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ANALYSIS OF THE EFFICACY OF MCPA HERBICIDE IN THE CONTROL OF *Convolvulus arvensis* and *Chenopodium album* IN FLAX CROPS

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Abstract

Linum usitatissimum is a valuable crop with food and industrial significance, yet its production is often reduced by biotic and abiotic factors, particularly weed competition. This study focused on the chemical control of Convolvulus arvensis and Chenopodium album in flax crops, aiming to determine the optimal dose of MCPA 750%. Four doses (0.16, 0.21, 0.27, and 0.33 l/ha) were tested in Western Romania, with evaluations conducted 14, 28 and 42 days after application (DAT). The results of this study showed that the two species had similar responses to the action of the MCPA herbicide. The population reduction of the two species, from the flax agroecosystem, was influenced by the applied dose and the time interval. The MCPA herbicide had maximum efficacy at 28 DAT. Good effectiveness was registered in the variants treated with MCPA 0.27 l/ha and 0.33l/ha. As a result of the relatively small differences between the two doses, as well as the phytotoxicity observed in the plots treated with the 0.33 l/ha dose, it is recommended to use the 0.27 l/ha MCPA.

***Key words**: Convolvulus arvensis, Chenopodium album, MCPA, Linum usitatsimum, chemical control.*

INTRODUCTION

Linum usitatissimum L. (flax) remains an agricultural crop of global interest due to its use for both seed production and fibre. Flax has numerous applications in the food, textile, pharmaceutical industries. Flaxseeds are recognized as a functional ingredient, rich in omega-3 fatty acids, lignans and dietary fibre, offering nutritional and health benefits (Popa et al., 2012), and flaxseed fibres are appreciated for their stability in use, the comfort they provide to textiles and their high biodegradability, contributing to the development of "green" value chains in the European Union (Nowak et al., 2023; Stavropoulos et al., 2023, Chishty, S. and Monika, 2016).

According to FAOSTAT data, the harvested area of flax for seed exceeded 3-4 million ha worldwide in the last decade, with an increasing trend in 2018-2021, with the main producing countries being Canada, Russia, Kazakhstan, China and some European states (Yaşar and Yetişshin, 2023).

Romania has historically played a significant role in flax production, reaching in the last decades of the twentieth century about 70-80 thousand ha, supported by a national fibre processing industry. However, after 1990, economic reset, the loss of industrial capacity, the orientation of farmers towards more profitable crops and the decline in domestic demand led to a drastic reduction in cultivated areas. The statistical data available for the period 1990-2008 confirm this contraction (Panaitescu et al., 2010), and after 2015 flax is no longer reported separately in the official statistics of the INS (https://insse.ro/cms/ro/tags/comunicat-productia-vegetala-la-principalele-culturi), which indicates the maintenance of the crop at a marginal, niche or experimental level. Paradoxically, the revival of global interest in natural fibres, bioindustries and premium vegetable oils could offer Romania strategic advantages, given its agricultural tradition, technological experience, favourable pedoclimatic conditions and potential for integration into European green value chains.

In this context, the reanalysis of the agronomic, economic and technological importance of flax, as well as the identification of the necessary conditions for the revitalization of this crop in

Romania, become relevant objectives for contemporary agricultural research, rural development and the transition to sustainable agri-food systems.

Under these circumstances, global germplasm collections highlight considerable genetic diversity that can support the adaptation of the crop to varied pedoclimatic conditions, including in Central and Eastern Europe (Diederichsen and Richards, 2003; Kaur et al., 2023).

However, the productive potential of flax is rarely achieved under production conditions, due to the complex interaction between abiotic factors (drought, extreme temperatures, inadequate fertilization) and biotic factors, among which weeds represent one of the most persistent and costly constraints (Zimdahl, 2018; Harker and O'Donovan, 2013). Flax is recognized as a crop that is poorly competitive with weeds, especially in the early stages of vegetation, due to its slow growth rate, erect architecture, and narrow leaves, which allows weeds to intercept a large proportion of light, water, and nutrient resources (Stevenson et al., 1996; Mühleisen, 2000; Stavropoulos et al., 2023). Recent studies indicate that weed interference can reduce flax production for seed by about 10-30% or even more, depending on the density and composition of the weed flora, cultivation technology, and local climatic conditions (Friesen, 1986, cited by Kurtenbach et al., 2019; Çiğnitaş, 2023).

In temperate regions of Europe, including the flax-cultivated area of western Romania, the species *Convolvulus arvensis* L. (bindweed) and *Chenopodium album* L. (lamb's quarter) are among the most problematic dicotyledonous weeds of arable land (Ștef et al., 2013, Ștef et al., 2017). Weaver and Riley (1982) described *Convolvulus arvensis* as a deeply rooted perennial species, capable of developing perennial root networks, with a remarkable vegetative regeneration capacity and a high longevity of seed reserves in the soil, which explains its persistence in crop rotations and the difficulty of mechanical control (Weaver and Riley, 1982). In addition, voluble stems twist around crop plants (Culhavi and Manea, 2011), reduce photosynthetic efficiency, favour plant fall, and make harvesting difficult. *Chenopodium album* is a phenotypically highly plastic annual species with a prolonged emergence period, high seed production potential, and rapid growth, which gives it a considerable ecological advantage in spring crops (Grundy et al., 2003). Studies frequently indicate *Chenopodium album* among the dominant species, in flax cultivation, associated with significant production losses and decreased fibre quality (Çiğnitaş, 2023; Ozer et al., 2004).

In the context of these pressures, effective weed management is an essential condition for the stability of flax production. Although agronomic measures (increasing seeding density, narrow rows, appropriate rotations) can improve crop competitiveness, in practice, weed control in flax fields relies heavily on herbicides, given the relatively short window in which mechanical interventions are effective and the high risk of mechanical plant damage (Stevenson et al., 1996; Mühleisen, 2000). However, compared to other crops (e.g. rapeseed, sunflower), flax has a limited number of approved herbicides, reflecting the high sensitivity of the crop and narrow margins of selectivity (Mühleisen, 2000; Kurtenbach et al., 2019; Morton et al., 2020). This situation is particularly problematic for the control of perennial or highly competitive species, such as *Convolvulus arvensis* and *Chenopodium album*, for which incomplete control in a single season can lead to rapid re-infestations.

In cereal and crop-based production systems, phenoxycarboxylic herbicides (synthetic auxins) have been a central component of dicotyledonous weed control for more than five decades (Harker and O'Donovan, 2013). 2-methyl-4-chlorphenoxyacetic acid (MCPA) is one of the most used representatives of this group, being applied post-emergent in numerous crops to control broadleaf weeds (Morton et al., 2019; Ștef et al., 2024). MCPA acts as a synthetic auxin, inducing profound growth disorders through uncontrolled elongation of cells, disruption of auxin transport, and changes in vascular tissues, ultimately leading to physiological collapse and death of sensitive weeds (Johnson et al., 2023; Morton et al., 2020). At the same time, registration labels and tolerance studies emphasize that flax has a relatively higher sensitivity to MCPA compared to other crops, and exceeding certain doses or applying at advanced stages of development can induce phytotoxicity (yellowing, delayed ripening, reduced production) (Greenbook, 2018; https://www.saskflax.com/quadrant/media/Pdfs/Flax%20on%20the%20Farm/180427Fla xon_the_Farm-April_2018_Final.pdf).

In addition to selectivity considerations, the use of MCPA is under increasing pressure from an environmental regulatory perspective. The European Union's Farm to Fork Strategy foresees a 50% reduction in the use and risk associated with chemical pesticides by 2030, as well as a 50% reduction in the use of more hazardous pesticides, which implies a strict optimisation of doses and treatment programmes in all crops, including minority crops, such as flax (European Commission, 2020). At the same time, recent reports on weed resistance to auxin herbicides already indicate more than 40 species with confirmed resistance to this group, and the global analysis of resistance cases highlights a gradual increase in the frequency of tolerant biotypes (Heap, 2024; Ghanizadeh and Harrington, 2017, https://www.weedscience.org/summary/MOA.aspx?MOAID=12&utm_source.com). This context underlines the need to define minimum effective doses ('low-input') that ensure a high level of control, while reducing the impact on the crop and the environment.

Although the efficacy of MCPA has been extensively studied in cereal crops and other dicotyledonous systems (e.g., rapeseed, maize in tank-mix mixes), data on the use of this herbicide in flax agroecosystems are relatively scarce, fragmented, and often limited to the conditions of specific regions (Vasilakoglou et al., 2001; Mühleisen, 2000; Morton et al., 2019; Yaşar and Yetişsin, 2023). More importantly, the comparative response of the species *Convolvulus arvensis* and *Chenopodium album* to different doses of MCPA in flax crops, under the pedoclimatic conditions of Central and Eastern Europe, is insufficiently documented, despite the high frequency and economic relevance of these weeds in the region. This knowledge gap limits the development of scientifically recommendations for farmers and advisors, especially in areas where the number of herbicides available is already restrictive.

In this context, the present study aimed to evaluate the efficacy of the herbicide MCPA 750 g L^{-1} applied post-emergently, in four doses (0.16; 0.21; 0.27; 0.33 L ha^{-1}), on the species *Convolvulus arvensis* and *Chenopodium album* in flax culture in western Romania (Carani, Timiş County). Weed control was analysed at 14, 28 and 42 DAA to characterise the temporal dynamics of efficacy and to identify the minimum effective dose that ensures maximum infestation reduction, while minimising risks of phytotoxicity to the crop. The results obtained have the potential to contribute to the optimization of weed management in flax production and to the formulation of strategies for the usability of phenoxy-carboxylic herbicides in modern agroecosystems.

MATERIALS AND METHODS

Site description

The study was carried out in the 2022 growing season in Carani locality - Sânandrei commune, Timiș county (Western Romania).

The altitude of the experimental site was at 117 m, located at the geographical coordinates 45°54'50.2"N 21°09'15.7"E, on a chernozem-type soil (Figure 1).

Figure 1. Geographical location of the experimental field (Carani - Western Romania) (Google Maps, 2025)

The area is characterized by a temperate-continental climate, with an average annual temperature of 12.4ºC and an average annual rainfall of 717 mm, the conditions being favorable for the cultivation of flax for fibers. The average values of precipitation and temperatures during the study period (2022) are shown in Figure 2.

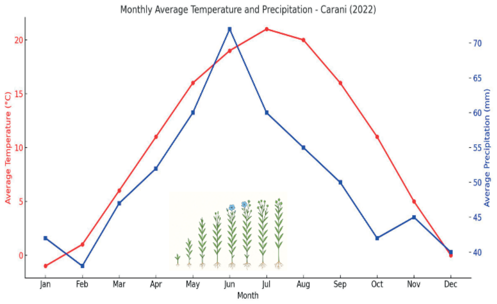


Figure 2. Monthly averages of temperature and precipitation recorded in Carami (Timiș county – Western Romania) in 2022

Biological material

In the present study, the flax variety (*Linum usitatissimum* L.) Attila. Drilling was performed on 02.05.2022, with a sowing norm of 55 kg/ha.

For the development and protection of the flax crop for fibre, ammonium nitrate fertiliser was applied (on May 1, 2022), and to limit pest attack, cypermethrin 100 g L^{-1} (on May 26, 2022) was applied. The cultivation technology was identical for all variants, the differences being generated exclusively by the herbicide regime.

Experimental design

The six experimental variants were organized into randomized blocks, including one untreated control and five herbicide-treated variants, each variant having four replicates. The experimental version had an area of 30 m2 (10 m * 3 m). Between replicates, 1 m paths were made to avoid cross-contamination.

Treatments

The herbicides were applied post-emergence, when flax plants were in BBCH growth stage 13-14 (02.06.2022).

The application was carried out with the back-pack sprayer using compressed air, the volume of water used in the experiment was 300 L $^{ha-1}$.

The following variants have been tested:

V1 – Untreated Control (CHK) (T0)

V2 – Dicopur M (MCPA 750 g L^{-1}) – 0.16 L ha^{-1}(T1)

V3 – Dicopur M (MCPA 750 g L^{-1}) – 0.21 L ha^{-1} (T2)

V4 – Dicopur M (MCPA 750 g L^{-1}) – 0.27 L ha^{-1} (T3)

V5 – Dicopur M (MCPA 750 g L^{-1}) – 0.33 L ha^{-1} (T4)

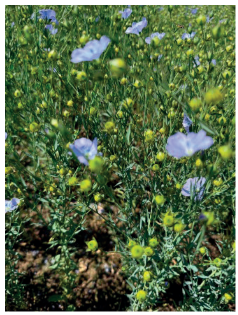
V6 – Cerlite (fluroxipyr-meptyl 250 g L^{-1}) – 1.0 L ha^{-1} (T5)

Determination of the floristic composition and the degree of weeding

The weeding was determined by the quantitative numerical method (a metric frame of 0.25 m^2 was used, it was randomly placed at four points in each variant), the metric frame was randomly placed at four points.

The degree of weeding was determined in: the day before the application of the treatments (01.06.2022), 14 days after application (16.06.2022), 28 days after application (30.06.2022) and 42 days after application (14.07.2022). Thus determining the floristic composition (Figure 3), the abundance and the percentage of soil cover (%).

a



b c

Figure 3. (a) Weeding in the untreated control version (Photo: Ramona Ștef, 2022); (b-c) The appearance of flax culture in the flowering growth stage (Photo: Alin Cărăbeț, 2022)

The efficacy of herbicides was determined using the Abbott formula:

Efficacy after Abbott %= $\left(\frac{C_a - C_t}{C_a}\right) x\ 100$

where:
C_a percentage of infestation is under control,
C_t percentage of infestation in the treated version.

Assessment of phytotoxicity on flax

The phytotoxicity of the products on the flax crop was assessed visually, at the same time intervals (14, 28 and 42 DAA), using **the EWRS scale 1-9**, in which 1 indicates the absence of symptoms, and 9 - severe damage. The following were followed: chlorosis and necrosis of the leaves, growth retardation, deformations of the vegetative organs and reduction of crop cover.

Statistical analysis

For the weed control percentages, factorial ANOVA was applied, with two factors: treatment (T0-T5) and time of evaluation after application (14, 28 and 42 DAA). Each treatment-time combination included four experimental repetitions.

In order to highlight the response of the two species to the applied treatments, ANOVA was used with three factors: the species, the treatment variant and the number of days after application, and the interactions between them were also tested. The analyses were performed based on the sums of squares of type III, and the effect was considered significant at $p < 0.05$.

After identifying the significant differences, the comparison of the means was carried out by the Tukey HSD post-hoc test. All statistical processing was performed using IBM SPSS Statistics software.

RESULTS AND DISCUSSIONS

The mapping carried out on the day before the application of the treatments revealed a spontaneous flora dominated by: *Chenopodium album*, *Convolvulus arvensis, Amaranthus retroflexus*, *Sorghum haelepense*, *Datura stramonium, Xanthium strumarium, Echinochloa crus-galli, Abutilon theophrasti, Polygonum convolvulus*, these being the species with the highest frequency and density in flax cultivation (Table 1).

Table 1 shows the total weed density in the flax crop of 43 plants/m2, which indicates the high weed pressure and a significant competitive potential on the crop. The percentage of participation shows that three species: *Chenopodium album* (32.56%), followed by *Amaranthus retroflexus* (18.60%) and *Convolvulus arvensis* (13.95%) account for over 65% of the total species present in the control version. The monocotyledonous species present in the flax crop were represented by the species *Sorghum halepense* and *Echinochloa crus-galli* with a participation percentage of 9.30%. The species of the annual dicotyledonous class (*Chenopodium album, Amarathus retroflexus, Datura stramonium*, *Xanthium strumarium, Abutilon theophrasti, Fallopia convolvulus*) were dominant, totaling a participation of ≈ 72% of the total.

Table 1. Composition of spontaneous flora from flax culture in Carani locality (Timiș county)

Species	Botanical family	Number of plants/m^2	Percentage of participation (%)	The notary class
Chenopodium album	Amaranthaceae	14	32,56	D.A.
Convolvulus arvensis	*Convolvulaceae*	6	13,95	D.P
Amaranthus retroflexus	*Amaranthaceae*	8	18,60	D.A.
Sorghum haelepense	*Poaceae*	2	4,65	M.P
Datura Stramonium	*Solanaceae*	2	4,65	D.A.
Xanthium strumarium,	*Asteraceae*	1	2,33	D.A.
Echinochloa crus-galli	*Poaceae*	2	4,65	M.A.
Abutilon theophrasti	*Malvaceae*	5	11,63	D.A.
Polygonum convolvulus/ Fallopia convolvulus	*Polygonaceae*	3	6,98	D.A.
	Total	43	100	

The presence of *Sorghum haelepense* and *Convolvulus arvensis*, both perennial species, indicates a potential long-term persistence in the absence of adequate control measures.

The floristic composition confirms the need to apply herbicides, especially against dominant and competitive – aggressive species such as *Chenopodium album*, *Amaranthus retroflexus* and *Convolvulus arvensis*, which can significantly reduce production if not properly managed.

The results obtained following treatments applied in the flax crop (Figure 4), located in Carani, were oriented on two target species, namely *Convolvulus arvensis* and *Chenopodium album*. Also, the impact of the treatments on the two target species was evaluated at three time intervals after their application, respectively at 14, 28 and 42 days.

Figure 4. Visual comparison between herbicidal variants and untreated control in flax crop at 28 DAA

The ANOVA analysis applied to the obtained results showed the existence of statistically significant differences between the variants, the main effect being very strong and significant ($F (35, 108) = 327.35$, $p < .001$; $Eta2 = 0.99$, 95% CI [0.99, 1.00]).

Focussing at this result, post hoc Tukey comparisons were performed to identify differences between treatment–species–endpoint combinations.

Figure 5 illustrates the temporal dynamics of control over the species *Convolvulus arvensis* in the six experimental plots, while Figure 5 shows the corresponding response of the species *Chenopodium album*. In both species, weed mortality increased significantly between 14 and 28 days after application, followed by a stabilization or slight improvement at 42 days. However, the rate and amplitude of response varied depending on the treatment.

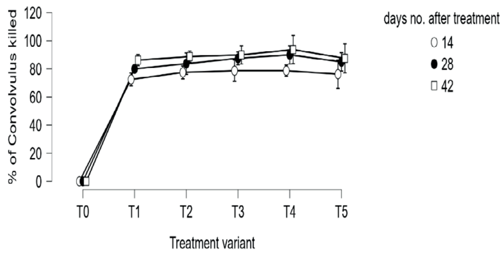


Figure 5. Descriptive plot of the response of *Convolvulus arvensis* to herbicide treatments in three time intervals after the treatment application (error bars are displayed)

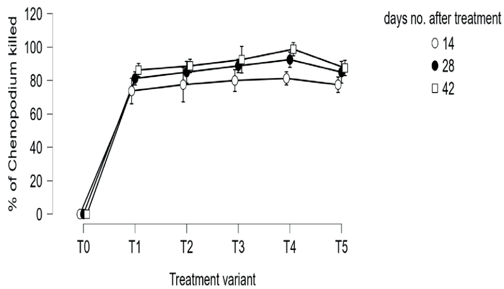


Figure 6. Descriptive plot of the response of *Chenopodium album* to herbicide treatments in three time intervals after the treatment application (error bars are displayed)

Table 2 shows the mean weed control values (± ES) for each treatment and time of assessment.

Efficacy of herbicides in controlling *Convolvulus arvensis species*

The first evaluation (14 DAA) of the efficacy of herbicides in combating the species *Convolvulus arvensis* showed that all treatments (T1-T5) ensured a level of protection for the flax crop between 72.5-78.75%, significantly higher than the control (untreated) variant. The post-hoc Tukey analysis confirmed very large statistical differences between the control and the herbicidal variants, with mean differences between - 72.5 and -78.75 ($p < 0.001$).

The control of *Convolvulus arvensis* in the herbicidal variants with MCPA (0.16-0.33 L ha^{-1}) (72.50-78.75%) was better compared to that obtained in the variant treated with fluroxypyr-meptyl (1.0 L ha^{-1}) 76.25%, but the differences did not present statistical assurance. MCPA 750 g $^{L-1}$ 0.33 L ha^{-1} (maximum dose) significantly exceeded the variant treated with minimum dose 0.16 L $^{ha-1}$ (T1), with a difference of 6.25% (p = 0.033; 95% CI: −12.02, −0.48).

The other treatments (MCPA 750 g L^{-1} – 0.21 L ha^{-1}, MCPA 750 g L^{-1} – 0.33 L ha^{-1}, fluroxypyr-meptyl 250 g L^{-1} – 1.0 L ha^{-1}) showed no statistical differences (Tukey test, $p > 0.05$).

At 28 DAA, the efficacy of herbicides in reducing the population of *Convolvulus arvensis* in flax crop increased slightly, ranging from 80–90% for all treatments. ANOVA indicates a significant effect of the "time after treatment" factor, and comparisons 14 vs. 28 DAA show significant increases in the percentage of destroyed plants ($p < 0.001$). These differences reflect the typical dynamics of auxin herbicides, in which symptoms gradually set in (epinasty, necrosis) in the weeks following application (Grossmann, 2010).

At 42 DAA, the efficacy of herbicides in the control of bindweed reached the maximum experimental values (86.25-93.75%), with the highest efficacy for T4 (0.33 L ha^{-1} MCPA) and very close values for T3 (0.21 L ha^{-1} MCPA) and T5 (fluroxypyr-meptyl 250 g L^{-1} – 1.0 L ha^{-1}). The treated variants showed strongly significant differences compared to the control ($p < 0.001$), but the differences between treatments were relatively small. However, Tukey's post-hoc analysis showed that T4 (0.33 L ha^{-1} MCPA) had superior efficacy over T5 (fluroxipyr-meptyl 250 g L^{-1} – 1.0 L ha^{-1}) in several treatment-time combinations, especially in the assessment of 42 DAA, the differences ranged from 6.25 to 8.75% (p = 0.004 – 0.040). For example, T4_d42 was higher than T5_d42 (Δ = 6.25 p.p., p = 0.0402) and T5_d28 (Δ = 8.75 p.p., p = 0.004). At the same time, T5 showed a significant increase in efficacy over time, from 14 to 42 DAA (Δ = 11.25 p.p., $p < 0.001$), which confirms the progressive nature of the herbicide's action in this variant.

Table 2. Mean weed control (%) for *Convolvulus arvensis* and *Chenopodium album* across treatments and assessment timing

Treatment	Days after application treatment	Mean *Convolvulus arvensis* control (%)	Mean *Chenopodium album* control (%)
T0 (untreated control)	14	0.000^{l}	0.000^{l}
	28	0.000^{l}	0.000^{l}
	42	0.000^{l}	0.000^{l}
T1 (MCPA 750 g L^{-1} – 0.16 L ha^{-1})	14	$72,500^{k}$	73.750^{jk}
	28	$80,000^{ghi}$	$81,250^{fghi}$
	42	86.250^{def}	86.250^{def}
T2 (MCPA 750 g L^{-1} – 0.21 L ha^{-1})	14	$77,500^{ijk}$	$77,500^{ijk}$
	28	83.750^{efgh}	$85,000^{defg}$
	42	$88,750^{bcde}$	$88,750^{bcde}$
T3 (MCPA 750 g L^{-1} – 0.27 L ha^{-1})	14	$78,750^{hij}$	$80,000^{ghi}$
	28	$87,500^{cde}$	$88,750^{bcde}$
	42	$90,000^{bcd}$	$92,500^{bc}$
T4 (MCPA 750 g L^{-1} – 0.33 L ha^{-1})	14	$78,750^{hij}$	$81,250^{fghi}$
	28	$90,000^{bcd}$	$92,500^{bc}$
	42	$93,750^{ab}$	$98,750^{a}$
T5 (fluroxipyr-meptyl 250 g L^{-1} – 1,0 L ha^{-1})	14	$76,250^{ijk}$	$77,500^{ijk}$
	28	$85,000^{defg}$	$85,000^{defg}$
	42	$87,500^{cde}$	$87,500^{cde}$

*Different letters indicate statistically significant differences (Tukey HSD, $p < 0.05$).

Overall, the results indicate that *Convolvulus arvensis* is sensitive to MCPA and fluroxipyr-meptyl, but a very clear separation between doses of MCPA and fluroxipyr is not statistically achieved – all treated variants are in a high efficacy "plateau" (86,250-93,750%). These results are in agreement with the literature, which shows that hormonal herbicides, including phenoxyacidides (MCPA, 2,4-D) and their combinations with other active substances, are commonly recommended for the control of perennial dicotyledons, such as *Convolvulus arvensis*. Previous studies have reported high efficacy of post-emergent hormonal treatments on perennial weeds (Schroeder et al., 1990; Robinson et al., 2015; Soltani et al., 2012), and the use of combinations from different groups can increase combat performance (Sosnoskie and Hanson, 2016; Bayat and Zargar, 2020). *Convolvulus arvensis* is a perennial weed with important reserves in deep roots, which makes it difficult to completely destroy the vegetative apparatus with a single treatment, chemical control usually only ensures a short-term reduction of aerial parts, which is why programs with repeated applications of systemic herbicides are required (Bayat and Zargar, 2020).

Efficacy of herbicides in controlling the species *Chenopodium album*

For *Chenopodium album*, the response to herbicides was higher.

At 14 days after the application of the treatments, the comparative analysis revealed very wide and statistically significant differences between the control variant (T0) and all treatments applied to *Chenopodium album*. The values of the mean differences ranged from −73.75 (T1; p < 0.001.95% CI: −79.04... −68.46) and −81.25 (T4; p < 0.001.95% CI: −87.27... −75,23), indicating effective and consistent weed control. The other variants showed similar differences: T2 (−77.5; p < 0.001, 95% CI: −83.27... −71.73), T3 (−80; p < 0.001, 95% CI: −85.98... −74.02) and T5 (−77.5; p < 0.001, 95% CI: −83.19... −71,81). Relatively narrow and overlapping confidence intervals demonstrate homogeneity of herbicide response, suggesting that at this early stage, all active substances acted effectively and reduced infestation by more than 73,750–81,250% compared to the control.

At 14 DAA, the efficacy of herbicides in controlling *Chenopodium album* ranged from 73.750% to 81.250% for the T1–T5 variants. Although the values show a slight upward trend with the dose of MCPA (T4 0.33 L $^{ha-1}$ ≈ T3 MCPA 750 g $^{L-1}$ 0.27 L $^{ha-1}$ > T2 0.21 L $^{ha-1}$ > T1 0.16 L $^{ha-1}$), the differences between treatments were not statistically significant (p > 0.05). The largest numerical differences were around 6.25 percentage points between Q3/Q4 and Q1, but these variations were not statistically validated. Fluroxipyr (T5) was at a similar level to the average doses of MCPA, with no significant differences.

At 28 DAA, the population of *Chenopodium album* was reduced by 81.250-92.500%, and at 42 DAA values of 86.250-98.750% were reached, with the maximum value in the T4 variant (0.33 L ha^{-1} MCPA), the differences recorded compared to the low doses T1 (Δ = 12.5, p < 0.001, 95% CI [6.45; 18.55), T2 (Δ = 10.0, p < 0.001, 95% CI [4.23; 15.77]) and fluroxipyr (T5) being significant.

Interspecific comparison between *Chenopodium album* and *Convolvulus arvensis*

The comparative analysis demonstrated the existence of consistent differences in sensitivity between the two dominant weeds. In general, *Chenopodium album* was more sensitive to the treatments applied compared to *Convolvulus arvensis*, this difference increased proportionally with the increase in the time interval after application.

At 14 DAA, the responses of the two species to the 5 treatments were almost similar (1–3 percentage points), with no statistically relevant differences.

At 28 DAA, interspecific separation was already detectable, but with small differences (≈2-4 percentage points) and only statistically significant in isolation, suggesting that after 3-4 weeks different responses on the sensitivity of the two species occur, when systemic translocation of herbicides is complete.

At 42 DAA the interspecific differences were the most obvious. For the same variant, the efficacy on *Chenopodium album* exceeded that recorded in *Convolvulus arvensis* by 8.75-11.25 percentage points, the differences being statistically significant (p < 0.01).

Treatment 4 (0.33 L ha^{-1} MCPA) reached 98.75% in *Chenopodium album* compared to

93.75% in *Convolvulus arvensis* (Δ = 11.25 p.p.; 95% CI [5.34; 17.16]), and similar differences were identified for T2 and T3 (Δ = 10.00 and Δ = 8.75 p.p.).

Overall, all treatments (T1-T5) were very effective compared to the control for both species ($p < 0.001$), but the response dynamics were distinct.

Chenopodium album showed rapid increases in efficacy between 14 and 28 DAA, followed by almost complete stabilization at 42 DAA (where T4 reached 98.75%). In *Convolvulus arvensis*, the final values were high (85-93.750%), but the differences between the doses were more attenuated, and the upper T4 variant statistically distanced itself from the low doses only in the late evaluations.

The results of the study showed that *Chenopodium album* is more sensitive to auxin herbicides as an annual species without a perennial structure; in contrast, *Convolvulus arvensis*, a perennial species, can diminish the effects of herbicides due to the underground reserves and cerate cuticle, which explains both the relatively lower efficacy and the need for higher doses for optimal results. This confirms that, for bindweed, the maximum effectiveness depends on the number of days after the application of the treatments (28-42) and the use of high-dose variants (T4). On the other hand, in *Chenopodium album*, the response to herbicides occurs more quickly, and the differences between doses are more clearly delineated statistically, the maximum control thresholds being reached from the first 28 days

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Table 3. Phytotoxicity and selectivity of herbicides (MCPA and fluroxipyr-meptyl) applied in flax culture

Treatment variant	Phytotoxicity				Mean (%)
	I	II	III	IV	
T0 (untreated control)	0	0	0	0	0
T1 (MCPA 750 g L⁻¹ – 0.16 L ha⁻¹)	0	0	0	0	0
T2 (MCPA 750 g L⁻¹ – 0.21 L ha⁻¹)	0	0	0	0	0
T3 (MCPA 750 g L⁻¹ – 0.27 L ha⁻¹)	0	0	0	0	0
T4 (MCPA 750 g L⁻¹ – 0.33 L ha⁻¹)	6	6	5	5	5.5
T5 (fluroxipyr-meptyl 250 g L⁻¹ – 1,0 L ha⁻¹)	7	7	6	7	6.75

The phytotoxicity assessment (Table 3) revealed clear differences in selectivity between the variants tested. In T1-T3 treatments (0.16-0.27 L ha^{-1} MCPA), flax culture did not show any visible symptoms of stress, all repetitions being evaluated with a score of 0. These results confirm the high tolerance of flax to low and medium doses of MCPA, a characteristic previously reported in other dicotyledonous crops, where MCPA is considered a herbicide with a low risk of phytotoxicity at approved doses.

In the high-dose MCPA variant (T4, 0.33 L ha^{-1}), phytotoxicity scores ranged from 5 to 6, corresponding to moderate chlorosis and minor foliar lesions, with no anticipated impact on production. These symptoms reflect the proximity of the dose to the upper limit of physiological tolerance of the plant, but the reduced severity suggests that the detoxification mechanisms of the crop are still functional.

The weakest selectivity was observed in fluroxypyr-meptyl (T5) treatment, where scores between 6 and 7 indicate a high level of stress: accentuated chlorosis, leaf deformities and a potential negative effect on production. Unlike MCPA, fluroxypyr causes a more aggressive hormonal flow and rapid redistribution of synthetic auxins, which may exceed the physiological compensating capacity of flax culture, especially at high doses.

These results underline that although efficacy against weeds increases with dose, herbicide selectivity may decrease and the trade-off between control and safety needs to be carefully assessed in integrated weed management programmes.

Discussions

The results of the study demonstrate a clear dependence of herbicide efficacy on both the treatment variant and the timing of evaluation, with weed control steadily increasing between 14 and 42 days after application. This progressive efficacy is characteristic of post-emergent systemic auxin herbicides, whose absorption, phloemic mobility, and metabolic activation require several weeks to reach maximum biological expression (Grossmann, 2010). In this case, the significant increases detected by the Tukey HSD test confirm a sustained herbicide action, which intensifies over time as the active substance accumulates in the meristematic tissues.

Of the treatments tested, T4 (0.33 L ha^{-1} MCPA) provided the most consistent and high level of control for both species, with efficacy reaching 93.75% for *Convolvulus arvensis* and 98.75% for *Chenopodium album* at 42 DAA. The statistical superiority of T4 over lower doses of MCPA (T1-T3) and fluroxipyr (T5) at assessment III (Δ = 10-12.5 p.p., $p < 0.001$) suggests either a higher systemic load or a more effective physiological disturbance. T3 was also in the upper efficacy group, representing a robust agronomic option in situations where the use of higher doses is limited by the authorisation label or economic considerations. In contrast, T1 showed the weakest control, especially in the early stages, indicating insufficient auxin stimulus at the minimum dose.

The interspecific comparison revealed marked differences in sensitivity, relevant for integrated weed management. *Chenopodium album* was consistently more sensitive than *Convolvulus arvensis*, and this difference became more pronounced in late evaluations. At 42 DAA, *Chenopodium album* outperformed *Convolvulus arvensis* by 8.75-11.25 percentage points in MCPA treatments ($p < 0.01$; 95% confidence intervals not including zero). These contrasts correspond to the distinct morphological and anatomical features of the species: *Chenopodium album* has a thinner cuticle, high leaf permeability, and a rapid rate of tissue growth and renewal processes, which favours the absorption of auxin herbicides (Pannacci and Covarelli, 2015). In contrast, *Convolvulus arvensis*, a species with an extensive network of rhizomes, exhibits superior tolerance due to abundant epicuticular waxes, rosette architecture, and well-documented metabolic detoxification pathways in numerous auxin-tolerant perennial weeds (Westra et al., 1992). Consequently, even if MCPA in increased doses produces numerical improvements in control, these increases are physiologically limited and do not exceed the threshold necessary to become statistically significant.

The herbicide–time interaction also differed between species. *Chenopodium album* was controlled at maximum after 28 DAA (92-93%), while *Convolvulus arvensis* required 42 DAA to reach similar levels. This result highlights a rapid loss of vegetative functions in the annual species, while in the perennial species the reduction in viability is gradual, reflecting the physiological tolerance conferred by the deep root system - an observation frequently reported in the literature on auxin responses of annual versus perennial weeds (Westra et al., 1992).

Regarding the selectivity towards flax cultivation, marked differences between treatments were highlighted. Low and medium doses of MCPA (T1-T3) produced no visible symptoms of phytotoxicity, consistent with the well-documented high selectivity for MCPA in dicotyledonous fibre and oil cultures (Hartzler and Anderson, 2016). These doses are within the physiological ability of the plant to rapidly detoxify the compound, mainly by conjugation with carbohydrates and amino acids. In contrast, the high dose (T4) induced moderate chlorosis and leaf deformations (5.5%), suggesting partial exceeding the detoxification capacity. Fluroxipyr (T5) produced the highest level of phytotoxicity (6.75%), corresponding to its higher auxin potency and rapid phloemic mobility. Similar effects are reported in flax and other sensitive cultures, where excessive auxin stimulation compromises vascular integrity and hormonal balance (Grossmann, 2010; Sosnoskie and Culpepper, 2014).

From an agronomic perspective, the high efficacy observed at 42 DAA underlines the significant potential for reducing weed competition during the critical period for the formation of flax production. However, the modest levels of control at 14 DAA suggest that in fields with high early infestations, additional cultural or mechanical measures may be required. The highlighted interspecific differences suggest a specific adaptation of strategies: annual weeds such as *Chenopodium album* can be effectively controlled with moderate doses of MCPA, while perennial weeds such as *Convolvulus arvensis* may require higher doses or mixtures of active substances to limit regeneration in underground organs.

Finally, integrating these results into a long-term approach highlights the need to rotate herbicides with different modes of action and avoid the repeated use of high doses of auxins, given the increasing number of auxin-resistant weed biotypes reported globally (Heap, 2024).

CONCLUSIONS

MCPA-based treatments tested at doses of 0.16-0.27 L ha⁻¹ (T1-T3) demonstrated effective control of dominant weeds, with an efficacy of 80–93% between 28 and 42 DAA, without inducing symptoms of phytotoxicity.

The higher dose of MCPA (0.33 L ha⁻¹, T4), although generating the highest efficacy under experimental conditions, resulted in moderate symptoms of phytotoxicity, indicating the need for further studies prior to any recommendation for use in flax culture.

Fluroxypyr-meptyl (T5) treatment achieved high levels of control, but induced the most pronounced phytotoxicity (6-7%) and is not approved for flax, which limits practical use. Its results must be considered strictly exploratory.

Chenopodium album was the most sensitive species, being 90-99% sensitive to MCPA, which confirms the vulnerability of this taxon to auxin herbicides.

Convolvulus arvensis showed a higher tolerance, with maximum efficacy at 42 DAA. The need for longer intervals is reflected by the fact that it is perennial with regenerative capacity.

Selectivity was outstanding for T1–T3 (no symptoms). In contrast, T4 and T5 generated stress reactions that can limit their application in practice, regardless of their effectiveness on weeds.

From an agronomic point of view, the optimal strategies remain those based on MCPA doses (T1-T3), and the high doses tested (T4) or non-approved alternatives (T5) require additional studies and crop safety evaluations before use.

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