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CONTROL OF *Eriochloa villosa* (Thunb.) Kunth, AN EMERGING THREAT TO SILAGE CROPS: A POT CULTURE STUDY

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Eriochloa villosa, an invasive Poaceae weed species, is an increasingly problematic pest in agricultural fields. In this study, the efficacy of 19 herbicide treatments applied in three replicates as formulations in various application rates and presence or absence of adjuvants was evaluated against E. villosa in an outdoor pot trial located in Giarmata, Romania. Three visual assessments were carried out every week after the single post-emergence application and inferential statistical analyses showed significant effects of treatments, assessment dates and their interactions ($p < 0.001$). Efficacy increased over time for most treatments, although those based on Propaquizafop, Clethodim and Cycloxydim provided the highest control, several variants already reaching total control by the second assessment, for both homologated rates as well as higher doses. Quizalofop-P-ethyl and Fluazifop-P-butyl also provided high control, while the others only reached a moderate amount of control. Our findings indicate that out of the tested formulations, those based on ACCase inhibitors performed the best, showing promising option for management strategies of E. villosa, although field trials are still needed to further investigate their effect in natural conditions.

Key words: *chemical control, phytotoxicity, Poaceae, post-emergence, treatment performance.*

INTRODUCTION

Eriochloa villosa (Thunb.) Kunth 1829, commonly known as the woolly cupgrass, is a grassy weed species part of the Poaceae family, native to East Asian countries (Shhagapsoev et al., 2018). It was first officially reported as an invasive species in the 1940s in the United States of America and by the 1980s deemed a problematic species of economic importance (Darbyshire et al., 2003). In Romania, *E. villosa* is increasingly present in agricultural fields, competing intensively with other crops and native flora, with both researchers and farmers raising awareness of its detrimental effects (Lele et al., 2025).

Although there are several studies that focus on the control of *E. villosa* published before year 2000, many of those tested herbicides are no longer approved for usage and, although a surge of new papers are being recently published on *E. villosa*, only a fraction of these focus on its chemical control (Lele et al., 2025). As such, it is necessary to assess the efficacy of as many prospective herbicides against *E. villosa* to develop a proper management program that could prevent its spread and diminish its economic impact.

Due to the negative impact herbicides have upon environmental and human health, the creation of new active ingredients, as well as formulae and premix improvements of already known, reliable approved herbicides was necessary in order to create more sustainable and efficient management programs (Parven et al., 2025). Many of those formulations were not tested against *E. villosa*, which creates a relevant knowledge gap (Lele et al., 2025).

While it may be found on disturbed land as well, *E. villosa* impact is most relevant on cultivated farmland and, as such, selecting herbicides that are safe for crop application as well as efficient is pivotal (Lele et al., 2025). Several modern herbicidal agents tested against *E. villosa* are part of the lipid synthesis (ACCase) inhibitor group (HRAC 1) and are generally efficient in controlling early developmental stages of this species (Cui et al., 2021; Guo et al., 2014; He et al., 2013; Lele et al., 2025). Another relevant HRAC group is 2, with acetolactate synthase (ALS) enzyme inhibitors. Although one of the most known active ingredients tested against it, Nicosulfuron, is becoming less effective against certain populations due to developed tolerance (Hinz & Owen, 1996; Ma et al., 2018; Song, 2022). Although Glyphosate, part of Group 9 (5-

enolpyruvylshikimate-3-phosphate, or ESPS, synthase Inhibitors), can be very effective against *E. villosa* even when mature, though it is not suitable for most crop applications because of its non-selective nature, so it is preferred for ruderal weed populations control or genetically modified resistant crop cultures (Nurse et al., 2015; Owen, 2008).

For this experimental trial, several types of herbicides and adjuvants were selectively chosen in order to gain a deeper understanding of the interaction between them and *E. villosa* in a controlled setting in a practical screening trial. A notable mention is that these are often used against weeds in important crops such as corn, sunflower, soybeans and more.

Several already known and tested active ingredients were chosen, whether tested in numerous studies or only once. Nicosulfuron based treatments were used in these trials due to its extensively studied effect against *E. villosa*, making it relevant as a point of reference in comparison to newly tested active ingredients (Lele et al., 2025; Ma et al., 2018). Three other active ingredients, all part of HRAC Group 1, Clethodim, Quizalofop-P-ethyl, Fluazifop-P-butyl, that were previously tested in two trials based in China were also chosen for their reported success in their control and modern composition, as well as to further study their effect in different conditions (Lele et al., 2025).

Two of the treatments consisted of mixes of pre-emergent and post-emergent active ingredients: S-metolachlor (HRAC 15, pre-emergent) in only one treatment, and Dicamba (HRAC 4, pre- and post-emergence), Mesotrione (HRAC 27, pre- and post-emergence) and Nicosulfuron in both. These are characterized by their efficacy both as pre- and post-emergence herbicides and were chosen specifically to observe their effect on *E. villosa*, as numerous farmers choose to apply mixed substances to protect their cultures as early as possible against a larger spectrum of weed species, which created a need to know of their reliability as a prospective choice (Carles et al., 2017; Morokhovets et al., 2024; Young & Hart, 1999).

Three HRAC group 1 herbicides (Propaquizafop and Cycloxydim) were chosen due to their successful control of other species within the same taxonomic family, as well as because no other research was performed to test the efficacy against *E. villosa* (Ohta et al., 2025; Raju, 2010; Willoughby & Forster, 2022).

We chose to study various dosage rates to observe their evolution in time as well as the response of *E. villosa*. Adjuvants *Silwet Gold* and *Dash* were chosen for several reasons, most important being that they are often commercialized and sold together with the treatment products that they are paired with. Adjuvants are also important in trials as observing treatments with or without them is relevant for management strategies or further studies (Brankov et al., 2025).

RStudio (version 2026.01.0, Build 392), based on the open-access R programming language, was used to conduct all data analyses and create figures due to its ready availability, wide community support and vast popularity among researchers, as well as because of its highly reliable data analysis, customizable data representations and visualizations (Del Toro et al., 2022; R Core Team, 2024).

The main objective of our study is to assess the control of 19 treatments that consist of various doses and adjuvants against *E. villosa*, with an aim to fill existing knowledge gaps within the field. We evaluate several modern active ingredients and commercial premixes never before tested against this species and published officially. The trial took place outdoors in Giarmata, Romania, using pots for a more controlled environment and 3 repetitions. Efficacy was visually assessed every week after the application of the treatments (7, 14 and 21 DAA), a timing based on common practices. Factors that affected the final rating for each treatment included the presence of chlorosis, necrosis and stunted growth. We hypothesize that every chemical treatment will present a significantly higher efficacy than untreated control. While several active ingredients present in this trial were not tested against *E. villosa* in the past, they are well appreciated in other trials against grasses and it is hypothesized that they will show additional differences when an adjuvant or higher doses are used within groups of the same active ingredient compared to lower application rates during the first and second assessment dates, at 7 DAA and 14 DAA. For the end of the trial, we hypothesize that the most efficient active ingredients will reach high control, regardless of dosage or adjuvant use.

MATERIALS AND METHODS

The experimental trial was located in Giarmata, Timiș County, Romania, in outdoor conditions. Environmental data on temperature, humidity and precipitation during the trial were acquired via DTN LLC and collected from May 16th 2023 to July 21st 2023 for this area (Figure 1).

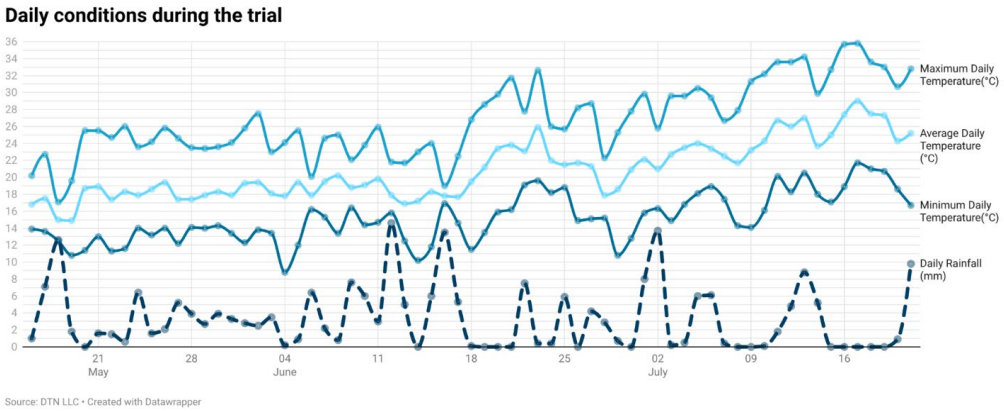


Figure 1. Visual representation of the maximum daily temperatures, average daily temperatures, maximum daily temperatures as well as daily rainfall during the period of the trial, starting from the 16th of May until the 21st of July. Each dot along the lines represents a day. Created using datawrapper.de

In May, temperatures were an average of 17.7°C, a minimum average of 12.9°C and a maximum average of 23.6°C. Rainfall averaged 3.5 mm per day, with a total of 54.3 mm. In June, temperature averaged at 19.9°C, with an average minimum of 14.5°C and an average maximum of 25.4°C. Rainfall averaged 3.4 mm per day, with a total of 102.4 mm. In July, temperatures averaged at 24.6°C, with a minimum average of 17.8°C and a maximum average of 31.4°C. A graphic visualization of the weather data may be seen in figure 1.

Seeds were collected in 2022 from infested fields surrounding Topolovățu Mic village, Timiș county, Romania and properly stored in glass jars covered by a breathable textile in dry conditions at constant room temperature. They were not treated prior to usage. Before sowing, black plastic pots with a height of 15 cm and diameter of 20 cm were prepared and filled with an equal combination of mixed *TS3 Fine Klasmann* and *BIO Plantella START* commercial seedling soils. Besides naturally occurring water from precipitation, the pots were watered as necessary for a uniform development of all plant individuals, every 2 to 3 days and natural direct sunlight was available until 2 to 3 PM, until the area was shaded by neighboring buildings, thus maintaining a more appropriate temperature for the potted plants, as black pots are susceptible to overheating.

On May 16th 2023, 5 seeds were sown per pot at 2 cm depth and all pots were watered afterwards. Emergence started on May 23rd and by May 29th all final seedlings emerged. Each pot contained an average of 3 to 5 seedlings by the start of the application timing, which was conducted on June 19th, when the seedlings' developmental stages ranged from 3 leaves to one emerging tiller. The herbicide treatments were applied at a rate of 200 L/ha using a battery powered hand sprayer with a cone nozzle at 1.2 bar pressure. The application volume per pot was calculated based on the pot surface area of 314.16 cm^2 (with 6.283 ml needed per pot), delivered at 1.1 seconds of application at 35 cm above the pot. The recipient was cleaned between each treatment application. The subsequent assessments each took place on June 26th, July 3rd and July 10th. The complete list of treatments, products, active ingredients and applied rates are presented in Table 1.

Table 1. List of all 20 treatments, condensed into two adjoined tables

Trt. No.	Active Ingredient(s)	Dose	Trt. No.	Active Ingredient(s)	Dose
1	**Propaquizafop 100 g/l**	1 l/ha	**12**	**Clethodim 120 g/l**	1 l/ha
2	**Propaquizafop 100 g/l**	1.5 l/ha	**13**	**Clethodim 120 g/l**	1.5 l/ha
3	**Propaquizafop 100 g/l**	2 l/ha	**14**	**Clethodim 120 g/l**	2 l/ha
4	**Propaquizafop 100 g/l**	1.5 l/ha	**15**	**S-metolachlor 960 g/l**	1.5 l/ha
	adjuvant	0.1 l/ha		**Dicamba 312,5 g/kg**	0.5 kg/ha
5	**Quizalofop-P-ethyl 50 g/l**	1.5 l/ha		**Mesotrione 150 g/kg**	
6	**Quizalofop-P-ethyl 50 g/l**	2 l/ha		**Nicosulfuron 100 g/kg**	
	adjuvant	0.1 l/ha	**16**	**Cycloxydim 100 g/l**	2 l/ha
7	**Nicosulfuron 40 g/l**	1.5 l/ha		**adjuvant**	2 l/ha
8	**Nicosulfuron 40 g/l**	1 l/ha	**17**	**Cycloxydim 100 g/l**	4 l/ha
	adjuvant	0.1 l/ha	**18**	**Cycloxydim 100 g/l**	1 l/ha
9	**Fluazifop-P-butyl 150 g/l**	1 l/ha		**adjuvant**	1 l/ha
10	**Fluazifop-P-butyl 150 g/l**	1 l/ha	**19**	**Dicamba 312,5 g/kg**	0.6 kg/ha
	adjuvant	0.1 l/ha		**Mesotrione 150 g/kg**	
11	**Fluazifop-P-butyl 150 g/l**	1.3 l/ha		**Nicosulfuron 100 g/kg**	
			20	Control	-

The control of 8 active ingredients and 2 adjuvants under commercial formulations was tested against *E. villosa* during this trial. The herbicidal formulation mixes used were Propaquizafop 100 g/l, Quizalofop-P-Ethyl 50 g/l, Nicosulfuron 40 g/l, Fluazifop-P-Butyl 150 g/l, Clethodim 120 g/l, S-metolachlor 960 g/l , Dicamba 312.5 g/kg + Mesotrione 150 g/kg + Nicosulfuron 100 g/kg together and Cycloxydim 100 g/l. The adjuvants were *Silwet Gold* and *Dash*. Adjuvants were used according to popular usage trends in the local area. Each herbicidal product was tested in one or several rates with or without a compatible adjuvant None of the Clethodim treatments were combined with adjuvants. We used approved doses, as well as higher doses, in order to observe their effect on *E. villosa* and the time required for them to reach full control.

The experimental setup consisted of 3 repetitions of 20 treatment variants, with a total of 60 experimental pots. Each pot was treated separately to avoid drifting, with the sprayer being thoroughly washed between each variant. Treatment number 20 was the control and left untreated. Treatments and doses are represented in Table 1, and the European Union non-approved rates highlighted and noted in the description, and should not, under normal circumstances, be applied on normal fields. Pot placements were systematic, in a grid layout of 3 rows by 20 columns, with variants in a succeeding sequence. Given that randomization was not employed, replicates were included as a random effect in the statistical linear mixed effects model, which ensures that treatment comparisons were made within rather than across replicates. A likelihood ratio test confirmed the replicate effect was statistically significant (χ^2=28.607, df=1, p<0.001), which indicates that between replicate variance was partitioned from the residual error. While this approach does not fully compensate for the lack of randomization, it represents a post-hoc statistical control for the systematic placement used.

Control assessments were carried out visually across 3 different timings: 7, 14 and 21 days after application. Signs of chlorosis, necrosis, bleaching, distortion and stunted growth were taken into consideration for a final assessment score ranging from 0 to 100 based on the percentage of the affected area, the latter being considered complete control and the plants dead. A statistical analysis was done using RStudio. A preliminary data visualization was completed by creating boxplots representing the comparison between treatments by day of assessment using the "ggplot2" package (Wickham, 2016). A linear mixed-effects model was used, which takes into consideration both the main factors (treatment and assessment date) and the random environmental variation, represented by the 3 replicates. A Type III ANOVA was done to determine whether there were significant effects or interactions between factors. We chose this particular analysis partly due to the heterogeneous nature of our biological data, but mainly because of the statistically significant interactions between the treatments and days of assessment (Kuznetsova et al., 2017; Satterthwaite, 1946). The analysis was implemented using the "lme4" and

"lmerTest" R packages using Satterthwaite's approximation for degrees of freedom for mixed-effects models.

To identify which treatments differed significantly, the estimated marginal means was calculated and adjusted for each treatment to represent their performance as though all other factors were constant. Every treatment is compared to all others for each of the 3 assessment days. To avoid risks of false positives and keep a high level of confidence, the Šidák adjustment was applied to *p*-values (with α=0.05) (Sidak, 1967). This analysis was performed using the "emmeans" R package (Lenth & Piaskowski, 2025).

The estimated marginal means efficacy percentages were represented numerically in a table using the "gt" package. For graphic representations, treatments were organized into groups of statistical significance so that if the difference is not statistically significant, they are assigned the same letter. This was represented via "ggplot2" using the "multcomp" and "multcompview" R packages as basis for data analysis (Hothorn et al., 2008).

RESULTS AND DISCUSSIONS

Results

A Type III analysis of variance (ANOVA) was performed to assess the statistical significance of the results by treatment, assessment date and ultimately, by their interaction.

The ANOVA confirmed our hypothesis that there are significant differences between the 20 treatments (F = 112.74, $p < 0.001$), as well as between the 3 assessments taken at 3 separate dates after the treatment application (F = 1577.18, $p < 0.001$). A significant interaction was also observed between treatment types and assessment timings (F = 12.74, $p < 0.001$), meaning the relative treatment efficacy is very dependent on the time duration between the time of application and date of assessment (Table 2). The model used accounted for variation or block effects. Because these two factors present significant differences among themselves, as well as within their interaction, the results are statistically significant and will be described as well as further statistically investigated.

Treatment types by herbicidal substance are described in this section as qualitative categories for an easier understanding of the active ingredients and their effect against *E. villosa*, though they were not included as statistical factors due to dosage and rate heterogeneity among them. Treatment means data and their visualization as boxplots are found in Table 3 and Figure 2, respectively. Means are represented by the results of the mixed-effects model statistical analysis, with a pooled standard error of 3.9.

Table 2. ANOVA of the estimated marginal mean (EMM) efficacies of the 20 treatments across the assessment days

Type III ANOVA							
Experimental Factor	Sum Sq	Mean Sq	Df1	Df2	F-value	P-value	Sig
Treatment	79610.55	4190.03	19	118	112.74	1.58×10^{-66}	***
Assessment Day (DAA)	117234.44	58617.22	2	118	1577.18	7.31×10^{-86}	***
Treatment x DAA	17987.79	473.36	38	118	12.74	6.11×10^{-27}	***

Experimental Factors: `Treatment` represents the 20 application variants; `Assessment day (DAA)` represents the time intervals (7, 14, 21 days). Significance levels (a = 0.05): *** p< 0.001, ** p<0.01, * p<0.05, p<0.1; `ns`=not significant (p> 0.05). Degrees of freedom calculated using Satterthwhaite's approximation for mixed effects models.

Values represent the predicted efficacy resulting from a linear mixed-effects model using the Satterthwaite approximation for degrees of freedom. EMMs are adjusted for the fixed effects of treatments, assessment dates and their interaction.

Table 3. Estimated marginal means of the efficacy of the 20 treatments over the 3 assessment dates

Mean Efficacy (%) per Treatment (*DAA = Days after application; 1-20: Treatments*)																			
DAA	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
7	43.3	33.3	30	36.7	13.3	43.3	10	16.7	13.3	16.7	30	36.7	23.3	36.7	30	56.7	66.7	23.3	26.7	0
14	100	100	96.7	100	63.3	96.7	26.7	40	56.7	53.3	86.7	96.7	100	100	60	100	100	100	76.7	0
21	100	100	100	100	86.7	100	53.3	76.7	93.3	90	96.7	100	100	100	76.7	100	100	100	93.3	0

Note: Values are estimated marginal means. Pooled Standard Error (SE) = 3.9

The values are derived from a linear mixed effects model used in the ANOVA. They are adjusted for the fixed effects of treatments and assessment days as well as by their interaction (which is significant at (p < 0.001). Data shows that the efficacy of the treatments changed significantly over time.

Propaquizafop 100 g/l was used in 4 treatments (T1 through T4). During the first assessment (7DAA), the best treatment was T1, with 43.3% control. During the second assessment (14DAA), every treatment provided a control of over 96.7%, with T1, 2 and 4 reaching full control. By the time of the last assessment, all Propaquizafop treatments reached full control.
Quizalofop-P-ethyl 50 g/l was used in 2 treatments (T5 and T6). There were notable differences between them throughout the trial, with T6 reaching 43.3% control during the first assessment, 96.7% during the second and eventually 100% by the last, while T5 reaching only up to 86.7% control on the last assessment.
Nicosulfuron 40 g/l was used in 2 treatments (T7 and T8). While there were differences between treatments, neither achieved full control, with a maximum efficacy of 76.7% at 21DAA, for T8.
Fluazifop-P-butyl 150 g/l was used in 3 treatments (T9 through T11). Their efficacy was between 13.3% and 30% during the first assessment, between 53.3% and 86.7% during the second and finally between 90% and 96.7% on the last, with T11 having the highest efficacy of all, especially during the first two assessments.

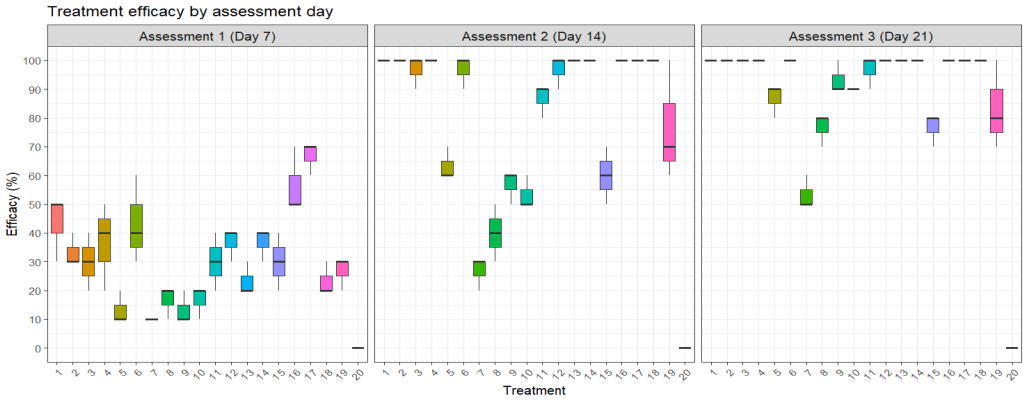


Figure 2. Boxplot graphic of the efficacy of all treatments (from 1 to 20, x-axis, horizontal) by day of assessment (7, 14 and 21 days after the treatment application, y-axis, vertical). An upward evolution is observed in most treatments except for 20, the control

Clethodim 120 g/l was used in 3 treatments with an efficacy of between 23.3% and 36.7% during the first assessment (7DAA), followed by a significant increase starting with the second assessment, of between 96.7% and 100%. By the last assessment, all treatments reached full control. Overall, T14 provided the best control throughout the assessments.
Cycloxydim 100 g/l was used in 3 treatments (T16 through T18). Efficacies ranged from 23.3% to 66.7% during the first week, with T17 having the highest efficacy at this time, followed by full control on all subsequent assessments.
Significance groups were determined using a mixed-effects model inference with multiplicity-adjusted pairwise comparisons using the Šidák correction. Two groups are considered statistically different when the adjusted *p*-value characteristic of a certain pair is lower than α=0.05. Thresholds between groups are visually represented in Figure 3 by using letters. If two treatments share at least one letter, they are not significantly different, while two treatments that fall within completely different letters groups are considered statistically different, as they pass the α=0.05 threshold.
On the first assessment date, 7 days after the application, grouping by letter ranges from A through H, as the herbicides behave very differently from one another. Letter H contains the treatment T17 with the most efficient control against *E. villosa* at this time. In group G, Treatments T1, T6 and T16 (both in G and H), the second most successful treatment group. On the other hand, letter A contains the treatments with the least amount of control, with results that were not significantly different even compared to the control (also part of A).

On the second assessment date, 14 days after the application, significance groups are reduced as a result of less significant differences between treatments. Group H disappears and G takes its place as the one containing the most efficient treatments, with T1 through T4, T6, T12 - T14 and T16 - T18 presenting the highest efficacies. T11 is part of both groups F and G. Group B containing T7 and T8 is the least efficient treatment, besides the control, A.

During the last assessment date, 21 days after the application, many groups are converged due to increasingly more similar effects against the target weed species, with treatments T1 - T4, T6, T11 - T14 and T16 - T18 are part of letter group D, with the best results, while the following most efficient, though part of both groups C and D, are T5, T9, T10 and T19. B remains the weakest treatment at this date as well, though at this time only T7 remains part of the group.

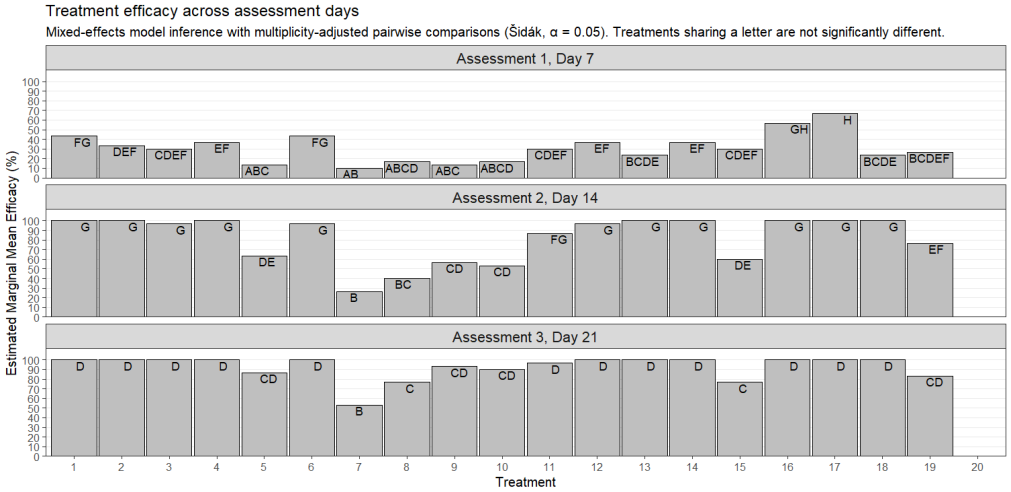


Figure 3. Estimated marginal mean efficacy of the 20 treatments over the 3 assessment dates (7, 14 and 21 days after application). The predicted mean efficacy based on a linear mixed effects model accounting for the two factors as well as environmental variation represented by replicates is visualized in bars. Statistical groupings were determined by the Sidak adjusted pairwise comparisons, where ($\alpha = 0.05$) and treatments with the same letter in the same assessment day are not significantly different. Treatment 20 is the control

Discussions

In this study, we demonstrated the efficacy of several herbicide treatments against the invasive weed species, *E. villosa,* in a pot trial experiment.

By the end of the experimental period, Propaquizafop, Clethodim and Cycloxydim treatments showed excellent results against the studied weed species as soon as the second assessment date, and full control by the last assessment date. They are approved for use on both soybean and sunflower crop cultures, though not in corn. Results provided by the Clethodim application are similar to that of another published trial, albeit under a different formulation (He et al., 2013).

Quizalofop-P-Ethyl and Fluazifop-P-Butyl had excellent control over *E. villosa*, both with over 95% control when at the highest application rate. They are approved for use on sunflower crop cultures. Treatments 15 and 19, comprising mixes of pre- and post-emergence herbicidal ingredients, provided good control, of between 76.7 and 83.3% at 21DAA. They are approved for use on sunflower and corn fields.

Treatments that included Nicosulfuron only performed the poorest, with a range of 53.3% and 76.7% (lower rate combined with an adjuvant) at 21DAA, though still within an acceptable control range. This active ingredient is approved for use on corn. While certain Asian populations were revealed to have become resistant to Nicosulfuron, it is not known whether this is the case for Romanian ones, as no prior investigations on the subject were conducted up to now (Ma et al., 2018).Differences between the treatments using ACCase inhibitors (Propaquizafop, Quizalofop-

P-ethyl, Fluazifop-P-butyl, Clethodim and Cycloxydim) and the ALS Nicosulfuron are significant, even though both modes of action are well known to affect seedling development and growth (Jhala et al., 2026; Whitcomb, 1999). A potential explanation for this difference may be due to the tolerance of *E. villosa* to Nicosulfuron, which was already documented in scientific literature, and which operates on two levels, its inherent biochemical capacity to partially hydroxylate it via its microsomes, and an evolutionarily acquired tolerance which was observed in certain populations following excessive Nicosulfuron applications (Hinz & Owen, 1996; Jhala et al., 2026; Lele et al., 2025; Ma et al., 2018; Song, 2022).

A caveat to the interpretation of our study is the presence of limitations such as those imposed by the nature of the experiment, as the number of weed individuals in each pot were low in number, and so, their growth stage heterogeneity could have had an important effect upon the results (Ogunkunle & Beckett, 1988). Another is the fact that randomization was not used for this trial, although measures were taken for all of the pots to be in the same condition. While most were of similar growth stages, they still varied between 3 to 5 leaves at the application timing, which is known to lead to different responses to herbicides, especially if tillers have emerged, as well, which was the case for several individuals (Barros et al., 2007). Another significant factor is that the experiment was not conducted in a greenhouse, but outside, in an open area, and placed in a non-randomized manner, in order from the first to the last treatment, with replicates in rows. While the pots were regularly watered and maintained, increasingly hot summer temperatures present by the end of the trial are very likely to have enhanced the later effect of herbicides, possibly in slightly unequal measure due to placement, which lead to an additional stress the plants had to face (Varanasi et al., 2016). These limitations might explain the differences between certain groups of active ingredients where the higher dosage had an initial lower effect upon *E. villosa*, such as for Propaquizafop, though quickly reaching the same level of statistical significance.

Despite abovementioned limitations, the overall trend of the treatments was very clear, with mostly excellent results, especially for the never before tested herbicidal ingredients Propaquizafop and Cycloxydim which, regardless of environmental or experimental factors, showed a decisively strong control effect throughout the trial for all application rates, with or without an adjuvant. These consistently positive results may be explained by the fact that they strongly target grassy species such as Poaceae members and have such a strong effect upon this family that they are not even approved for use on corn, as it would destroy the crop alongside the grassy weeds. Clethodim showed similarly excellent results.

Great control is also shown by the highest rates of Quizalofop-P-Ethyl and Fluazifop-P-Butyl, results that are similar to that of the two previous studies that tested their efficacy against this same species, which noted the full control of early applications (Guo et al., 2014; He et al., 2013). Their lower performance may be explained by the fact that the growth stages of the weed individuals in this trial were higher than in the original paper. The difference in efficacy between T5 (86.7%) and T7 (100%) may be due to the combination of higher application rate and the addition of the adjuvant, but since both treatments differ simultaneously in both application rate and adjuvant presence, the experimental design does not allow the two effects to be separated statistically.

Corn approved herbicidal ingredients Nicosulfuron, showed results similar to that of previous research, being highly dependent on application timing and the growth stage of the weed species. As they are specifically created for use on corn, these ingredients do not exhibit the same strong effect as the ones above, though often perform well in double application combinations (Lele et al., 2025).

T19 performed better than T15, and while T19 had two active ingredients, S-metolachlor is a strictly pre-emergent herbicide and had no effect upon the already emerged and growing young plants. In any case, care should be taken that herbicide dosage is not exceeded for applications, as their effect upon cultivated crops can seriously stunt their development, as well as may have a negative impact on the environment.

Even though corn is one of the most sensitive crops when competing against *E. villosa* for

resources, we chose to study new herbicides that are only approved to use on sunflower and soybean fields for several reasons. The main reason was the fact that most are either understudied or not officially studied at all against this species, and we decided this knowledge gaps are worth investigating further. Another reason is the fact that we believe it is important to adopt integrated control methods, which include crop rotations including dicots such as the sunflower and soybean in weed management plans, with the double effect of a stronger herbicide applied and the disruption of the normal development timings of weeds such as *E. villosa* by the yearly crop change. Our findings are relevant in the light of newer and harsher regulations imposed by various countries, which may force farmers to change their preferred herbicides in favor of newer, more environmentally friendly ones. Data strongly suggests that regardless of the doses we used, the results are still satisfying, and so reducing the application rate may also be a viable economic choice farmers could adopt, as all treatments applied below the maximum approved rate had efficacies of over 76.7% and up to 100% control. Although this trial revealed relevant information regarding the chemical control potential of the tested active ingredients, it is still a controlled pot trial and thus should be followed by larger scale field trials, so that the response of crops to both the competition against *E. villosa*, and to the application rates may be studied and better understood. Future field based studies are especially important as the heterogeneity of the studied weed species is greatly reduced, especially if the trial grounds are carefully chosen for their population density homogeneity. Of equal importance is that application rates, as well as the addition or absence of adjuvants, are further studied, especially in experimental designs that carefully consider statistical analyses that allow regression modelling, which may be of great use in predicting the effect of even smaller doses and in planning weed management protocols.

CONCLUSIONS

In our pot trial study, the efficacy of several herbicidal ingredients applied as commercial products with or without adjuvants was studied against *E. villosa* in an outdoor environment. Overall, the most efficient herbicides were those belonging to the HRAC Group 1, the ACCase Inhibitors, regardless of dosage or the addition of adjuvants. Propaquizafop, Clethodim and Cycloxydim, never tested against *E. villosa* in an experimental trial, performed the best, with some treatments reaching full control as soon as the second assessment. While not approved for use on corn, one of the most susceptible crops to resource competition against *E. villosa*, they are approved on sunflower and soybean fields. They may be used successfully both as part of a management plan including crop rotation, as well as offering flexibility in herbicide usage alongside those used on monocot crops such as corn and cereals.

The results of this study should be considered indicative of their potential rather than fully predictive of their performance in fields. Future studies should include a broader range of dosages and adjuvants, as well as both pre- and post-emergence herbicides in field conditions. Competition dynamics studies between *E. villosa* and crop cultures are also necessary for their better understanding and development of more effective management strategies.

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