



## Review Article

## Sugarcane Weed Management in Iran: Evolution and Current Status

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## Abstract

Sugarcane is a key industrial crop in Khuzestan province, Iran. However, sugarcane production is constrained by a remarkably diverse weed flora encompassing over 140 species. This flora includes some of the most dangerous annual and perennial species such as *Leptochloa fusca*, *Echinochloa colona*, *Cynanchum acutum*, *Imperata cylindrical* and *Cynodon dactylon* can reduce cane yield by as much as 80%. For decades, chemical control relying on some Photosystem II inhibitors (Atrazine, Metribuzin) and synthetic auxin (2,4-D + MCPA) herbicides was the dominant strategy. This strategy resulted in several major challenges, including the emergence of herbicide-resistant weed populations (*Echinochloa colona*), a shift in the weed flora favoring invasive species (*Cynanchum acutum*), increased weed management costs, and environmental concerns. In response to these challenges, the weed management paradigm has shifted towards an Integrated Weed Management (IWM) approach based on the optimization and integration of chemical, mechanical and physical control methods tailored to the specific conditions of sugarcane production. Some of the most important measures include introducing new herbicides with different sites of action (e.g., indaziflam, pendimethalin), applying a herbicide rotation program, optimizing application timing and method (e.g., delayed pre-emergence), and significantly increasing the role of physical-mechanical control. As a result, the average herbicide input has declined from approximately 20 kg/L ha<sup>-1</sup> to less than 6 kg/L ha<sup>-1</sup>. Effective management of perennial weeds in sugarcane requires a thorough understanding of their biological and ecological characteristics, together with the integration of chemical, mechanical, and cultural control methods into species-specific management programs. The future outlook emphasizes strengthening this trend through training, developing precision application technologies, optimizing water and fertilizer management, and implementing crop rotation to achieve sustainable sugarcane production. This journey from a chemically dependent system to a multifaceted IWM framework highlights the critical importance of adaptive, research-based strategies for the long-term sustainability of sugarcane agroecosystems in Iran.

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## مقاله مروری

### مدیریت علف‌های هرز نیشکر در ایران: سیر تحول وضعیت کنونی

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#### چکیده

نیشکر یکی از محصولات صنعتی کلیدی استان خوزستان در ایران است. با این حال، تولید نیشکر با یک محدودیت عمده از جمله فلور بسیار متنوع علف‌های هرز روبرو است که بیش از ۱۴۰ گونه را در بر می‌گیرد. برخی از گونه‌های یکساله و چندساله خطرناک از جمله *Leptochloa fusca*، *Echinochloa colona*، *Cynanchum acutum* و *Imperata cylindrica* در این فلور حضور دارند که می‌توانند تا ۸۰ درصد موجب کاهش عملکرد شوند. برای دهه‌ها، مبارزه شیمیایی با تکیه بر علف‌کش‌های بازدارنده سامانه نوری ۲ (آترازین، متریوزین) و اکسین‌های مصنوعی (تو، فور-دی + ام‌ث‌پ‌آ)، استراتژی غالب بود. این رویکرد منجر به بروز چالش‌های جدی از جمله ظهور علف‌هرز مقاوم (*Echinochloa colona*)، تغییر در ترکیب فلور علف‌های هرز به سود گونه‌های مهاجم (*Cynanchum acutum*)، افزایش هزینه‌های مبارزه و نگرانی‌های زیست محیطی شد. در پاسخ به این چالش‌ها، الگوی مدیریت به سمت مدیریت تلفیقی علف‌های هرز از طریق اصلاح و بهینه‌سازی روش‌های مبارزه شیمیایی، فیزیکی-مکانیکی و ترکیبی از تمام روش‌های مناسب با شرایط کشت نیشکر تغییر جهت داد. برخی از اقدامات مهم انجام شده عبارت بودند از معرفی علف‌کش‌های جدید با محل‌های اثر متفاوت (مانند ایندازیفلام، پندیمتالین)، اجرای برنامه تناوب علف‌کش‌ها، بهینه‌سازی زمان و روش کاربرد (مانند روش پیش‌رویشی تأخیری) و افزایش قابل توجه نقش مبارزه فیزیکی-مکانیکی. در نتیجه، میانگین میزان کاربرد علف‌کش از حدود ۲۰ پیمانه (کیلوگرم یا لیتر) در هکتار به کمتر از ۶ پیمانه از گذشته تا به اکنون کم شده است. در مورد گونه‌های چندساله در نیشکر، افزون بر مطالعه و درک ویژگی‌های زیستی و بوم‌شناختی آنها، نیاز به تلفیق روش‌های شیمیایی، مکانیکی و زراعی در چارچوب برنامه‌های مدیریتی ویژه هرگونه است. چشم‌انداز آینده بر تقویت این روند از طریق آموزش، توسعه فن‌آوری‌های کاربرد دقیق، بهینه‌سازی مدیریت آب و کود، و اجرای تناوب زراعی برای دستیابی به یک سامانه تولید پایدار نیشکر تأکید دارد. این روند از یک سامانه وابسته به سموم شیمیایی به یک چهارچوب چندسویه مدیریت تلفیقی، جایگاه سرنوشت‌ساز راهبردهای سازش‌پذیر و پژوهش‌بنیان را برای ماندگاری درازمدت زیست‌بوم‌های کشاورزی نیشکر در ایران برجسته می‌کند.

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## Introduction

Sugarcane (*Saccharum officinarum* L.) is a significant economic crop, supplying over 60% of the global sugar demand (Sulaiman et al., 2023). It is widely cultivated in several countries located in tropical and subtropical regions of the world. The main sugar-producing countries globally are Brazil, India, China, and Thailand (Voora et al., 2023). Sugarcane is cultivated on approximately 27.3 million hectares in over 90 countries worldwide (FAOSTAT, 2023). This plant is an important global crop, recognized not only for sugar production but also as a notable option for bioenergy production (Surendran et al., 2016; Gunarathna et al., 2018). Brazil, India, the European Union, and China, with shares of 24, 15, 9, and 6% (equivalent to 43.7, 28, 16.5, and 11 million tons), respectively, are the largest sugarcane producers in the world (USDA, 2024). In Iran, the growing environment for sugarcane requires high temperatures, frequent irrigation, wide row spacing (150-183 cm), and the application of chemical fertilizers. In the 2022-2023 crop year, the cultivated area of sugarcane in Khuzestan province reached 102 thousand hectares. With a production of 7.59 million tons of sugarcane and a yield of 74 tons per hectare, it ranked third (10.05% of the total) after silage corn and wheat in terms of production of irrigated field crops. Khuzestan province, with a 99.99% share, was the largest producer of sugarcane in the country that year (Anonymous, 2024a).

## Weed Damage in Sugarcane and the Importance of Control

Sugarcane is an important crop for bioenergy and sugar production. It annually is damaged by

various biotic and abiotic factors, among which weeds are one of the most important limiting factors (Hussain et al., 2018).

Weeds exhibit very high diversity in the sugarcane fields of Khuzestan. Results from conducted studies have shown that so far, over 140 plant species have been recorded in sugarcane fields, of which about 60 species are competitive with this crop and have been reported as weeds in sugarcane fields. Among these weeds, 18 annual and 13 perennial species have greater importance and distribution compared to other species (Zand et al., 2009; Abdolahi Lorestani et al., 2019a). The studies conducted show that the share of weeds in reducing sugarcane yield can be between 50 to 80 percent, and in other studies including in countries like India, Indonesia, the Philippines, Sudan, and Ethiopia, it is significant and ranges from a minimum of 16 to a maximum of 96 percent (Yirefu et al., 2012; Elahifard et al., 2017). Results from various studies have shown that the critical period for weed control in sugarcane, in order to reduce competition and limit maximum yield loss to 5%, is within 3 to 4 months after planting (Maurya et al., 2021). Sugarcane being a long duration crop and due to its initial slow growth it takes longer time for ground coverage and so crop faces tough competition with weeds upto 120 days after planting (DAP) which causes significant yield reduction. The critical period of crop weed competition in sugarcane ranged between 100 to 105 days (Rathika et al., 2023). In Iran, effective weed management particularly before the sugarcane canopy is fully developed within the initial 100 days after planting, is also

extremely critical (Abdolahi Lorestani et al., 2008).

### Diversity and Importance of Weeds in Iranian Sugarcane Fields

Since the beginning of sugarcane cultivation in Iran and the conversion of uncultivated and virgin lands into sugarcane fields located in the north and south of Khuzestan, predominant annual and biennial broadleaf and grass weeds included *Beta maritima* L., *Malva neglecta* Wallr., *Spergula fallax* (Lowe) E.H.L.Krause., *Scorpiurus muricatus* L., *Sonchus* spp., *Schanginia aegyptiaca* L., *Carthamus oxyacantha* M.Bieb., *Medicago* spp., *Melilotus indicus* (L.) All., *Sonchus asper* (L.) Hill, *Sonchus oleraceus* L., *Cressa cretica* L., *Trifolium* spp., *Eruca sativa* Mill., *Erucaria hispanica* (L.) Druce., *Aeluropus littoralis* (Gouan) Parl., *Alhagi pseudalhagi* (M.B.) Desv., *Alopecurus myosuroides* Huds., *Dichanthium annulatum* (Forssk.) Stapf, *Setaria glauca* (L.) P. Beauv., *Panicum capillare* L., *Polypogon monspeliensis* (L.) Desf., *Diplachne fusca* (L.) P. Beauv. ex Roem. & Schult., *Digitaria sanguinalis* (L.) Scop., *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) P. Beauv., and *Phalaris minor* Retz. (Bani Abbasi et al., 1971; Khajavi, 1978; Kazemi, 1990b; Dezfoli, 1997; Mousavi, 2001; Pour Azar et al., 2011b). Some weeds with lesser importance in distribution and density have also been consistently present in sugarcane fields, among which *Capsella bursa-pastoris* (L.) Medik., *Anagallis arvensis* L., *Dinebra retroflexa* (Vahl) Panz., *Heliotropium*

*europaeum* L., *Urtica urens* L., *Spergularia marina* (L.) Besser., and *Spergula fallax* (Lowe) E.H.L. Krause. can be mentioned. In some leached fields, some hydrophilic weeds such as *Phragmites australis* (Cav.) Trin. ex Steud., *Typha angustifolia* L., *Juncus* spp., *Scirpus* spp., and *Cyperus rotundus* L. are also observed in patches and dense stands (Pour Azar et al., 2011b; Abdolahi Lorestani et al., 2019a).

In some sugarcane fields with inadequate drainage and high water table, perennial weeds including *Imperata cylindrica* (L.) P. Beauv., *Sorghum halepense* (L.) Pers., *Paspalum dilatatum* Poir., *Cynodon dactylon* (L.) Pers., *Cynanchum acutum* L., *Convolvulus arvensis* L., *Cyperus rotundus* L., and *Trachomitum venetum* L. are among the important and problematic types (Taherkhani, 1999; Ahmadpour & Alizadeh, 2008a; Ahmadpour & Alizadeh, 2008b; Abdolahi Lorestani et al., 2023b). These species are often able to complete their life cycle in the fields during the crop growth stage and spread not only by seed but also through reproductive organs such as tubers, rhizomes, stolons, and roots (Taherkhani et al., 2003; Abedinzadeh, 2006; Abdolahi Lorestani et al., 2021b; Eskandari et al., 2022). Given the importance and role of understanding the biological and ecological characteristics of weeds, especially the perennial and problematic species in sugarcane fields, in their management, numerous studies have been conducted in this area, the results of which are summarized in Table 1.

**Table 1.** Summary of the results of research conducted to determine the biological characteristics of perennial sugarcane weeds and the effect of environmental stresses on them.

| Weed Species                                       | Key Findings and Management Implications                                                                                                                                                                                                                                                                                                                                                                                                                | References                                                              |
|----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Cogongrass<br>( <i>Imperata cylindrica</i> )       | High Stress Tolerance: Seed germination tolerates salinity up to 160 mM NaCl and drought up to -0.8 MPa osmotic potential. Rhizomes can germinate even under saline (6.42 dS/m) and drought (-0.96 MPa) stress, confirming its high resilience.<br>Management Implications: Requires strategies targeting both seeds and resilient rhizomes.                                                                                                            | Abin et al. (2014);<br>Hamidavi et al. (2015)                           |
| Bearded Sprangletop<br>( <i>Leptochloa fusca</i> ) | Cardinal Temperatures: Base temperature: 1.4°C; Optimal range: 9.2-40.8°C; Ceiling temperature: 54.7°C.<br>Management Implications: Use thermal thresholds to predict emergence and plan pre-emergence control.                                                                                                                                                                                                                                         | Ebrahimi et al. (2017);<br>Ghanbarpour et al. (2015)                    |
| Swallow-wort<br>( <i>Cynanchum acutum</i> L.)      | Germination Dynamics: Peak germination rate occurs 56 days after fruiting at ~30°C (97% germination). Seedlings from seeds and root buds require 349.09 and 428.58 GDD, respectively, to reach 50% emergence.<br>Spatial Distribution: Exhibits a strong patchy distribution (patch diameter 14-23 meters before earthing up).<br>Management Implications: Critical control window is within 2 weeks after fruiting. Use GDD models and target patches. | Abdolahi Lorestani et al. (2020)<br>Abdolahi Lorestani et al. (2021a,b) |

From the late 1990s and during the 2000s and 2010s, the weed population in sugarcane underwent relative changes, resulting in increased density and distribution of some weeds including *Malva neglecta*, *Rottboellia cochinchinensis* (Lour.) Clayton., *Galium aparine* L., *Alternanthera philoxeroides* (Mart.) Griseb., *Polygonum aviculare* L., *Eclipta prostrata* (L.) L., *Leptochloa fusca* ssp. *fascicularis* (Lam.) N. Snow, *Cynanchum acutum*, *Physalis divaricata* D. Don, *Corchorus trilocularis* L., *Crepis sancta* (L.) Bornm., and *Cleome viscosa* L. (Pour Azar et al., 2011b; Rafatjoo & Saedi Nasab 2013c; Abdolahi Lorestani et al., 2019a; Abdolahi Lorestani et al., 2021c). So far, in total, over 140 weed species from 118 genera and 37 families have been observed in sugarcane fields, among which the highest number of weed species belong to the families Poaceae with 36 species,

Asteraceae with 26 species, Fabaceae with 12 species, Brassicaceae with 10 species, and Chenopodiaceae with 6 species (Dezfoli, 1997; Saradar Zadeh, 2006; Ahmadpour & Alizadeh, 2008a, b; Abdolahi Lorestani et al., 2019a).

Considering the various aspects of damage caused by these weeds, determining their relative importance in the sugarcane agro-industries has been an estimate and depends on various factors including the weed's life cycle, seed production capacity, vegetative reproductive organs (rhizomes, stolons, tubers), the quality of land preparation operations, etc. (Pour Azar et al., 2011b; Abdolahi Lorestani et al., 2019a). Accordingly, among the weeds in Khuzestan's sugarcane fields, 15 annual broadleaf species (Table 2), 11 annual grassy weeds (Table 3), and 17 perennial species (Table 4) have relatively greater importance and distribution.

**Table 2.** Importance and distribution of annual broadleaf weeds in Sugarcane fields of Khuzestan province, Iran (Bani Abbasi et al., 1971; Khajavi, 1978; Kazemi, 1990b; Dezfoli, 1997; Mousavi, 2001; Pour Azar et al., 2011b).

| Scientific Name | Location of Weed Presence (Agro-industries Co.) |
|-----------------|-------------------------------------------------|
|-----------------|-------------------------------------------------|

|                                      | In the North of Khuzestan | In the South of Khuzestan |
|--------------------------------------|---------------------------|---------------------------|
| <i>Carthamus oxycantha</i> M.Bieb.   | * 2                       | ** 2                      |
| <i>Chenopodium murale</i>            | * 3                       | * 1                       |
| <i>Cleome viscosa</i>                | ** 1                      | ** 1                      |
| <i>Corchorus trilocularis</i>        | ** 1                      | ** 1                      |
| <i>Cucumis melo</i> L.               | * 2                       | * 2                       |
| <i>Erigeron canadensis</i> L.        | * 2                       | * 2                       |
| <i>Lactuca serriola</i> L.           | * 3                       | ** 2                      |
| <i>Malva neglecta</i>                | * 2                       | ** 3                      |
| <i>Medicago</i> spp.                 | ** 2                      | ** 3                      |
| <i>Melilotus indicus</i>             | ** 4                      | ** 4                      |
| <i>Physalis divaricata</i>           | ** 2                      | ** 2                      |
| <i>Polygonum patulum</i> L.          | * 2                       | ** 2                      |
| <i>Silybum marianum</i> (L.) Gaertn. | ** 1                      | * 1                       |
| <i>Sonchus asper</i>                 | *** 3                     | ** 3                      |
| <i>Xanthium strumarium</i> L.        | * 2                       | ** 1                      |

Importance guide: (\*) Unimportant, (\*\*) Moderately important, (\*\*\*) Important. Distribution guide: (1) Low spread, (2) Moderate spread, (3) High spread, (4) Very high spread. (-) indicates absence or no data.

**Table 3.** Importance and distribution of annual grassy weeds in Sugarcane fields of Khuzestan province, Iran (Bani Abbasi et al., 1971; Khajavi, 1978; Kazemi, 1990b; Dezfoli, 1997; Mousavi, 2001; Pour Azar et al., 2011b).

| Scientific Name                                  | Location of Weed Presence (Agro-industries Co.) |                           |
|--------------------------------------------------|-------------------------------------------------|---------------------------|
|                                                  | In the North of Khuzestan                       | In the South of Khuzestan |
| <i>Alopecurus myosuroides</i>                    | ** 2                                            | ** 1                      |
| <i>Avena ludoviciana</i> L.                      | ** 2                                            | ** 1                      |
| <i>Brachiaria</i> sp.                            | *** 1                                           | -                         |
| <i>Dichanthium annulatum</i>                     | *** 3                                           | ** 2                      |
| <i>Digitaria sanguinalis</i>                     | ** 1                                            | * 1                       |
| <i>Echinochloa colona</i>                        | *** 4                                           | *** 4                     |
| <i>Leptochloa fusca</i> ssp. <i>fascicularis</i> | ** 2                                            | *** 4                     |
| <i>Phalaris minor</i>                            | ** 3                                            | ** 3                      |
| <i>Polypogon monspeliensis</i>                   | *** 3                                           | ** 1                      |
| <i>Rottboellia cochinchinensis</i>               | *** 1                                           | -                         |
| <i>Setaria glauca</i>                            | ** 3                                            | ** 2                      |

Importance guide: (\*) Unimportant, (\*\*) Moderately important, (\*\*\*) Important. Distribution guide: (1) Low spread, (2) Moderate spread, (3) High spread, (4) Very high spread. (-) indicates absence or no data.

### Key Challenges in Sugarcane Weed Management

Effective weed management in sugarcane is hindered by several interconnected challenges, which can be summarized as follows:

#### Neglect of Prevention and Field Sanitation

The fundamental principle of prevention is often overlooked, leading to the introduction and spread of weed seeds via irrigation water, wind, and contaminated machinery. Essential practices such as field monitoring, using certified seeds, and cleaning equipment are frequently neglected (Anonymous, 2007b; Abdolahi Lorestani et al., 2019a).

### Inefficient Spraying Equipment and Technology

Key issues include the use of outdated sprayers and nozzles, inadequate operator knowledge, poor calibration, and improper storage of herbicides. These factors reduce application efficacy, increase resistance risks, and pose contamination hazards. Environmental conditions and poor field preparation further diminish herbicide performance (Ahmadpour and Abdolahi Lorestani, 2013b; Abdolahi Lorestani et al., 2019a).

**Table 4.** Importance and distribution of perennial weeds in Sugarcane fields of Khuzestan province, Iran (Taherkhani, 1999; Saradar Zadeh, 2006; Ahmadpour & Abdolahi Lorestani, 2008a; Ahmadpour & Alizadeh, 2008a; Abdolahi Lorestani et al., 2019a).

| Scientific Name                           | Location of Weed Presence (Agro-industries Co.) |                           |
|-------------------------------------------|-------------------------------------------------|---------------------------|
|                                           | In the North of Khuzestan                       | In the South of Khuzestan |
| <b>Grassy Weeds</b>                       |                                                 |                           |
| <i>Aeluropus littoralis</i> (Gouan) Parl. | ** 3                                            | ** 2                      |
| <i>Cynodon dactylon</i>                   | *** 3                                           | *** 3                     |
| <i>Diplachne fusca</i>                    | *** 4                                           | *** 4                     |
| <i>Eleusine indica</i> (L.) Gaertn.       | * 2                                             | * 1                       |
| <i>Imperata cylindrica</i> (L.) P. Beauv. | *** 4                                           | *** 4                     |
| <i>Panicum capillare</i>                  | ** 2                                            | * 1                       |
| <i>Paspalum distichum</i> L.              | ** 2                                            | * 1                       |
| <i>Phragmites australis</i>               | ** 4                                            | ** 4                      |
| <i>Sorghum halepense</i>                  | *** 3                                           | *** 2                     |
| <b>Broadleaved Weeds</b>                  |                                                 |                           |
| <i>Convolvulus arvensis</i>               | *** 3                                           | *** 2                     |
| <i>Conyzanthus squamatus</i> (L.) Gaertn  | ** 2                                            | ** 2                      |
| <i>Cynanchum acutum</i>                   | *** 2                                           | *** 4                     |
| <i>Cyperus rotundus</i>                   | *** 3                                           | ** 2                      |
| <i>Glycyrrhiza glabra</i> L.              | ** 1                                            | ** 1                      |
| <i>Ipomoea cairica</i> (L.) Sweet         | * 2                                             | * 2                       |
| <i>Trachomitum venetum</i>                | ** 2                                            | ** 2                      |

Importance guide: (\*) Unimportant, (\*\*) Moderately important, (\*\*\*) Important. Distribution guide: (1) Low spread, (2) Moderate spread, (3) High spread, (4) Very high spread. (-) indicates absence or no data.

### Herbicide Resistance and Limited Herbicide Portfolio

Overreliance on chemical control has led to resistance in major weeds like *Echinochloa colona* to Photosystem II inhibitors (e.g., metribuzin, atrazine) (Elahifard et al., 2013, 2017; Ahmadpour et al., 2017). The limited availability of selective herbicides with diverse modes of action restricts the implementation of effective resistance management strategies such as herbicide rotation (Sayyad Mansour, 2007a; Ahmadpour et al., 2017).

### Impact of Inefficient Water and Input Management

Low water-use efficiency and imbalanced fertilizer application promote weed growth and competition. Weeds exploit these resources, leading to increased crop damage. Additionally, aquatic weeds in irrigation canals reduce water efficiency and damage infrastructure (Ahmadpour & Alizadeh, 2008b; Abbasi &

Sheini Dashtgol, 2016; Pour Azar et al., 2011b; Abdolahi Lorestani et al., 2023b).

### Shifts in Weed Flora and Invasion of Aggressive Species

Rapid changes in weed communities and the invasion of highly competitive perennial species, such as *Cynanchum acutum* and *Leptochloa fusca* ssp. *fascicularis*, have complicated control efforts (Ebrahimi et al., 2017; Abdolahi Lorestani et al., 2021c). Managing these species requires a deep understanding of their biology and ecology.

### Methodology

To compile the review article entitled "Sugarcane Weed Management in Iran: Evolution and Current Status," a systematic methodology was employed. First, a comprehensive search was conducted across relevant domestic and international scientific databases, conference proceedings, and the

archives of research reports of the Iranian Sugarcane Research and Training Institute. The inclusion criteria encompassed the direct relevance of the content to sugarcane weed management under Iranian conditions and the availability of the full-text. Following the collection, documents were screened based on their titles and abstracts. Pertinent data were then extracted from the selected sources and systematically classified according to a methodological framework comprising five principal categories: "Basic Studies," "Applied Field Studies," "Management & Strategic Studies," "Review & Meta-Studies," and

"Technological & Innovative Studies" (Table 5). This framework was adopted to move beyond a purely thematic analysis and to critically examine the nature and scope of the research conducted. A qualitative and quantitative content analysis was performed, taking into account the historical sequence and prevailing methodological trends. Subsequently, by synthesizing these findings, a comprehensive overview of the evolution of research approaches, current knowledge status, and future directions within this domain is presented.

**Table 5.** Distribution of literature by primary weed management category.

| No.              | Methodological Category            | Definition                                                                                  | Number of References | Percentage (%) |
|------------------|------------------------------------|---------------------------------------------------------------------------------------------|----------------------|----------------|
| 1                | Basic Studies                      | Foundational research on weed biology, ecology, physiology, and identification.             | 33                   | 20.6           |
| 2                | Applied Field Studies              | Field trials evaluating the efficacy of a specific method, tool, or input.                  | 103                  | 64.4           |
| 3                | Management & Strategic Studies     | Research focused on developing, comparing, or evaluating management strategies and systems. | 15                   | 9.4            |
| 4                | Review & Meta-Studies              | Review articles, guidebooks, policy reports, and meta-analyses.                             | 7                    | 4.4            |
| 5                | Technological & Innovative Studies | Research centered on developing, modifying, or assessing novel technologies and inputs.     | 2                    | 1.2            |
| Total References |                                    |                                                                                             | 160                  | 100            |

### Guidelines for Weed Control in Iranian Sugarcane Fields

In Iran, chemical control using herbicides has always been the most important strategy for controlling weeds, to the extent that overreliance resulted in an average consumption of up to 20 kg or L per hectare during one growing season of sugarcane field. This approach led to a dramatic increase in herbicide consumption, the emergence of herbicide resistance (*Echinochloa colona*), the establishment of some new weed species (*Physalis divaricata*, *Cleome viscosa*,

*Cynanchum acutum*), created environmental problems, and higher control costs (Pour Azar et al., 2011b). Currently, the main methods of weed control in Khuzestan's sugarcane include chemical control using herbicides and mechanical control. Most of the research conducted on sugarcane weed control has belonged to chemical herbicides, their application methods, and thereafter mechanical and physical control. A summary of the results of research conducted over the past three decades (1990–2025) for each control method is presented in Tables 6, 7, and 8.

**Table 6:** Comprehensive review of herbicide efficacy and resistance groups in Iranian Sugarcane fields.

| Herbicide Group (HRAC) & Herbicide   | Herbicide Combination and Formulation                  | Application Rate & Key Findings                                                                                                     | References                                                                                                                                                                                                |
|--------------------------------------|--------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Triazines (5)                        | Atrazine (WP 80%)                                      | 1-4 kg ha <sup>-1</sup> (Pre): 50-80% control; Better on broadleaves.                                                               | Taherkhani (1999); Makvandi et al. (2011); Rafatjoo et al. (2013a); Anonymous (2007a).                                                                                                                    |
|                                      | Atrazine (WP 80%) + Metribuzin (WP 70%)                | 2+2 and 3+2 kg ha <sup>-1</sup> (Pre): Best density reduction; increased yield.                                                     | Taherkhani et al. (2003); Makvandi et al. (2011); Abdolahi Lorestani et al. (2021d).                                                                                                                      |
|                                      | Metribuzin (WP 70%)                                    | 2.5 kg ha <sup>-1</sup> (Pre and Early Post): Best density reduction; increased yield.                                              | Abdolahi Lorestani et al. (2019c); Makvandi et al. (2011).                                                                                                                                                |
|                                      | Ametryn (WG 80%)                                       | 2-2.5 kg ha <sup>-1</sup> (Pre): Control of annual broadleaf and grass weeds.                                                       | Abedinzadeh & Ahmadi (2006).                                                                                                                                                                              |
|                                      | Ametryn (WG 80%) + Atrazine (WP 80%)                   | 6+6 kg ha <sup>-1</sup> (Pre): Effective control without crop damage.                                                               | Kazemi (1990a).                                                                                                                                                                                           |
| Triazines (5) + Synthetic Auxins (4) | Atrazine (DF 90%)                                      | 1-2 kg ha <sup>-1</sup> (Pre): control of annual broadleaf and grass weeds.                                                         | Anonymous (2007a).                                                                                                                                                                                        |
|                                      | Terbuthylazine + MCPA (SC 27.5+16%)                    | 1-1.5 L ha <sup>-1</sup> (Pre): control of annual broadleaf and grass weeds.                                                        | Anonymous (2007a).                                                                                                                                                                                        |
| Triazines (5)                        | Metribuzin (EC 48%)                                    | 3-3.5 L ha <sup>-1</sup> (Pre): control of annual broadleaf and grass weeds.                                                        | Anonymous (2023).                                                                                                                                                                                         |
| Sulfonylureas (2) + Triazines (5)    | Trifloxysulfuron-sodium + Ametryn (WG 75%)             | 2-2.5 kg ha <sup>-1</sup> (Pre): Superior control of <i>Cyperus rotundus</i> and <i>Echinochloa colona</i> : Mild phytotoxicity.    | Pour Azar et al. (2006a); Pour Azar et al. (2008); Boromand Far et al. (2008); Ahmadpour et al. (2009); Abdolahi Lorestani et al. (2019c); Sayyad Mansour (2007b); Ahmadpour & Abdolahi Lorestani (2006). |
| Sulfonylureas (2)                    | Mesosulfuron + Iodosulfuron + Mefenpyr-diethyl (WG 6%) | 250-400 g ha <sup>-1</sup> (Post, 2-3 leaf): Effective control of annual weeds.                                                     | Farahbakhsh et al. (2005); Al-Kathir & Borumandfar, (2003); Soraghi et al. (2003).                                                                                                                        |
| Sulfonylureas (2)                    | Sulfosulfuron (WG75%)                                  | 6-7 g ha <sup>-1</sup> (with surfactant): control of annual grass weeds.                                                            | Al-Kathir et al. (2003).                                                                                                                                                                                  |
| Sulfonylureas (2)                    | Rimsulfuron (25%)                                      | 40-60 g ha <sup>-1</sup> (Post): Control of annual weeds. Causes phytotoxicity.                                                     | Al-Kathir et al. (2003).                                                                                                                                                                                  |
| Sulfonylureas (2)                    | Nicosulfuron (OD 4%)                                   | 2 L ha <sup>-1</sup> (Post): Control of perennial grasses. Causes crop injury.                                                      | Rafatjoo et al. (2013a); Abdolahi Lorestani et al. (2024).                                                                                                                                                |
| Triazines (5) + Ureas (5)            | Tebuthiuron (SC 50%) + (Atrazine (WP 80%))             | 2+2 kg ha <sup>-1</sup> (Pre): Highest efficacy on annual weeds; superior combination.                                              | Taherkhani et al. (2003); Shimi et al. (2004); Mohemati Shirazi et al. (2003); Abedinzadeh (2005); Daman Afshan & Maknali (2005b).                                                                        |
| Dinitroanilines (3)                  | Pendimethalin (CS 45.5%)                               | 3 L ha <sup>-1</sup> (Early post): Best density reduction; increased yield.                                                         | Abdolahi Lorestani et al. (2020).                                                                                                                                                                         |
|                                      | Pendimethalin (EC 33%)                                 | 2-3.5 L ha <sup>-1</sup> (Pre): Effective in late-harvest; 91-92% efficacy on <i>E. colona</i> ; controls triazine-resistant weeds. | Kheyr Andish et al. (2013); Abdolahi Lorestani et al. (2023a); Abin et al. (2017); Abdolahi Lorestani et al. (2019c, 2020); Ahmadpour et al. (2013);                                                      |

| Herbicide Group (HRAC) & Herbicide                     | Herbicide Combination and Formulation                  | Application Rate & Key Findings                                                                                                                 | References                                                                                                                                |
|--------------------------------------------------------|--------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
|                                                        |                                                        |                                                                                                                                                 | Ehsanipour et al. (2024); Anonymous (2024b).                                                                                              |
|                                                        | Trifluralin (EC 48%)                                   | 2-2.5 L ha <sup>-1</sup> (Soil Inc.): Control of annual weeds.                                                                                  | Rezaei et al. (2017); Haji Sharafi (2005, 2006).                                                                                          |
| Chloroacetamides (15)                                  | Alachlor (EC 50%)                                      | 3-5 L ha <sup>-1</sup> (Pre): control of annual weeds.                                                                                          | Kazemi (1990b, 1995); Rokouei et al. (2008); Abdolahi Lorestani et al. (2019a).                                                           |
| Chloroacetamides (15) + Triketone (27) + Triazines (5) | S-Metolachlor + Mesotrione + Terbutylazine (SE 53.75%) | 4 L ha <sup>-1</sup> (Pre): Suitable efficacy; safe for sugarcane.                                                                              | Sasanfar et al. (2021); Abdolahi Lorestani et al. (2019b).                                                                                |
| Chloroacetamides (15)                                  | Acetochlor (EC 50%)                                    | 3 L ha <sup>-1</sup> (Pre): control of annual weeds.                                                                                            | Abdolahi Lorestani et al. (2019c).                                                                                                        |
| Diphenyl Ethers (14)                                   | Oxyfluorfen (EC 24%)                                   | 1.5-2 L ha <sup>-1</sup> (Pre to Early Post): Highest population reduction; controls annual weeds. Phytotoxic.                                  | Bigdeli Shamloo et al. (2003); Al-Kathir et al. (2003); Ebrahimi et al. (2023).                                                           |
| Isoxazoles (27)                                        | Isoxaflutole (WG 75%)                                  | 100-200 g ha <sup>-1</sup> (Pre): control of annual weeds.                                                                                      | Taherkhani et al. (2003); Al-Kathir et al. (2003); Daman Afshan & Maknally (2005a); Farahbakhsh & Taherkhani (2005).                      |
| Isoxazoles (27) + Triazines (5)                        | Isoxaflutole (WG 75%) + Atrazine (WP 80%)              | 200 g + 2.5 kg ha <sup>-1</sup> (Pre): Effective weed control; better combination.                                                              | Daman Afshan et al. (2003a).                                                                                                              |
| Imidazolinones (2)                                     | Imazamethabenz-methyl (EC 25%)                         | 2.5 L ha <sup>-1</sup> (Post): control of annual weeds.                                                                                         | Daman Afshan et al. (2003a); Bigdeli Shamloo et al. (2003).                                                                               |
| Triazolinones (5)                                      | Amicarbazone (WG 70%)                                  | 2 kg ha <sup>-1</sup> (Pre): control of annual weeds.                                                                                           | Pour Azar (2011c); Ahmadpour et al. (2011); Abdolahi Lorestani & Pour Azar (2012b); Pour Azar (2011a); Abdolahi Lorestani et al. (2019c). |
| Triazinones (5)                                        | Hexazinone + Diuron (DF 60%)                           | 4 kg ha <sup>-1</sup> (Pre): Control of annual weeds.                                                                                           | Sayyad Mansour (2007b); Pour Azar et al. (2006b, 2008); Ahmadpour et al. (2013).                                                          |
| Alkylazines (29)                                       | Indaziflam (SC 50%)                                    | 100-125 mL ha <sup>-1</sup> (Pre): >85% control; density reduction up to 90%. Superior control of <i>C. rotundus</i> (150 mL ha <sup>-1</sup> ) | Zand et al. (2016); Abin et al. (2017, 2019); Abdolahi Lorestani et al. (2019c); Ahmadi et al. (2017); Kheyr Andish et al. (2024).        |
| Alkylazines (29) + Triazines (5)                       | Indaziflam (SC 50%) + Metribuzin (WP 70%)              | 150 mL + 2 kg ha <sup>-1</sup> (Pre): 90% control; potential for consumption reduction.                                                         | Kheyr Andish et al. (2024).                                                                                                               |
| Carbamates (8)                                         | EPTC (EC 82%)                                          | 3.12-8 L ha <sup>-1</sup> (Pre): Better efficacy on <i>D. annulatum</i> ; grass weed control.                                                   | Kazemi (1990a); Kazemi (1998); Rokouei et al. (2008).                                                                                     |
| Glycin (9)                                             | Glyphosate (SL 41%)                                    | 2-3% (Post): Highest control of <i>R. cochinchinensis</i> ; significant density /dry weight reduction.                                          | Rafatjoo & Saedi Nasab (2013c).                                                                                                           |
| Synthetic Auxins (4) + Triazines (5)                   | (2,4-D + MCPA) + Ametryn (SL 67.5% + WP 80%)           | (Post): Highest weed control and sugarcane yield; Optimal combination.                                                                          | Ahmadpour et al. (2009).                                                                                                                  |

| Herbicide Group (HRAC) & Herbicide | Herbicide Combination and Formulation  | Application Rate & Key Findings                                                                           | References                                                       |
|------------------------------------|----------------------------------------|-----------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| Synthetic Auxins                   |                                        |                                                                                                           |                                                                  |
| (4) + Chloroacetamides             | Quinmerac + Metazachlor (SC 33.3+8.3%) | 2.5 L ha <sup>-1</sup> (Pre): control of annual weeds.                                                    | Abdolahi Lorestani et al. (2019c).                               |
| (15) Nitrile (6)                   |                                        |                                                                                                           |                                                                  |
| Synthetic Auxins (4)               | Ioxynil + 2, 4-D (EC70%)               | 2 L ha <sup>-1</sup> (Post): control of annual weeds.                                                     | Ahmadpour & Abdolahi Lorestani (2006, 2013a); Anonymous (2007a). |
| Synthetic Auxins (4)               | Clopyralid (SL30%)                     | 600-800 ml ha <sup>-1</sup> (Post): control of annual weeds. Limited spectrum.                            | Daman Afshan et al. (2003b).                                     |
| Synthetic Auxins (4)               | Triclopyr (EC 48%)                     | 2-2.5 L ha <sup>-1</sup> (Post): Control of annual /perennial broadleaves, emphasis on <i>C. acutum</i> . | Anonymous (2025).                                                |

Table 7. Mechanical and physical weed control methods in Sugarcane - A research review.

| Method/Tool Studied                              | Research Implications                             | Key Findings                                             | Reference                        |
|--------------------------------------------------|---------------------------------------------------|----------------------------------------------------------|----------------------------------|
| Hilling up (earthing up)                         | Simple mechanical method for annual weed          | Weed density reduction (up to 75%) vs. control           | Ahmadpour et al. (2011)          |
| Sweep cultivator                                 | Optimal tool for mechanical control               | Effective when used properly                             | Abdolahi Lorestani (2012a)       |
| Seasonal mechanical control (autumn/winter)      | Cost-effective integrated management              | 80% cost reduction when combined with chemicals          | Hossein Zadeh et al. (2012)      |
| Deep moldboard plowing (30-40 cm)                | Suitable for control of perennial weeds in fallow | Effective control of <i>Imperata cylindrica</i> rhizomes | Rafatjoo et al. (2013b)          |
| Optimizing sweep cultivator operation            | Critical operational parameters                   | Best at 10 km/h with 14-16% soil moisture                | Hamidavi et al. (2014)           |
| Disk cultivator + broadcast fertilization        | Supplementary effect on weed control              | Enhanced canopy closure and highest cane yield           | Abdolahi Lorestani et al. (2014) |
| Black polyethylene plastic mulch                 | Sustainable reduction in herbicide dependency     | Effective control of <i>Imperata cylindrica</i> patches  | Abedinzadeh et al. (2015)        |
| Comparative study: Rotovator vs sweep cultivator | choice of best tools for annual weed              | 96.4% and 94.7% weed reduction respectively              | Sharafizadeh et al. (2018)       |
|                                                  |                                                   |                                                          | Abdolahi Lorestani et al. (2017) |

**Table 8.** Research synthesis and practical recommendations for integrated weed management in Sugarcane.

| Methods/Tools Studied                                          | Key Findings                                                                                    | Practical Recommendations                                                        | References                                           |
|----------------------------------------------------------------|-------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|------------------------------------------------------|
| Band application + hilling-up + tillage                        | Significantly reduced weed density and control costs                                            | Combine band spraying with mechanical methods                                    | <a href="#">Ahmadpour et al. (2009)</a>              |
| Moldboard plow + glyphosate vs. disk + glyphosate              | Moldboard plow (2 passes) + glyphosate, showed 62.5% efficacy against <i>Cynanchum acutum</i>   | Use deep tillage combined with systemic herbicides during fallow.                | <a href="#">Abdollahi Lorestani et al. (2016)</a> .  |
| Herbicide combinations + mechanical control                    | Excellent broadleaf weed control with integrated approach                                       | Implement herbicide mixtures with mechanical weeding                             | <a href="#">Ahmadpour et al. (2011)</a> .            |
| Tillage + indaziflam pre-emergence ± post-emergence herbicides | Tillage + indaziflam most effective (6.33-9.33 plants/m <sup>2</sup> ) against <i>C. acutum</i> | Apply pre-emergence herbicides after tillage                                     | <a href="#">Parian et al. (2019)</a>                 |
| Mechanical weeding + herbicides                                | Rotovator + indaziflam showed 52.47% weed reduction and yield increase                          | Prefer rotovator and combine with residual herbicides                            | <a href="#">Rezaei et al. (2021)</a> .               |
| Sequential herbicides + mechanical weeding                     | 96% weed reduction and 102-104 ton/ha yield                                                     | Use sequential pre/post-emergence herbicides with mechanical control             | <a href="#">Abdollahi Lorestani et al. (2022)</a> .  |
| Deep tillage + herbicide combinations                          | 95.9-96.4% control of <i>C. arvensis</i> in spring-summer.                                      | Apply deep tillage followed by herbicide mixtures in warm seasons during fallow. | <a href="#">Abdollahi Lorestani et al. (2023c)</a> . |
| Dredging + glyphosate in drainage canals                       | Higher glyphosate rate (6 L/ha) more effective in warm seasons.                                 | Use elevated herbicide rates with dredging for aquatic weed management           | <a href="#">Abdollahi Lorestani et al. (2023b)</a> . |

## Chemical Control

### Pre-emergence Application

Pre-emergence herbicides are applied in plant cane and ratoon fields using tractor-mounted sprayers specific to sugarcane fields. Application of herbicides by the delayed pre-emergence method and/or early post-emergence is done before the second irrigation of the fields, which increases the efficiency and effectiveness of herbicides in controlling weeds. If at the time of spraying before the second irrigation, germination and emergence of annual grass and broadleaf species at early growth stages are observed in the field, herbicides metribuzin and/or 2,4-D + MCPA can be used in mixture with other recommended herbicides to achieve maximum weed control ([Anonymous, 2025](#)) (Table 8).

### Post-emergence Application

After performing pre-emergence spraying in new plantings and ratoon fields, usually for various reasons including clod formation in the furrow after ratoon subsoiling operations, soil bed disturbance due to hilling-up operations and displacement of weed seeds to the soil surface and provision of conditions for their germination, inadequate pre-emergence spraying due to nozzle clogging, problems with pesticide quality, leaching of the applied pesticide due to heavy irrigation, the reduction in residual activity of the herbicide due to chemical, photolytic, or microbial degradation, we will face weed emergence in sugarcane fields. Therefore, post-emergence control of weeds under such conditions will be essential. In the early stages of sugarcane growth where plant height is low, tractor-mounted (mechanized) spraying is used; otherwise,

manual spraying is performed. For this purpose, selective herbicides such as metribuzin and 2,4-D + MCPA are used. Typically, a mixture of selective herbicides is used for optimal control of various broadleaf and grass species. Non-selective herbicides are used for controlling annual and perennial species in a directed manner or on field margins (Anonymous, 2025) (Table 8).

### Mechanical and Physical Control

Mechanical or Physical control is among the strategies to reduce chemical pesticide use, which for example uses non-living mulch and mechanical tools such as sweep cultivator and rotovator. Cultivation between crop rows before weed establishment is very effective (Liebman & Zimdahl 2018; Abdolahi Lorestani 2015). Table 8 presents the latest guidelines for the application of mechanical and physical methods for controlling sugarcane weeds under crop growth and fallow conditions.

### Hand Weeding

In cases where chemical control of seasonal weeds is not possible for any reason, or delay in control has led to their excessive growth for using mechanized control methods (chemical/mechanical), hand weeding or hoeing operations can be used. In this method, laborers equipped with tools such as hand hoes, picks, trowels, rakes, and sickles are used. The average efficiency per worker for weeding grass weeds, broadleaf weeds, and a mixture of the two is 0.13, 0.18, and 0.16 hectares per day, respectively (Anonymous, 2025) (Table 8).

### Mechanized Weeding

The use of mechanical machine tools is done when weeds are in their early stages of growth and development. Under sugarcane growth conditions, this time period starts from late winter and can continue until mid-spring depending on the harvest time of sugarcane fields. Various implements including cultivators and rotovator (after hilling-up between rows), and combined cultivator (before hilling-up on the row) are used (Table 8). These equipment cultivate the soil to a depth of 5 (Up to 10) centimeters and cause cutting, uprooting, and burying of the weed's aerial organs. Uniform tillage of the soil bed and complete coverage of the tilled surface are advantages of this equipments. (Anonymous, 2025) (Table 8).

### Integrated Management

For fields where the infestation of perennial weeds has reached high density, the only effective control method is to take advantage of the fallow period for integrated weed management. In such fields - often severely infested with Cogongrass (*Imperata cylindrica*), common reed, or Swallow-wort (*Cynanchum acutum*) - the initial step should be the use of consecutive moldboard plowing + disc plowing (at least twice) with intervals of one to three weeks. During this process, light irrigation prior to tillage, spaced one-month apart, will help control rhizomes that may have escaped mechanical management. To complete mechanical operations, chemical control can be applied using non-selective herbicides like glyphosate. In standing crop fields, thick,

durable black plastic mulch can be used as a non-living mulch and physical barriers to cover patches of perennial weeds such as Cogongrass up to a maximum coverage of 200 square meters. Under such conditions, it is necessary that the aerial organs of the weeds have been destroyed beforehand, either using a contact herbicide (e.g., Glufosinate ammonium) or by

mowing. Then the patch surface should be thoroughly covered, and the edges of the cover should be sealed to prevent any opening or outlets that could allow weed growth. The retention period required for effective destruction of underground organs should be considered 4 to 6 months (Anonymous, 2025) (Table 9).

**Table 9.** Weed management framework in Iranian sugarcane fields.

| Management Strategy              | Category            | Key Herbicide Combinations / Techniques                                                                                                       | Key Technical Notes & Terminology                                                                                                      |
|----------------------------------|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| Chemical Control                 | Pre-Emergence       | Metribuzin (±Atrazine); Pendimethalin; Diuron; EPTC; Tebuthiuron.                                                                             | Applied before weed emergence; foundational for resistance management. Terms: Pre-emergence, Residual activity, Resistance management. |
|                                  | Post-Emergence      | 2,4-D + MCPA; Triclopyr; Glyphosate (directed); Glufosinate-ammonium; Metribuzin + (2,4-D + MCPA); S-metolachlor + Terbutylazine + Mesotrione | *4-6 weed leaf stage; phenoxy mixes control broadleaves. Terms: Systemic, Contact, Directed spraying                                   |
| Mechanical & Physical Control    | Tillage (Mechanize) | Inter-row cultivation (Sweep cultivator, Rotovator, other cultivators), Fallow (moldboard plow and Disc.                                      | *Effective at 6-8 weed leaf stage; soil moisture dependent. Terms: Inter-row cultivation, Soil moisture dependency                     |
|                                  | Manual Control      | Hand weeding                                                                                                                                  | High precision but labor-intensive. Terms: Labor-intensive, Precision.                                                                 |
| Integrated Weed Management (IWM) | Combined Methods    | Chemical-Mechanical: Glyphosate + tillage<br>Chemical-Physical: Herbicide + Plastic mulch<br>Cultural: Crop rotation (wheat, canola)          | Sustainable approach reducing herbicide reliance. Terms: Burndown, Crop rotation, Sustainable.                                         |

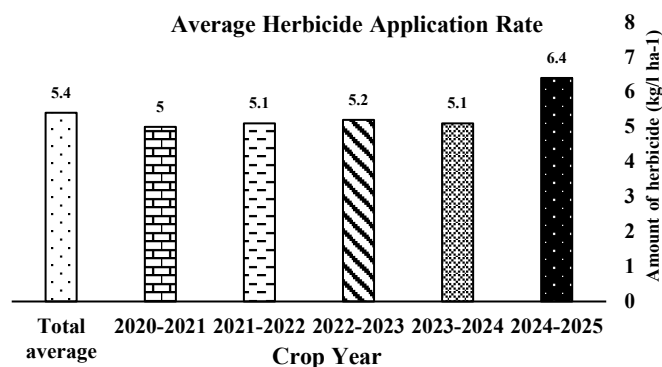
\*Note: This framework emphasizes strategic principles over specific application rates, which may vary based on regional regulations, soil conditions, and herbicide formulations. Always consult local agricultural extension services for region-specific recommendations

## Strategies for Improving Sugarcane Weed Management

### Diversifying the Herbicide Portfolio

In recent years, continuous efforts to introduce new herbicides from different chemical families and groups along with applying lower doses and changing methods of herbicide application, optimizing sprayer technology and using non-chemical weed control strategies, have contributed to a declining trend in herbicide use (Ahmadpour et al., 2013;

Abdolahi Lorestani et al., 2019a). A look at the trend of herbicide application over a five-year period shows that the general orientation has been towards optimal use and improved management of herbicides in sugarcane. Average consumption decreased from 20 kg/liter per hectare (Pour Azar et al., 2011b) until the late 2000s to nearly 12 kg/liter per hectare by the mid-2010s (Abdolahi Lorestani et al., 2019a), and reached six units or less by the end of the 2010s (Figure 1) (Anonymous, 2024b).



**Figure 1.** Average herbicide rate in sugarcane fields (plant and ratoon cane) during the crop years 2020-2021 to 2024-2025 (Anonymous, 2024b).

Considering the planting, cultivation, and harvesting conditions of sugarcane and the presence of weeds, a herbicide will be successful and effective when it has suitable persistence in controlling weeds during sugarcane growing season. As mentioned earlier, atrazine, metribuzin, ametryn and 2,4-D + MCPA, tebuthiuron, and EPTC (pre-emergence application by herbigation method) as selective herbicides and the two non-selective herbicides glyphosate and paraquat constituted all the herbicides used in sugarcane (Abdolahi Lorestani et al., 2019a). So far, the largest share of consumption among selective and non-selective herbicides has belonged to metribuzin and glyphosate, respectively (Anonymous, 2024b). One of the strategies to prevent resistance and reduced herbicide efficacy is introducing a greater number and diversity of herbicides and their rotational use in sugarcane. For example, using multi-purpose

herbicides and mixing compatible herbicides for simultaneous control of various types of weeds are among these advantages. Table 8 shows the characteristics and qualitative evaluation summary of herbicides tested over the past two decades to introduce new sugarcane herbicides (Pour Azar et al., 2011b; Abdolahi Lorestani et al., 2019a). Following the conducted investigations, a number of new herbicides with different modes of action were introduced for application in sugarcane fields (Abdolahi Lorestani et al., 2019a; Abdolahi Lorestani et al., 2021d; Anonymous, 2024b). The specifications of conventional and promising herbicides are presented in Table 10. Field evaluations for promising herbicides have been conducted in sugarcane agro-industries and are included in the spraying area development program based on the herbicide rotation model.

**Table 10.** Conventional and promising herbicides in Iranian sugarcane fields.

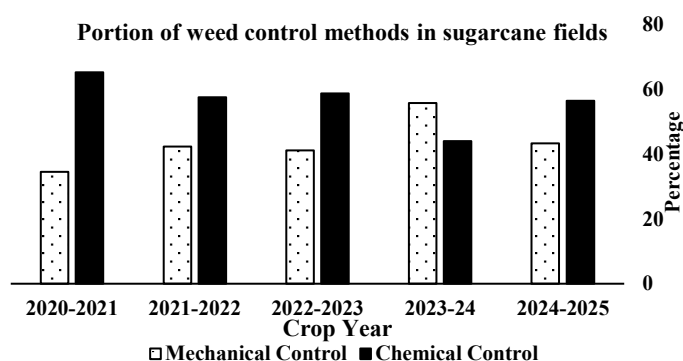
| Weed Species                                           | Key Findings and Management Implications | References                                                                                     |
|--------------------------------------------------------|------------------------------------------|------------------------------------------------------------------------------------------------|
| Metribuzin (WP 70%)                                    | Pre & Post-emergence                     | Photosynthesis inhibitor at PS II (C1)                                                         |
| Atrazine (WP 80%)                                      | Pre & Post-emergence                     | Photosynthesis inhibitor at PS II (C1)                                                         |
| Ametryn (WP 80%)                                       | Pre & Post-emergence                     | Photosynthesis inhibitor at PS II (C1)                                                         |
| Tebuthiuron (SC 50%)                                   | Pre & Post-emergence                     | Photosynthesis inhibitor at PS II (C1)                                                         |
| 2,4-D + MCPA (SL 67.5%)                                | Post-emergence                           | Synthetic auxins (O)                                                                           |
| EPTC (EC 80%)                                          | Pre-emergence                            | Lipid synthesis inhibitor (N)                                                                  |
| Glyphosate (SL 41%)                                    | Post-emergence                           | EPSPS synthase inhibitor (G)                                                                   |
| Paraquat* (SL 20%)                                     | Post-emergence                           | Photosynthesis inhibitor at PS I (D)                                                           |
| Diuron (DF 90%)                                        | Pre & Post-emergence                     | Photosynthesis inhibitor at PS II (C2)                                                         |
| Pendimethalin (CS 45.5%)                               | Pre emergence & Early Post-emergence     | Cell division inhibitor (K1)                                                                   |
| Indaziflam (SC 50%)                                    | Pre emergence & Early Post-emergence     | Cellulose synthesis inhibitor (Z)                                                              |
| Quinmerac + Metazachlor (SC 33.3+8.3%)                 | Pre emergence & Early Post-emergence     | Synthetic auxins (O) + Cell division inhibitor (K3)                                            |
| Acetochlor (EC 50%)                                    | Pre emergence & Early Post-emergence     | Cell division inhibitor (K3)                                                                   |
| Trifloxysulfuron-sodium + Ametryn** (WDG 75%)          | Pre emergence & Early Post-emergence     | ALS inhibitor (B) + Photosynthesis inhibitor at PS II (C1)                                     |
| Amicarbazone (WDG 70%)**                               | Pre emergence & Early Post-emergence     | Photosynthesis inhibitor at PS II (C1)                                                         |
| Mesotrione + S-metolachlor + Terbutylazine (SE 53.75%) | Post-emergence                           | Pigment inhibitor (F2) + Cell division inhibitor (K3) + Photosynthesis inhibitor at PS II (C1) |
| Metribuzin (SC 48%)                                    | Pre emergence & Post-emergence           | Photosynthesis inhibitor at PS II (C1)                                                         |
| Triclopyr (EC 48%)                                     | Post-emergence                           | Synthetic auxins (O)                                                                           |
| Pendimethalin (EC 33%)                                 | Pre-emergence                            | Cell division inhibitor (K1)                                                                   |

\* Its use is prohibited or \*\*unavailable

### Attention to Non-Chemical Control Methods

The employment of various tillage implements, especially in the past decade, for weed control in sugarcane fields (various types of sweep cultivator and rotovator) and during fallow (moldboard plow, disc, and sub-soiler) has increased the area of mechanical control. Statistical review of weed management in sugarcane agro-industries in recent years shows that overall reliance on herbicides has decreased, and in contrast, with emphasis on using non-

chemical control methods, the share of mechanical and manual weeding has increased (Anonymous, 2024b). Although the area of weeding operations has fluctuated in some years due to unfavorable weather conditions and patchy infestations of perennial weeds over relatively wide areas, it has nevertheless increased significantly, such that over a 5-year period from 2020-2021 to 2024-2025, it accounted for more than 30% of the weed control area in sugarcane fields (Figure 2).



**Figure 2.** Portion of chemical and Mechanical method (mechanized and manual) on weeds control in sugarcane fields during the crop years 2020-2021 to 2024-2025 (Anonymous, 2024b).

### Management of Perennial and Noxious Weeds of Sugarcane

Research into controlling perennial weeds should leverage modern technologies such as GPS, satellite guidance, and video imaging to monitor and target weed populations (Abdolahi Lorestani et al., 2021c). Key activities include improving expert training, establishing diagnostic and reporting systems for invasive species, creating distribution maps, and studying the biology and integrated management of these weeds (Abdolahi Lorestani et al., 2019a). Effective control requires species-specific strategies. For example, deep plowing to bury Cogongrass (*Imperata cylindrica*) rhizomes at a depth of 30-40 cm can suppress its growth (Hamidavi et al., 2014). Covering infested patches with black plastic or timely spraying with glyphosate application using Controlled Droplet Application (CDA) sprayers are also effective approaches (Parian et al., 2019; Sharafizadeh et al., 2018). Preventive measures are essential and include preventing the introduction of invasive species into new areas, rapid eradication of new patches, adhering to quarantine principles during the transfer of seed cuttings, and controlling weeds in fallow fields

using non-selective herbicides and tillage before they set seed (Pour Azar et al., 2011b).

### Optimizing Methods and Tools for Weed Control

Effective and efficient weed control is not possible without using methods and technologies that are novel and compatible with sugarcane cultivation. Some suggested strategies for optimizing sugarcane weed control include: using the delayed pre-emergence or early post-emergence spraying method (before the second irrigation in new plantings); limiting the use of the herbigation method for pre-emergence control in new planting fields as much as possible (except for controlling some weeds like *Dichanthium annulatum* and *Leptochloa fusca* ssp. *fascicularis* (Lam.) N. Snow to prevent herbicide loss through leaching and poor control); timely control and in the early growth stages of annual or perennial weeds considering their applied biology and ecology; designing and supplying sprayers specific to sugarcane fields, using microner sprayers, standard spraying equipment, and efficient mechanized weeding tools (Pour Azar et al., 2011b); using reduced doses of pre-emergence herbicides

especially from the second half of September in the planting season (Ahmadpour et al., 2013); using additives including surfactants, pH modifiers, and water hardness reducers (ammonium sulfate) to increase pesticide efficiency (Mirzaei et al., 2023); observing the timing and dose of herbicides, especially in post-emergence applications, as two important factors for achieving the highest level of weed control (Harker et al., 2004), using high-quality water for post-emergence spraying (Daramola et al., 2022; Buhler and Melinda, 1999).

### **Optimal Management of Water and Inputs to Reduce Weed Competition with Sugarcane**

The substantial water requirements of sugarcane, along with the use of nitrogen-based fertilizers during its cultivation, establish proper conditions for weed proliferation. In the absence of timely and effective control, weeds efficiently utilize these nutrient resources, rapidly colonize the field and through competition for light and other essential resources, they can lead to significant reductions in sugarcane yield (Kazemi, 1995; Tomar & Singh, 2024). The nitrogen (N) requirement of sugarcane is very high due to the extensive growth of biomass. N fertilisers are applied excessively to ensure the optimum growth of the sugarcane crop. Improper N management causes a decrease in nitrogen utilisation and leading to unintended negative consequences (Abhiram et al., 2025). In sugarcane fields of Iran, excessive irrigation (1400-1700 m<sup>3</sup>/ha) raises the water table, which hinders crop growth and promotes hydrophilic weeds (Sheini Dashtgol, 2015). Optimizing

water use through practices like irrigation scheduling, alternate furrow irrigation, and using gated pipes can reduce water application to the recommended 1000-1200 m<sup>3</sup>/ha, thereby suppressing these weeds (Abbasi and Sheini Dashtgol, 2016; Sheini Dashtgol, 2015). Proper fertilizer use improves crop health and competitiveness against weeds (Shafiei Bafti and Behravan, 2012). Fertigation is a key strategy, as it allows for precise, split fertilizer applications. This increases efficiency, reduces nutrient leaching, and limits the nutrient availability for nitrophilous weeds, suppressing their growth (Salamati et al., 2015b). Sub surface drip fertigation is a highly effective method of water application, which is also ideally suited for controlling the placement and supply rate of water-soluble fertilizers in sugarcane cropping system (Christy Nirmala Mary and Jeyachandran, 2019). Sheini Dashtgol et al. (2020) demonstrated that subsurface drip irrigation could reduce irrigation water consumption in sugarcane fields by up to 31% compared to conventional furrow irrigation. Salamati et al. (2015a), in an evaluation of water distribution uniformity and nitrogen application in furrow fertigation of sugarcane, demonstrated that optimal fertigation management enhances the coefficients of uniformity for both water and fertilizer distribution. Using the model proposed in their study, it was shown that by considering different field conditions including defining infiltration coefficients for the model, adjusting slope, increasing or decreasing flow rate, and modifying furrow length, optimal

conditions can be established to improve water use efficiency and fertilizer distribution uniformity. Consequently, optimizing irrigation and adopting precise fertigation techniques, such as subsurface drip irrigation, are essential for suppressing weeds and enhancing water and nitrogen use efficiency in sugarcane cultivation.

### **Managing Herbicide Resistance: Do's and Don'ts**

#### ***The do's of managing herbicide resistance in sugarcane:***

pursuing populations suspected of resistance and regular field monitoring, rotating herbicide applications, using pre-tillage irrigation to remove weeds suspected of resistance with plowing or using contact herbicides, performing tillage in fallow, collecting and removing aerial organs containing seeds and vegetative reproductive parts of perennial weeds, using pesticides proportionally and optimally, using low-persistence pesticides, observing the recommended dose to increase the frequency of susceptible phenotypes in the population, applying herbicide at a sensitive stage of the weed's life, using additives such as surfactants to increase herbicide efficacy, using crop rotation in sugarcane.

#### ***The don'ts of managing herbicide resistance:***

not using herbicides more or less than the recommended amount, not using crop seeds contaminated with weed seeds in crop rotation with sugarcane, not using herbicides with the same family or chemical group in consecutive years in one field, and not providing arbitrary

and non-expert recommendations in weed control (Abdolahi Lorestani et al., 2019a).

### **Future Horizons in Weed Management of Sugarcane Cultivation in Iran**

#### **Employing New and Alternative Methods in Sugarcane Weed Control**

Some suggested alternative and practical methods regarding sugarcane weed management include the use of natural products and materials, intercropping, mixed and companion cover crops, various types of mulch (Mansuy et al., 2016; Di Bella et al., 2021; Viaud et al., 2023), crop rotation (Jos et al., 2013), and allelopathic plants (Webber et al., 2018; Shukla et al., 2022). Also, determining the optimal planting date, consuming sufficient number of setts per hectare to achieve optimal density and row spacing are among other methods that should be considered in sugarcane weed management (El-Shafai et al., 2010; Takim and Suleiman, 2017). Various types of organic mulch (cover crops, straw or sugarcane bagasse) and non-organic mulch (filter cake, polyethylene plastic cover of hydroflume pipes) can also effectively prevent weed growth, especially annuals. Organic mulches also reduce weed growth through allelopathy. Non-organic mulches control them by burying weeds and also preventing light penetration (Tabatabaei, 2015).

#### **Attention to Biological and Ecological Approaches**

Effective weed management policies in sugarcane require a deep understanding of weed biology, ecology, and their interaction with the crop (Zafar et al., 2010). Shifts in cropping patterns and agronomic management

have been reported to cause significant changes in the composition and distribution of weed populations (Rathika et al., 2023). Climate change will have direct and indirect effects on weed biology, their competitive ability, as well as the efficacy of herbicides (Ramesh et al., 2017; Kaur et al., 2024). Consequently, a proper understanding of the biological characteristics of weeds and monitoring the population dynamics in response to evolving agronomic practices and climatic shifts is essential (MacLaren et al., 2020; Leguizamón, 2024). Hence, the primary challenge for weed scientists today is to develop innovative and effective management strategies based on a deep understanding of weed biology under climate change conditions. Insufficient knowledge can also lead to failed control operations, both chemical and non-chemical. The adoption of modern practices (e.g., minimum tillage, herbicide-tolerant cultivars) can shift weed flora, selecting for highly adaptive species. Therefore, predicting the impact of new technologies on weed dynamics is crucial before implementation.

Key research priorities for developing predictive models include:

**Weed Emergence Patterns;** Understanding the germination of key weeds like Swallow-wort.

**Seed Bank Dynamics;** Assessing the non-uniform seed bank in response to management.

**Competition Mechanisms;** Elucidating the physiological and ecological basis of crop-weed competition.

**Competitive Ability;** Determining how biotic and abiotic stresses affect the competitive balance between the crop and weeds.

### Reducing Environmental Risks

Mitigating the risks posed by chemical herbicides to human health and the environment necessitates the investigation and development of strategies to reduce their application rates, enhance efficacy, and minimize spray drift (Mohd Ghazi et al., 2023; Siddique, 2023). Practical approaches in this regard include: implementing precise spot spraying to reduce treated area and herbicide consumption (Pokharel et al., 2024; Azghadi et al., 2025); decreasing volatilization through optimal timing, such as delayed pre-emergence or early post-emergence applications in sugarcane fields (Araldi de Castro, 2024; Moges et al., 2024); improving and optimizing tractor-mounted and manual spraying equipment (Araldi de Castro, 2024; Otero, 2024). Furthermore, applying herbicides under suitable climatic and growth conditions to maximize absorption and translocation within the weed tissue is another key factor in enhancing effectiveness and reducing the required dose (De la Cruz et al., 2020; Mendes et al., 2022). In the realm of research, future priorities may include establishing safer herbicide application systems, employing remote sensing technology to facilitate targeted spraying, and utilizing optimized delivery methods such as centrifugal nozzles, Controlled Droplet Application (CDA), and anti-drift nozzles, all of which ultimately contribute to

improved herbicide performance and reduced drift (Jalu et al., 2023; Huang et al., 2025).

### Forward-Looking Research

From a weed science perspective, key research priorities for sustainable sugarcane systems include:

**Optimizing Herbicide Use:** Investigating reduced rates, split applications, improved timing, and the use of adjuvants to enhance efficacy while minimizing environmental impact (Queiroz et al., 2022; Moges et al., 2024).

**Integrated Weed Management (IWM):** Developing and combining mechanical, physical, and cultural control methods with chemical tools to create robust, multi-tactic strategies (Rezaei et al., 2021; Patel et al., 2024).

**Proactive Invasive Species Management:** Using germination models and distribution mapping to monitor, predict, and manage the spread of invasive weed species (Abdolahi Lorestani et al., 2021a, b, c; Oveisi et al., 2024).

### Conclusion

The progression of weed management in Iranian sugarcane cultivation illustrates a critical shift toward agricultural sustainability, moving from a narrow reliance on herbicides to a dynamic Integrated Weed Management (IWM) system. Excessive past dependence on a limited range of modes of action, particularly Photosystem II inhibitors, triggered serious consequences: evolved herbicide resistance in weeds such as *Echinochloa colona*, a shift in

weed spectra toward resilient perennials like *Imperata cylindrica* and *Cynanchum acutum*, and increased environmental and economic problems. Strategic adaptation has since materialized through diversifying herbicide chemistry with new sites of action (e.g., indaziflam, pendimethalin), refining application timing via delayed pre-emergence sprays, and enhancing mechanical and physical control measures. This integrated strategy has successfully cut average herbicide use from approximately 20 to below 6 units per hectare. Advances in species-specific management, informed by an improved understanding of weed biology and ecology, further underscore a transition to more precise, knowledge-based control. However, persistent and emerging challenges including weed population shifts under climate change, emerging resistant biotypes, and the necessity of optimizing agronomic practices to enhance crop competitiveness highlight that IWM is an ongoing, adaptive process rather than a fixed solution. Ensuring long-term sustainability depends on reinforcing this multidimensional framework through dedicated research into precision technologies and non-chemical tools, continuous education and support for end users, and the systemic integration of weed management with optimized crop, water, and nutrient management. The Iranian experience confirms that enduring productivity and ecological integrity are best achieved through proactive, science-informed, and holistic management practices.

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