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Survey of major weed problems, management practices and herbicide use in extensive row crops from Argentina

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Abstract: Background: Weeds pose a significant challenge to Argentine crops, leading to herbicide resistance and environmental concerns. **Objective:** To identify key weed problems, assess management practices, and herbicide use. **Methods:** A web-based survey system, with closed questions, was distributed from March to August 2020 among 147 agricultural stakeholders related to soybean, corn, wheat, and sunflower crops in Argentina. **Results:** Notable troublesome weeds included Conyza bonariensis (L.) Cronq., Digitaria sanguinalis (L.) Scop., Eleusine indica (L.) Gaertn., Amaranthus hybridus L., and Sorghum halepense (L.) Pers. Herbicide usage was as follows: 86% used burndown fallow chemical control, 51% adhered to labeled application rates, 40% applied herbicides at the labeled growth stage, and 37% rotated modes of action. Non-chemical controls were also employed, with 67% favoring crop rotation and 36% focused on preventing weed seed production. Glyphosate was the dominant herbicide, employed by over 90% of respondents. For summer crops, frequently used herbicides included paraquat, 2,4-D (80% of respondents), atrazine (60% of respondents), sulfentrazone, flumioxazin, S-metolachlor (60% of respondents), and clethodim (65% of respondents). In winter cereals, 2,4-D, flurochloridone, flumioxazin, and pyroxasulfone were the top choices. **Conclusions:** This survey underscores the high reliance on chemical control in Argentina's major crops. The findings provide crucial insights for regional policy planning, emphasizing the importance of integrating diverse weed management tactics. It also highlights the need for proactive integrated management strategies at the field level to mitigate and prevent weed issues in Argentina, offering a valuable approach for analyzing weed problems in extensive crops worldwide.

Keywords: Chemical Control; Integrated Weed Management; Problematic Weeds; Spring-Summer Crops; Winter Cereals

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1. Introduction

Crop production in no-till (NT) systems has increased in Argentina since the mid-1990s. This increase can be attributed to the rapid adoption of glyphosate-resistant (GR) soybean varieties. This system simplifies weed management, increases crop yields, reduces weed control costs by approximately four times compared to conventional systems (Scursoni, Satorre, 2010; Scursoni et al., 2019a) and lowers fuel and labor costs (Qaim, Traxler, 2005). No-tillage systems also offer benefits such as soil water conservation and soil erosion reduction (Peiretti, 1999; Viglizzo et al., 2010), making soybean and corn production profitable not only in traditional cropping areas but also in marginal areas.

Simultaneously with the increased adoption of GR crops, crop rotations mainly consisted of soybean monoculture, soybean/corn, or wheat/late soybean-soybean (Fuente et al., 2021a). These changes in production systems heightened reliance on glyphosate, leading to its multiple applications within the same crop (Vila-Aiub et al., 2007). The high and intense selection pressure on glyphosate-susceptible species led to a shift in the weed community from glyphosate-susceptible to GR (Young, 2006; Ryan et al., 2010). The consequences of this oversimplification of rotations in Argentinean agroecosystems resulted in a loss of biodiversity among weedy plants in primary cropping lands, with only a few challenging-to-control species remaining (Fuente et al., 2006; 2021a) and an increasing number of GR biotypes since 2005 (Heap, 2023; Asociación Argentina de Productores en Siembra Directa, 2023; Oreja et al., 2024). According to results obtained in a previous survey distributed to producers and crop consultants, among the top 15 most challenging weeds to manage, 11 were glyphosate-tolerant species or GR biotypes (Scursoni et al., 2019). The difficulty to manage tolerant and herbicide-resistant weeds is leading producers to increase the use of additional herbicides, in many cases increasing toxicity and environmental risks compared with glyphosate-based herbicide programs (Kniss, 2017). Nevertheless, there is a growing awareness of this issue among producers (Rodriguez et al., 2019), and the adoption of integrated weed management (IWM) programs is increasing (Scursoni et al., 2019). Argentinean producers and consultants surveyed reported using crop rotation, row spacing, competitive crop cultivars, and planting dates as their strategies (Scursoni et al., 2019). Among the best management practices (BMP) aimed at reducing the risks of herbicide resistance, 75% to 95% of the surveyed producers and consultants in Argentina indicated that the rotation of multiple modes of action, following labeled herbicide recommendations (including rates and plant sizes), and managing weed seed production were the most commonly utilized BMPs (Norsworthy et al., 2012; Scursoni et al., 2019). Since the last survey reported by Scursoni et al. (2019), some crops such as corn, wheat and sunflower increased their planted areas, by 35, 14 and 7%, respectively, while soybean area was reduced 13% (Bolsa Cereales, 2024). These changes in the crop planted areas may have changed as well weed management decisions and resulting weed communities.

The growth of herbicide-resistant weeds poses enormous challenges for the sustainability of production systems. While significant efforts are being made in weed management at the field level, the influence of regional production context on the presence of herbicide-resistant weeds remains unknown (Garibaldi et al., 2023). Despite the continuous confirmation of herbicide-resistant weed biotypes in Argentina (Heap, 2023; Oreja et al., 2024), there is a positive trend towards the adoption of IWM programs (Scursoni et al., 2019). Some IWM practices have seen increased adoption, such as the use of cover crops (Relevamiento de Tecnología Agrícola Aplicada de la Bolsa de Cereales, 2022), the intensification and diversification of crop rotations (Fuente et al., 2021b), and the implementation of targeted herbicide applications (Arditi et al., 2023).

Given the dynamic nature of crop management practices, there has been limited documentation of recent developments in the adoption of IWM practices and herbicide use in Argentina. Despite increased interest in the environmental and economic impacts of monocultures, reports on soybean monoculture have been scarce and based mainly on the observation of area changes at the regional level (Barros et al., 2015; Duval et al., 2015). In the past, information on Argentinean harvested area or crop yield was only available at the regional level and the occurrence of monoculture was based on this type of information for many years (Barros et al., 2015; Duval et al., 2015; Sly, 2017). Recently, high-resolution maps of annual crop were generated in Argentina, allowing the characterization of the spatial distribution of crops in large regions, and the quantification of crop rotation and monoculture at the regional level (Abelleyra et al., 2019; Abelleyra et al., 2020; Abelleyra et al., 2021; Abelleyra et al., 2022). Given that agricultural landscapes are tending towards simplification, larger plots and monocultures, species resistant to herbicides may increase compared to more diverse and complex landscapes (Abelleyra et al., 2024). For example, resistance-inducing mutations are often related to fitness costs under non-herbicide-treated conditions (Vila-Aiub, 2019). More diverse and complex weed communities could promote genetic variation of weeds within the crop field with those found outside in other fields and thus reduce the spread of herbicide-resistant traits. As weed community composition within a crop field changes with distance from the field edge (Bourgeois et al., 2020), plots will encounter large natural and semi-natural habitats that can function as barriers to the spread of herbicide-resistant traits.

Surveys that evaluate management practices are important tools to monitor the impact on weed communities (Norsworthy et al., 2012). Producers and consultants have information about the main problematic weed species and the strategies applied to different situations in their respective regions (Riar et al., 2013; Schwartz-Lazaro et al., 2021). However, information about weed management and herbicide use covering the main crop producing provinces in Argentina is scarce. The information derived from surveys will allow to provide information of the current weed management practices and issues in Argentinean crop production and future research needs to be based on producer concerns. Given that weed management decisions are dynamics and weed communities change continuously, we proposed to conduct a new survey to determine i) the major weed problems, ii) the adoption of weed management practices and iii) the use of herbicides in the main crops in Argentina.

2. Materials and Methods

A web-based survey system containing eight questions was distributed from March to August 2020 among agricultural stakeholders in Argentina. One hundred and forty-seven surveys were completed by producers and consultants from the main crop production areas in Argentina, which include the provinces of Buenos Aires, Chaco, Córdoba, Entre Ríos, La Pampa, Salta, San Luis, Santa Fe, Santiago del Estero, and Tucumán. The survey covered the location and the most important crops in Argentina, including soybean, corn, sunflower, and wheat, for each respondent. For questions 4 to 7, a list of predefined answers (Table 1) was provided, allowing respondents to select none, one, or more options for: i) the most problematic weed species per field and crop; ii) the frequency of use (always, often, sometimes, or never) of each farming practice ; and iii) the frequency of use (always, often, sometimes, or never) of each herbicide (Table 2).

When considering species as the most troublesome to manage, the ranking of the most problematic weeds for each area was determined based on the number of times each weed was mentioned. Additionally, the ranking of IWM practices and herbicides used in summer crops (soybean, corn, and sunflower) and winter crops (wheat) was determined by considering the frequency of each practice. Responses to multiple-choice questions were converted into percentages and analyzed using descriptive statistics. Absolute frequency was used to determine the number cases of most problematic weeds reported by respondents, and the relative frequency of farming practices and frequency of herbicide was expressed in percentages.

Table 1 - The first part of the questionnaire included in the survey

1 - Are you adviser, producer or commercial adviser?
2 - Area where you work:
3 - Surface of the area you manage:
4 - Five main weeds handled in soybean, corn, wheat, other
5 - Resistant weeds handled in soybean, corn, wheat, other
6 - Indicate how often you do the following farming practices (always, often, rarely, never):
6.1. Chemical fallow
6.2. Application of herbicides at the recommended / suitable time
6.3. Application of the recommended complete dose of herbicide
6.4. Preventing weed seed production during cultivation
6.5. Preventing weed seed dispersion with machinery
6.6. Preventing weed seed production after cultivation
6.6. Preventing weed seed production in no cropped area
6.8. Preventing weed seed dispersal
6.6. MOA* rotation
6.7. Crop rotation
6.8. Cleaning of tillage and harvesting equipment
6.9. Manual or localized weeding
6.10. Tillage
6.11. Reducing of row distance
6.12. Increasing crop density
6.13. Choosing more competitive crops
6.14. Changing sowing date
6.15. Using cover crops
6.16. Use of predictive models
6.17. Periodic monitoring of weeds
6.18. Use of targeted application systems
7 - Rate the following herbicides according to the frequency of use in spring-summer crops, including fallow.
8 - Are you aware of the herbicide use on the environment

*MOA: mode of action

Table 2 - Second part of the questionnaire included in the survey

7 - Rate the following herbicides according to the frequency of use in different seasonal crops	
Spring-summer crops, including fallow	**Wheat, including fallow**
1. 2,4-D	1. 2,4-D
2. Atrazine	2. Bromoxynil
3. Benazolin	3. Clethodim
4. Chlorimuron-ethyl	4. Dicamba
5. Clethodim	5. Diflufenicam
6. Clethodim+quizalofop-ethyl	6. Doble knock down
7. Cloransulam-methyl	7. Fenoxaprop
8. Dicamba	8. Flumioxazin
9. Diclosulam	9. Fluorocloridona
10. Diflufenican	10. Fluroxypir
11. Double knock down	11. Glufosinate
12. Flumioxazin	12. Glyphosate
13. Fomesafen	13. Haloxifop
14. Glufosinate	14. Iodosulfuron+mesosulfuron
15. Glyphosate	15. Metsulfuron
16. Haloxyfop-methyl	16. Paraquat
17. Imazapyr	17. Picloram
18. Imazethapyr	18. Pinoxaden
19. Iodosulfuron + thiencarbazone-methyl	
20. Lactofen	
21. Metribuzin	
22. Metsulfuron-methyl	
23. Metolachlor/S-metolachlor)	
24. Paraquat	
25. Picloram	
26. Pyroxasulfone	
27. Saflufenacil	
28. Sulfentrazone	
29. Sulfometuron + chlorimuron-ethyl	

3. Results and Discussion

3.1 Characterization of respondents

According to the survey, 84% of respondents worked in the most important agricultural provinces in Argentina (Figure 1). Among the respondents, 98% were involved in the production of soybeans or corn, 89% in wheat production, and 45% in sunflower production. Approximately 54% to 64% of respondents managed more than 500 hectares of corn, wheat, and soybeans, while 14% to 23% managed 300 to 500 hectares. Around 9% managed 100 to 300 hectares, and 6% to 12% managed less than 100 hectares (Figure 2).

3.2 Troublesome weeds

According to the survey, the most problematic weed species included hairy fleabane [*Conyza bonariensis* (L.) Cronquist], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], goosegrass [*Eleusine indica* (L.) Gaertn.], smooth pigweed (*Amaranthus hybridus* L.), johnsongrass [*Sorghum halepense* (L.) Pers.], pigweed (*Amaranthus* sp.), hairy fleabane, (*Conyza* sp.), *Chloris* sp., erect dayflower (*Commelina erecta* L.) and fleabane [*Conyza sumatrensis* (Retz.) E. Walker] (Figure 3). All of these species have been reported as GR biotypes in Argentina (Heap, 2023; Asociación Argentina de Productores en Siembra Directa, 2023; Oreja et al., 2024). *Sorghum halepense* was the first GR weed registered in Argentina (Vila-Aiub et al., 2007) followed by resistance to clethodim and haloxyfop-methyl (Heap, 2023). *Digitaria sanguinalis* (Yanniccari et al., 2022), *E. indica* (Heap, 2023), *C. bonariensis* (Puricelli et al.,

2015) and *C. sumatrensis* biotypes were also identified as GR (Balassone et al., 2020). A biotype of *C. sumatrensis* resistant to acetolactate synthase (ALS)-inhibiting herbicides (Group 2) was also reported by Balassone et al. (2021). The genus *Amaranthus* has the highest number of herbicide-resistant biotypes reported in Argentina, with the majority being *A. hybridus* biotypes and among them, GR biotypes (Bracamonte et al., 2018; Dellaferrera et al., 2018; Perotti et al., 2018; García et al., 2019) but also, to other herbicides such as imazethapyr, chlorimuron, 2,4-D and dicamba (Tuesca, Nisensohn, 2001; Bracamonte et al., 2018; Dellaferrera et al., 2018). Recent evaluations of over 50 populations from the central area of Argentina revealed that more than 80% of the assessed *Amaranthus* biotypes were GR. Among them, 71% showed resistance to topramezone (a 4-hydroxylphenylpyruvate dioxygenase [HPPD]-inhibiting herbicide) (Group 27), and 56% were resistant to fomesafen (a protoporphyrinogen oxidase [PPO]-inhibiting herbicide) (Group 14) (Scursoni et al., 2022). Additionally, in Argentina, Palmer amaranth (*Amaranthus palmeri* S. Watson) populations resistant to glyphosate and other herbicides such as imazethapyr, imazapic, chlorimuron, nicosulfuron, and diclosulam have been identified (Berger et al., 2016; Larran et al., 2017; Palma-Bautista et al., 2019; Kaundun et al., 2019).

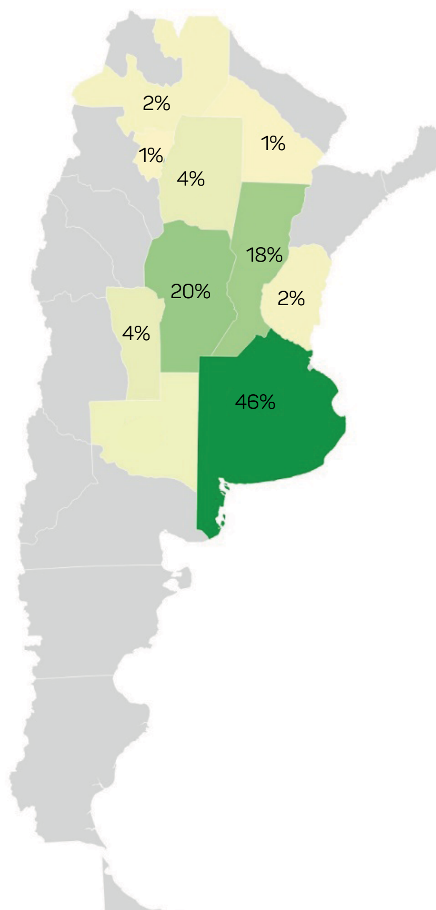

Figure 1 - Percentage of respondents of the survey from each province of Argentina

The list of species was similar to that reported by Scursoni et al. (2019); however, the weed ranking changed. *D. sanguinalis* rose from 8th place in Scursoni et al. (2019) to the 2nd place in the present survey, confirming the difficulty of managing of this weed with herbicides due to a long emergence period (Oreja et al., 2020). *Lolium* sp. decreased from 7th to the 16th place on the present survey, possibly due to the increased use of acetyl-CoA carboxylase–(ACCase)-inhibiting (Group 1) herbicides to control this species (Yanniccari, Gigon, 2020), especially in the fallow period before summer crops (Figures 5 and 6). However, the repetitive use of these herbicides is selecting for herbicide-resistant populations (Yanniccari, Gigon, 2020). *Commelina erecta,* a weed that is challenging to control in NT systems due to glyphosate tolerance (Panigo et al., 2012) and perennial lifecycle; requiring long-term management

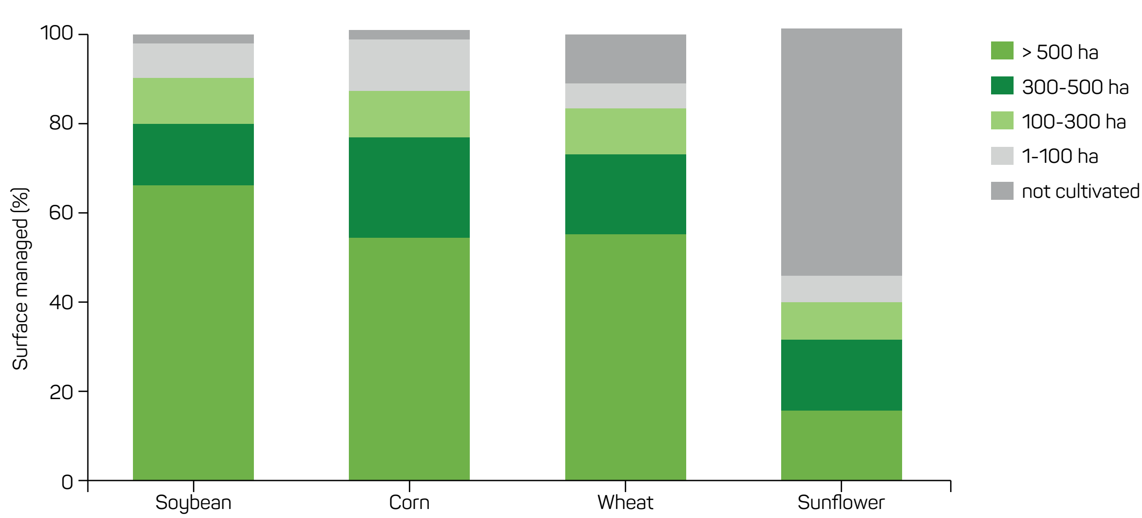

Figure 2 - Area managed (%) for each crop grouped according to farm size

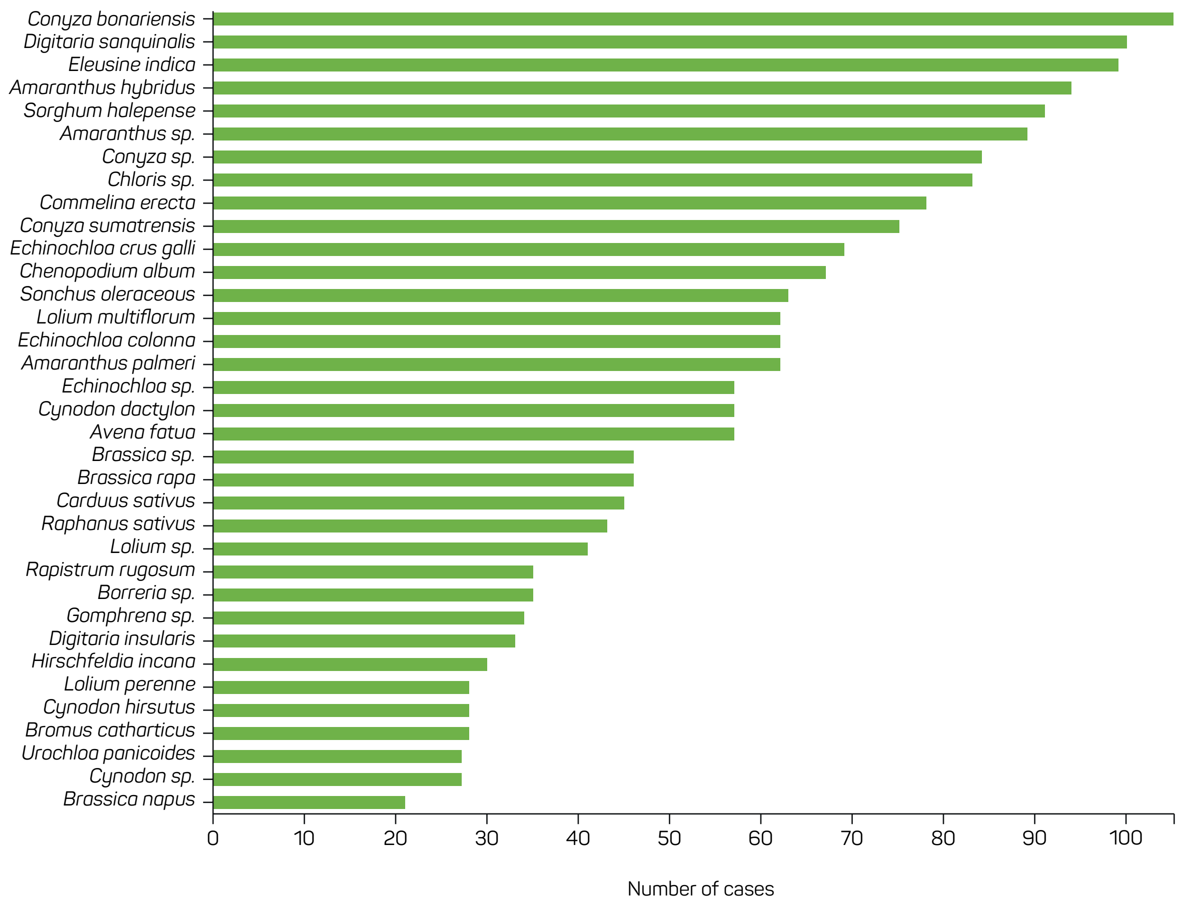

Figure 3 - Ranking of weed species in the surveyed agricultural area of Argentina, considering the number of informed cases. In cases without species identification, only the genus was registered

instead of single applications, went up from 15th to 9th place in the present survey. The present ranking of the main winter species was: *Sonchus oleraceus* L. and *Conyza* sp. (including *C. sumatrensis*), the latter is a facultative winter species problematic in summer crops (Figure 3). The increasing importance of *S. oleraceus* importance as a problematic species highlights the growing challenges in its control (Daita et al., 2021), however there are no HR biotypes identified in Argentina so far (Oreja et al., 2024).

3.3 IWM practices adoption

Compared with the previous survey (Scursoni et al., 2019), the use of IWM practices has increased. Among the most adopted strategies, herbicides are still more adopted than non-chemical weed management practices (Figure 4). Chemical burndown during the fallow period, periodic monitoring of weeds and crop rotation were the most adopted, since almost 100% of the respondents reported always conducting weed monitoring. High use of herbicides during fallow period is the result of the wide adoption of NT crop production (91% in 2019/20) (Asociación Argentina de Productores en Siembra Directa, 2020; Relevamiento de Tecnología Agrícola Aplicada de la Bolsa de Cereales, 2022). Producers commonly use chemical fallow by applying residual and postemergence herbicides to control problematic facultative winter weeds such as *Conyza* sp. (Walker et al., 2012), *Lolium* sp. and *S. oleraceus*. They also use herbicides to manage early spring-emerging species like *D. sanguinalis*, *E. indica* and *Echinochloa crus-galli* (L.) P. Beauv. before planting summer crops. The percentage of producers and consultants adopting crop rotation with the response “always” increased from 45% in the previous survey to nearly 67% when considering those responding with “almost always,” and when including those adopting crop rotation “often,” it reached nearly 98%. This was also observed by the reduction of 2.2 million hectares planted with soybean between the last survey and the present with an increase in corn, wheat and sunflower areas by 2.4, 1.6 and 0.1 million hectares respectively (Bolsa Cereales, 2024). The intensification of crop rotations could significantly reduce herbicide use without negatively affecting the functional structure or species richness of the weed community (de la Fuente et al., 2021b). Among Argentinean producers, the benefits of crop rotation are widely accepted, not only for weed management but also for disease control and improving soil properties. However, the

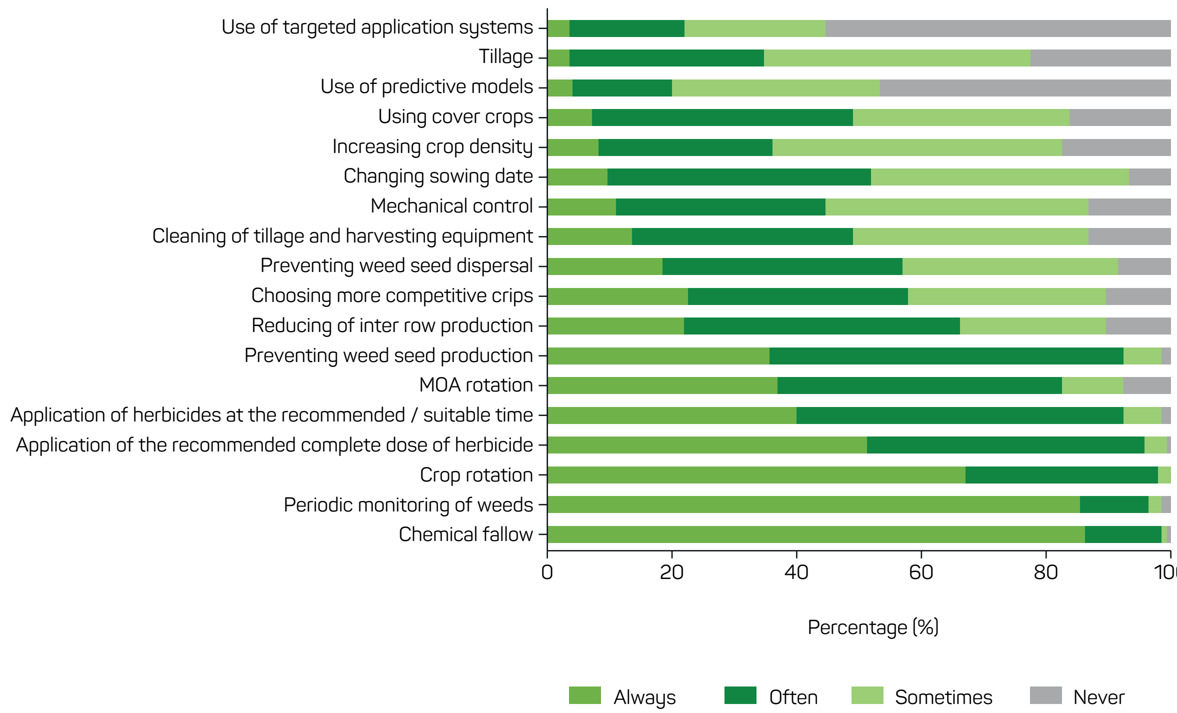

Figure 4 - Use of weed management practices expressed as a percentage of the following categories: always, often, sometimes, and never. MOA, mode of action

final decision often hinges on short-term crop profitability considerations (Dury et al., 2012).

The rotation of herbicide modes of action (MOA) and measures to prevent weed seed production increased to 20% compared to Scursoni et al. (2019). Repeated applications of herbicides with the same MOA accelerate herbicide-resistance evolution, such as, several applications of glyphosate in glyphosate-HR soybean monoculture (or glyphosate-HR cotton) in some regions of the United States (Beckie, 2006). Highly simplified systems with minimal crop and herbicide MOA rotation favor weed communities with fewer difficult-to-control species, for instance, the overuse of glyphosate or ACCase- and ALS-inhibiting herbicides (Storkey, Neve, 2018; Oreja et al., 2021). The increasing number of herbicide-resistant weed populations (Oreja et al., 2024) has prompted producers to adopt herbicide MOA rotation. Among the BMP to delay resistance (Norsworthy et al., 2012), MOA rotation is the most widely accepted and adopted by producers. The reduction of 2.2 M ha of soybean and the increase in area of other summer crops, such as corn and sunflower, means that producers are rotating MOA from one crop to the other in fields. Another widely adopted practice is preventing weed seed production, with 36% of respondents reporting its adoption. Late-season weed control may incur additional short-term costs for producers, but it offers long-term benefits by reducing the seedbank size (Bagavathiannan, Norsworthy, 2012).

The adoption of practices aimed at enhancing crop competitive ability, such as the adoption of competitive cultivars and adjusting row spacing, increased by 15% to 18%. Approximately 8% of respondents reported making modifications to planting dates and seeding density. The cleaning of tillage and harvesting equipment and the application of the recommended herbicide rate increased by 12% for the "always" response. A significant 78% responded that they always applied the recommended herbicide rate, while the remaining 10% responded with "often". As stated by Scursoni et al. (2019), these practices do not typically imply high costs for producers and yet are still not fully integrated into weed management programs. The adoption of cover crops reached a total of 75% of respondents when considering the "often" and "always" responses together, representing a 35% increase compared to the previous survey. (Scursoni et al., 2019). The proportion of producers practicing cover crops and consultants recommending this practice "always" (15%) is similar to the 19% reported in the survey by ReTAA (2022). The benefits of cover crops in reducing weed pressure are well-known among producers (Laloy, Bielders, 2010; Bergtold et al., 2017). The adoption of cover crops is influenced by various factors, including demographic characteristics, establishment practices, adoption of related management practices, environmental attitudes, and climate (Lee, McCann, 2019). Practices with mid to long-term benefits could be a significant adoption barrier (Bergtold et al., 2012). This concern is particularly relevant in the context of farming on rented land, which constitutes a substantial portion of Argentina's agriculture. Additionally, worries regarding water and nutrient consumption, as well as sowing costs, may limit the widespread adoption of cover crops. Depending on the climate and seasonal precipitation, delaying the termination of cover crops may deplete soil moisture, negatively impacting cash crops (Balkcom et al., 2015).

Finally, the use of targeted herbicide application and the adoption of predictive models were the only practices some respondents declared "never" considering in their weed management plans (Figure 4). Despite the increasing availability and well-documented benefits of predictive models, their adoption by producers is still low globally (Evans et al., 2017). According to Wilkerson et al. (2002), producers have cited several reasons for avoiding the use of models, including the perception that some are too simplistic, based on a single species, neglect spatial distribution of weeds, or are overly complex and require excessive information. The limited adoption of targeted herbicide application is primarily due to its high cost and the absence of explicit short-term monetary benefits (Tidemann et al., 2017).

3.4 Herbicide use

Glyphosate was the most commonly applied herbicide, with more than 90% of responses indicating very frequent use across different crops. These findings align with those reported by ReTAA (2023), where glyphosate ranked as the most used herbicide in terms of the number of applications per season among the most important crops in the country. Since the adoption of GR crops in the mid-90s, the global use of glyphosate has increased significantly (Clapp, 2021), and a similar trend has been observed in Argentina (Penna, Lema, 2003). The majority of soybean and corn genotypes cultivated in Argentina are GR (Consejo Argentino para la Información y el Desarrollo de la Biotecnología, 2022), especially under NT systems (Asociación Argentina de Productores en Siembra Directa, 2020). Among the non-selective herbicides used in fallow before summer crops, paraquat has been more commonly used than glufosinate. This is despite the availability of summer crop genotypes tolerant to glufosinate in the market (Consejo Argentino para la Información y el Desarrollo de la Biotecnología, 2022). This pattern is consistent with the findings of a report by Bolsa Cereales (2023), where paraquat was also more frequently used than glufosinate in terms of the number of applications and doses, except in the case of corn. Notably, glufosinate-tolerant corn genotypes have been available in Argentina since 1998, which is earlier than the introduction of glufosinate-tolerant genotypes for other crops such as soybean (the first glufosinate-tolerant genotype was released in 2011) and wheat (the first glufosinate-tolerant genotype was released in 2020) (Consejo Argentino para la Información y el Desarrollo de la Biotecnología, 2022).

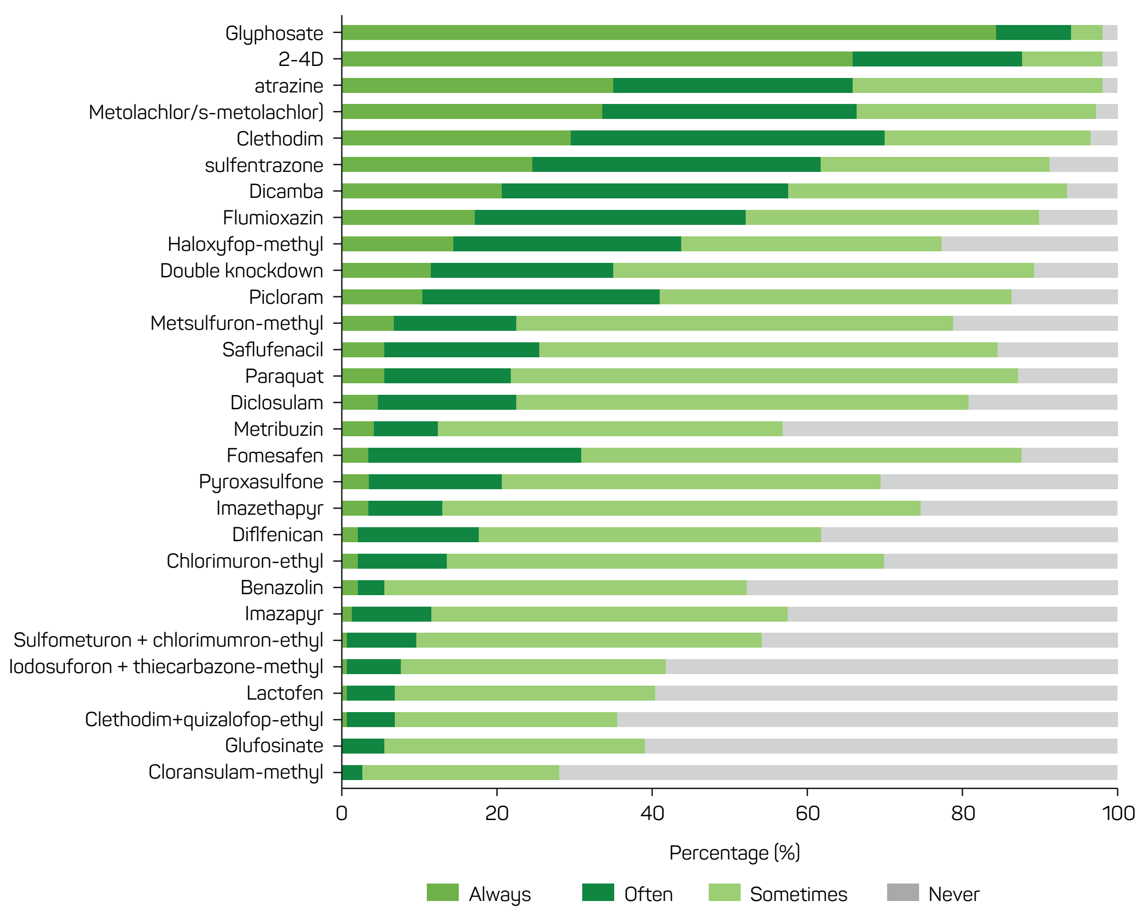

Figure 5 - Use of herbicides in summer crops and fallow expressed as a percentage of the following categories: always, often, sometimes, and never

In North Carolina, glufosinate has been rarely applied initially, primarily due to the availability of other effective herbicides (Jones et al., 2022), which may also be the case for other crops apart from corn. Furthermore, a significant proportion of Argentinean producers rent fields in mid-spring when *Conyza* sp. plants are at an advanced phenological stage, making control challenging. To address this issue, especially in soybean crop, producers employ the double-knockdown technique, which involves the application of glyphosate plus 2,4-D followed by paraquat (Walsh, Poles, 2007). Another reason for the increasing use of non-selective herbicides like paraquat is the proliferation of GR weeds (Heap, 2023; Oreja et al., 2024). Nearly 90% of those surveyed reported using the double-knockdown technique, with responses indicating that 12% always used it, 23% often used it, and 54% used it sometimes (Figure 5). Finally, it should be noted that the use of glufosinate was usually more expensive than the use of paraquat, which may explain why growers prefer paraquat instead of glufosinate.

Summer crops. In terms of auxinic herbicides (Group 4), the most commonly used were 2,4-D (80% always/often) and dicamba (57% always/often) as a burndown strategy previous to soybean and corn planting, and as post emergent herbicide in corn during the period emergence to V4 stage. Despite being one of the earliest herbicides used in extensive agriculture, 2,4-D continues to be widely used as a chlorophenoxy product (Peterson et al. 2016). This is due to its high efficacy against broadleaf weeds, a relatively low incidence of herbicide-resistant cases (Heap 2023), and its cost-effectiveness compared to other herbicides. These findings align with herbicide usage patterns reported by ReTAA (2022), where 2,4-D was the most commonly used auxin herbicide across all crops, and dicamba was consistently the second most applied auxin herbicide. When considering herbicides with long-term activity in the soil, atrazine, a photosystem II-inhibiting herbicide, was more frequently used (65.7% always/often) than sulfonylureas and imidazolinones, which are ALS-inhibiting herbicides (35%). Atrazine serves as the primary residual herbicide employed in corn cultivation for the control of broadleaf weeds. Its usage has also increased during the fallow period preceding soybean planting to manage *Conyza* sp. during the winter and early spring (Wu et al., 2008). According to ReTAA (2022), atrazine was the most commonly adopted residual herbicide in corn during the 2019/2020 and 2020/2021 seasons. Conversely, in wheat crops, the most commonly used residual herbicides belonged to the sulfonylurea family (Relevamiento de Tecnología Agrícola Aplicada de la Bolsa de Cereales, 2022).

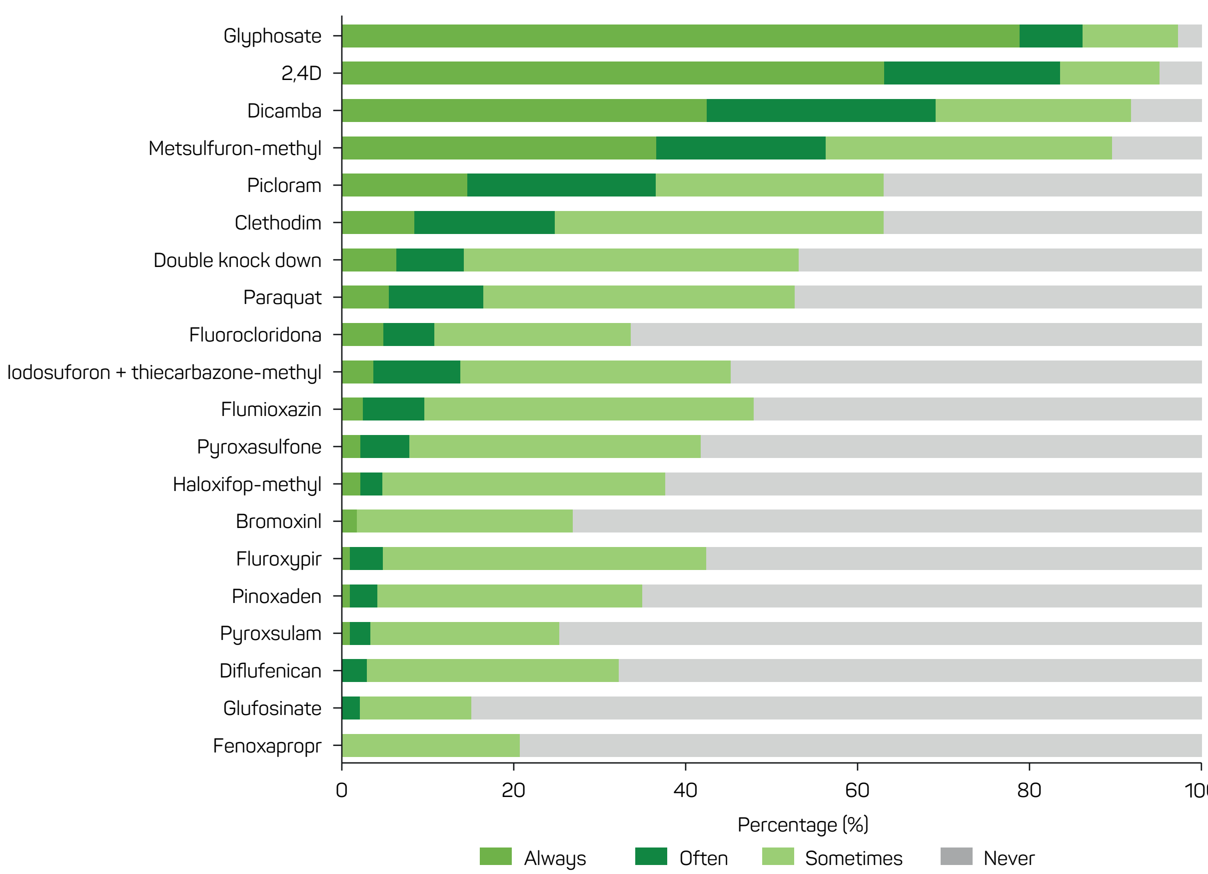

Figure 6 - Use of herbicides in wheat and previous fallow expressed as a percentage of the following categories: always, often, sometimes, and never

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Regarding preemergence herbicides, sulfentrazone (a protoporphyrinogen oxidase [PPO]-inhibiting herbicide), flumioxazin (PPO-inhibiting herbicide) and *S*-metolachlor (very long-chain fatty acid synthesis inhibiting-herbicide) (Group 15) were the most commonly used (60% often/always). These findings align with those of ReTAA (2022), which reported sulfentrazone and flumioxazin as the most widely used preemergence herbicides in soybean and S-metolachlor in corn. Among the graminicides, clethodim was the more frequently used option (70% often/always) compared to haloxyfop-methyl (44%). This preference for clethodim can be attributed to the increasing number of cases of *S. halepense* resistance to haloxyfop-methyl in recent years (Heap 2023), a trend also noted by ReTAA (2022). In the context of controlling broadleaf weeds in soybeans, particularly *Amaranthus* sp., fomesafen (a PPO-inhibiting herbicide) was the preferred choice (31% often/always), surpassing lactofen (a PPO-inhibiting herbicide) at 7% and benazolin (an auxin herbicide) at 5%.

Winter crops. Among the auxinic herbicides, both in winter cereals and summer crops, 2,4-D was more frequently used, with 83.4% reporting its use always or often, compared to dicamba at 69% and picloram at 18%. It's worth noting that the use of metsulfuron-methyl (an ALS-inhibiting herbicide) was similar to dicamba but is specifically included in wheat management for residual control. Mixtures of iodosulfuron-methyl-Na + mesosulfuron-methyl (both ALS-inhibiting herbicides) and pinoxaden (an ACCase-inhibiting herbicides) were applied to control grasses in wheat. During the fallow period preceding the wheat crop, clethodim and haloxyfop-methyl were applied to control GR *Lolium* spp. At pre-planting, the application rates of flurochloridone, flumioxazin, and pyroxasulfone were similar, ranging from 8 to 10% for "always" and "often" responses (Figure 6).

4. Conclusions

The survey provided a valuable information about most troublesome weeds, weed management practices adopted and herbicide use in the main Argentinian crop producing regions. The most troublesome weeds according to the survey are *C. bonariensis, D. sanguinalis*, *E. indica, A. hybridus* and *S. halepense* and all of these species have herbicide-resistant biotypes in Argentina. Survey results showed that weed management is still very dependent on herbicides and MOA rotation, but producers are beginning to adopt IWM to a certain extent. Despite producers unknowingly adopting IWM, it is necessary to highlight that non-chemical practices do not imply high costs for producers to accelerate IWM adoption. Future management recommendations should focus on IWM strategies to avoid the evolution of herbicide resistance and weed community shifts.

Describing the different types of weed management, and quantifying their frequency, allow the diagnosis and the identification of possible causes and consequences of the adoption of agricultural practices, opening the door to the development of public policies that promote good agricultural practices, conserve the environment and guarantee security in access to markets. This diagnosis is a useful tool to plan political strategies at regional scale promoting the combination of different tactics and to implement proactive integrated management decisions at field scale reducing and preventing weed problems in Argentina, and the approach may be useful to analyze weed problems in extensive crops worldwide.

Authors' contributions

All authors read and agreed to the published version of the manuscript. FHO, ACDV, BCK, EBD and JAS: conceptualization of the manuscript and development of the methodology. FHO, ACDV, BCK, EBD and JAS: data collection and curation. FHO, and ACDV: data analysis. FHO, ACDV, BCK, EBD and JAS: data interpretation. EBD: funding acquisition and resources. BCK, EBD and JAS: project administration. FHO, ACDV, BCK, EBD and JAS: supervision. FHO: writing the original draft of the manuscript. FHO, ACDV, BCK, EBD and JAS: writing, review, and editing.

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