intensity of injury symptoms, plant necrosis, growth suppression, and mortality of the weed community. Spray quality parameters, including deposition volume, droplet density, Relative Span, drift risk potential, and VMD, were determined using water-sensitive papers positioned within the target area and subsequently analyzed to characterize spray distribution and application performance under field conditions.

2.7 Statistical analysis

The data were subjected to analysis of variance (ANOVA) to determine the effects of treatments on the evaluated variables. When significant differences were detected, treatment means were compared using *Tukey's* test at the 5% probability level. All statistical analyses were performed using the SISVAR software package, version 5.8 (Ferreira, 2019), which is widely used in agronomic research for the analysis and interpretation of experimental data.

3. Results

3.1 Weed desiccation efficiency under ground application

The desiccation efficiency of the evaluated treatments increased progressively throughout the assessment period, with marked differences observed among the adjuvants tested under ground application conditions (Table 2). At 7 DAA, all treatments containing adjuvants provided higher weed control than the treatment without adjuvant, with AgroPlus® showing the greatest initial efficiency (49%). This trend was maintained during the subsequent evaluations, with control levels increasing at 14, 21, and 28 DAA. At the end of the experimental period, AgroPlus® achieved the highest desiccation efficiency (75%), followed by DNA (70%) and Action Sil® (70%), while the treatment without adjuvant presented lower control (67%). These results indicate that the inclusion of adjuvants enhanced herbicide performance, contributing to improved weed desiccation over time.

Table 2. Weed control efficiency (%) under ground application at 7, 14, 21 and 28 days after application (DAA).

	Control efficiency at 7 DAA (%)	Control efficiency at 14 DAA (%)	Control efficiency at 21 DAA (%)	Control efficiency at 28 DAA (%)
Control	0.00	0.00	0.00	0.00
No adjuvant	41.75	56.25	61.00	67.20
DNA	44.25	57.75	68.25	70.75
Action Sil	47.25	60.50	68.75	70.70
AgroPlus	49.75	65.00	74.75	75.25

Means followed by different letters within the same column differ significantly according to *Tukey's* test at the 5% probability level ($p \leq 0.05$). The coefficient of variation (CV) ranged from X to Y%, indicating satisfactory experimental precision. Source: Authors, 2026.

Figure 1 shows the weed desiccation efficiency under ground application conditions at different evaluation periods. In Figure 1A (7 DAA), all treatments containing adjuvants provided higher control levels than the treatment without adjuvant, with AgroPlus® showing the greatest initial effectiveness. In Figure 1B (14 DAA), an increase in desiccation efficiency was observed for all treatments, with AgroPlus® maintaining superior performance. Figure 1C (21 DAA) demonstrates a continued increase in weed control, highlighting the positive effect of adjuvants on herbicide activity. Finally, Figure 1D (28 DAA) shows the highest control levels recorded during the experiment, with AgroPlus® presenting the greatest desiccation efficiency and the most consistent performance throughout the evaluation period.

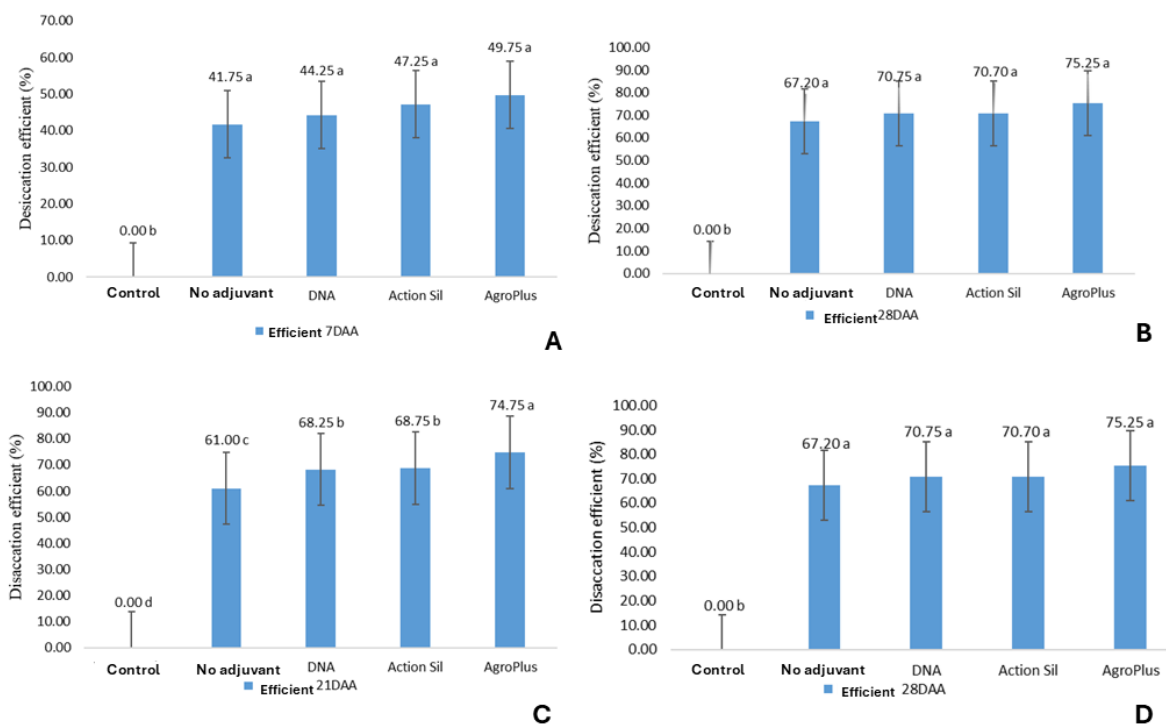


Figure 1. Weed desiccation efficiency (%) under ground spraying conditions. (A) 7 days after application (7 DAA), (B) 14 DAA, (C) 21 DAA, and (D) 28 DAA. Source: Authors, 2026.

Figure 2 demonstrates that AgroPlus® promoted greater spray deposition on the target surface compared with the other evaluated treatments. The increased deposition volume observed on water-sensitive papers indicates

improved retention and distribution of spray droplets, which may have contributed to the superior desiccation efficiency recorded throughout the evaluation period. Treatments containing DNA[®] and Action Sil[®] also enhanced deposition relative to the treatment without adjuvant; however, their performance remained lower than that observed for AgroPlus[®].



Figure 2. Spray droplet deposition volume ($\mu\text{L cm}^{-2}$) quantified on water-sensitive paper treated with Luminol, demonstrating the distribution and coverage of the spray solution in the target area following herbicide application. Values represent the mean deposition obtained under field conditions during the experimental period. Source: Authors (2026).

Figure 3 presents the spray quality parameters obtained under aerial application conditions. Figure 3A illustrates the percentage of sample area covered and the deposition volume on the sample, indicating the effectiveness of spray distribution over the target surface. Figure 3B shows the Relative Span and Drift Risk Potential, demonstrating the influence of the treatments on droplet size uniformity and the likelihood of drift losses. Figure 3C presents Droplet Density and Volumetric Median Diameter (VMD), highlighting differences in droplet spectrum characteristics among the evaluated treatments. Overall, the adjuvants contributed to improving spray quality, with AgroPlus[®] showing favorable results for deposition, droplet distribution, and drift reduction.

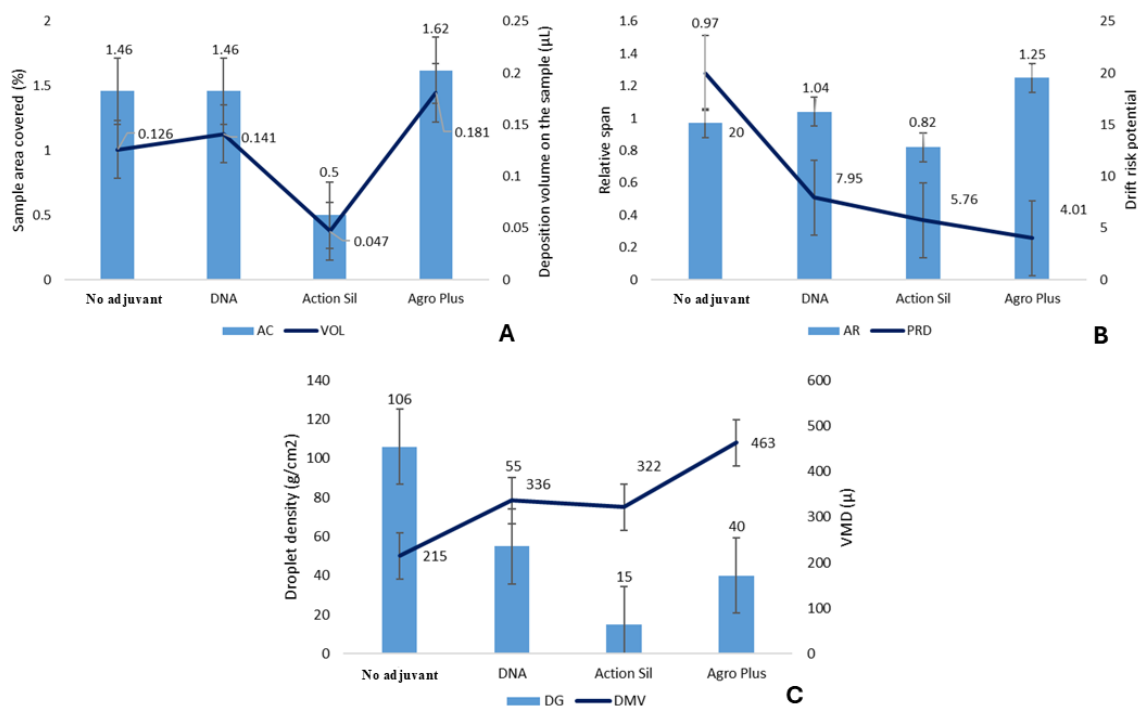


Figure 3. Aerial application performance parameters. (A) Sample area covered (%) and deposition volume on the sample ($\mu\text{L cm}^{-2}$); (B) Relative Span and Drift Risk Potential (%); and (C) Droplet Density (droplets cm^{-2}) and Volumetric Median Diameter (VMD) (μm). Source: Authors (2026).

4. Discussion

The progressive increase in weed desiccation efficiency observed throughout the evaluation period demonstrates the importance of adjuvants in enhancing herbicide performance, particularly under ground application conditions. The superiority of AgroPlus® throughout all evaluation periods suggests that this adjuvant improved spray deposition and retention on the target, favoring herbicide absorption and translocation within the weed tissues. The higher control levels recorded at 21 and 28 DAA indicate that the benefits provided by the adjuvant were cumulative over time, resulting in greater effectiveness of the desiccation process (Castro et al., 2018; Daramola et al., 2022).

The results obtained are consistent with those reported by Castro et al. (2018), who verified that adjuvants can modify the physicochemical properties of spray solutions and improve herbicide effectiveness by increasing spreading and retention on leaf surfaces. Although reductions in surface tension do not always result in greater deposition, improvements in spray coverage may increase herbicide absorption and consequently improve weed control efficiency.

The deposition results presented in Figure 2 further support the superior performance of AgroPlus®. Increased deposition volume on the target surface enhances herbicide availability for absorption, particularly in weed species characterized by thick cuticles, waxy leaf surfaces, or advanced developmental stages. Consequently, improved deposition may explain the higher desiccation levels observed throughout the evaluation period. Moreover, greater spray retention on the target reduces losses caused by runoff and evaporation, increasing the proportion of active ingredient effectively available for weed control (Castro et al., 2018; Daramola et al., 2022).

The superior performance of AgroPlus® may also be associated with improvements in droplet spectrum characteristics. According to Basilio et al. (2024), adjuvants capable of increasing the Volumetric Median Diameter (VMD) and reducing the proportion of fine droplets significantly decrease drift potential while maintaining adequate target coverage. These authors observed that suitable adjuvant formulations increased droplet uniformity, reduced Relative Span values, and promoted greater deposition efficiency, characteristics that

are consistent with the spray quality parameters observed in the present study.

The spray quality parameters obtained in Figure 3 reinforce this interpretation. The greater sample coverage and deposition volume associated with AgroPlus® indicate more efficient distribution of the spray solution over the target surface. Simultaneously, the reduction in drift risk potential suggests that the adjuvant promoted a more homogeneous droplet spectrum, reducing the production of droplets highly susceptible to environmental transport. Similar findings were reported by Basílio et al. (2024), who demonstrated that adjuvants based on oils and polymers can substantially reduce drift losses while improving droplet deposition.

From a statistical perspective, the differences observed among treatments became more pronounced during the later evaluation periods. While all adjuvant-containing treatments improved weed control compared with the treatment without adjuvant, AgroPlus® consistently presented the highest desiccation values. At 28 DAA, weed control reached 75.25% with AgroPlus®, whereas the treatment without adjuvant achieved 67.20%, representing an increase of approximately 11.98% in control efficiency. This difference is agronomically relevant because weed populations in advanced reproductive stages generally exhibit greater tolerance to herbicides due to reduced translocation and increased structural barriers to herbicide penetration (Piasecki et al., 2020; Rodrigues et al., 2024).

The predominance of difficult-to-control species in the experimental area, including *Digitaria insularis*, *Eleusine indica*, *Commelina benghalensis*, and *Ipomoea grandifolia*, may also explain the moderate control levels obtained (Ferreira et al., 2024; Takano et al., 2020). Several studies have demonstrated that perennial grasses and broadleaf weeds at advanced developmental stages require optimal spray coverage and deposition to maximize herbicide efficacy. In such situations, improvements in application technology often become as important as the herbicide itself (Daramola et al., 2022; Guimarães et al., 2019; Piasecki et al., 2020).

The aerial application results revealed a different behavior. Although improvements in spray quality parameters were observed, the gains in weed control were less pronounced than those recorded under ground application. This finding is expected because aerial applications typically operate with lower spray volumes, increasing the dependence on droplet spectrum characteristics and environmental conditions. Studies evaluating aerial spraying have shown that drift reduction adjuvants improve deposition and reduce off-target movement; however, these improvements do not always translate into significant increases in biological efficacy when herbicide deposition on the target is already sufficient for weed control (Basílio et al., 2024; Henry et al., 2016).

Furthermore, the reduction in drift risk potential observed in the present study has important environmental implications. Recent research has demonstrated that adjuvants capable of modifying droplet formation mechanisms can reduce drift losses by up to 50%, contributing to greater application efficiency and minimizing environmental contamination risks. Such characteristics are particularly relevant for aerial applications, where meteorological conditions exert a stronger influence on droplet behavior (Basílio et al., 2024; Xue et al., 2024).

Overall, the results demonstrate that the benefits of AgroPlus® were not limited to improvements in physicochemical spray characteristics but also translated into greater weed desiccation efficiency, especially under ground application conditions. The association between increased deposition, reduced drift potential, and improved droplet spectrum characteristics highlights the importance of selecting appropriate adjuvants as part of integrated weed management strategies (Basílio et al., 2024; Castro et al., 2018; Daramola et al., 2022; Tavares; Cunha, 2023). One limitation of the present study is that evaluations were conducted under a single set of environmental conditions and herbicide combinations. Additional investigations involving different climatic scenarios, spray volumes, and weed communities may contribute to a broader understanding of the interactions between adjuvants and herbicide performance.

5. Conclusions

The use of adjuvants enhanced the desiccation efficiency of difficult-to-control weed species by improving spray deposition and application performance. Among the evaluated products, AgroPlus® demonstrated superior spray quality, characterized by increased droplet deposition, reduced drift risk, and greater application efficiency. Under ground application conditions, AgroPlus® consistently provided the highest weed control performance throughout the evaluation period, representing the most effective treatment among the tested adjuvants. In aerial applications, although AgroPlus® improved spray characteristics and operational quality, its contribution to weed control efficiency was comparable to that of the other adjuvants, with no substantial differences observed in final control levels. Overall, the results indicate that AgroPlus® is a promising adjuvant for herbicide applications, particularly in ground spraying systems, where its benefits on spray quality translated into greater control

effectiveness and operational reliability.

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7. Authors' Contributions

Igor Assoni Oliveira: conceptualization, methodology, investigation, data curation, formal analysis, writing – original draft. *Gabriel Aumeira Lemes*: investigation, data curation, formal analysis, visualization, writing – review & editing. *Christiano Lima Lobo de Andrade*: co-supervision, methodology, validation, formal analysis, writing – review & editing. *William Ferreira da Silva*: resources, methodology, validation, writing – review & editing. *Vitor Moreira Guimarães*: resources, methodology, validation, writing – review & editing. *Marconi Batista Teixeira*: resources, data curation, validation, writing – review & editing. *Fernando Rodrigues Cabral Filho*: supervision, project administration, conceptualization, funding acquisition, formal analysis, writing – review & editing.

8. Conflicts of Interest

No conflicts of interest.

9. Ethics Approval

Not applicable.

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