Indian Journal of Weed Science (2024) **56**(3): 223–229
http://dx.doi.org/10.5958/0974-8164.2024.00037.8

REVIEW ARTICLE

Integrated weed management is the key to delay the evolution of herbicide resistance in weeds under conservation tillage – Insights

Tejinder Singh[1], Anuj Choudhary[2], Sachin Dhanda[3] and Simerjeet Kaur[4]*

Received: 19 June 2024 | Revised: 15 August 2024 | Accepted: 28 August 2024

ABSTRACT

Zero tillage is a no-till technique for raising crops in conservation agriculture. It has been proven that zero tillage causes a shift in weed flora from annuals to perennials and remnant emerged weeds are controlled by chemical tactics. Many developed nations such as the United States of America, Southern Brazil, Australia, Argentina, Paraguay, and Uruguay practice zero tillage (with or without surface cover) over a large area. In India, zero tillage is being adopted over an area of 7.6 mha with increasing herbicidal market trends at a rate of 15%. Over-reliance on a single group of herbicides results in the evolution of resistance. Presently, the reported number of unique resistance cases is 532 in 273 weed species (156 dicots and 117 monocots). The Indo-Gangetic plains, being at the forefront of the agricultural revolution in India, are witnessing a surge in zero tillage adoption. However, this trend raises concerns regarding the emergence of herbicide resistance, especially in regions where certain modes of action are already under threat. In India, 7 unique herbicide resistant cases have been reported in rice and wheat crops. The problem of herbicide resistance in weeds is feared and imminent and different weeds in India may evolve the same resistance mechanisms. The integrated and diversified weed management approach is the need of the hour to realize higher yields, and also to delay the evolution of resistance in weeds.

Keywords: Herbicides, Herbicide resistance, Rice-wheat cropping system, Sustainable weed management, Zero tillage

INTRODUCTION

Sustainable agriculture breaks up the cycle of soil and water degradation resulting in the conservation of natural resources. All around the world, conventional agriculture exhausted the most precious patrimony, consisting of fertile soils, water reservoirs, and the biodiversity of nature, and increased the production cost (Sumberg and Giller 2022). Zero tillage emerged as a solution that reduced the cost of production involved in the seedbed preparation and saved time between harvesting one crop and planting the next. Zero tillage is an extreme form of minimum tillage, and it aims at growing crops without disturbing the soil through tillage (Kumar *et al.* 2021). Zero tillage with residue is practiced in standing crop residues, acting as mulch by suppressing the weeds. Zero tillage is environmentally, socially, and economically advantageous tillage practice (Keil *et al.* 2020). Soil physical, chemical, and biological characteristics improve by an increase in the number of micropores, leading to a dense soil structure and increasing the water-holding capacity of the soil (Wang *et al.* 2024). Runoff losses of water are reduced which increases the soil moisture availability while soil erosion is also reduced due to the presence of abundant crop residue over the surface leading to a reduction in the siltation of canals and enhancing the recharge of aquifers. As soil remains covered with mulch material, it moderates the soil temperature by decreasing in summers and increasing in winters (Thakur and Kumar 2021). An increase in net profit from crops proves it to be socially acceptable, economically viable and environmentally friendly. Regular retention of crop residues enhances the soil's organic matter content. Due to these positive aspects, the area under zero tillage has reached 7.60 m ha in India (Singh *et al.* 2010) and 35.6 m ha in the USA (Kassam *et al.* 2013).

Tillage is a mechanical measure that influences the density and distribution of weed flora over a region. Repetitive tillage minimizes the weed population provided weeds are buried before seed

[1] Department of Plants, Soils and Climate, Utah State University, Logan, Utah 84322, USA

[2] Department of Biology and Environmental Sciences, CSKHPKV, Palampur, H.P 176061, India

[3] Department of Agronomy and Plant Genetics, University of Minnesota, St Paul, MN 55108, USA

[4] Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab 141004, India

* Corresponding author email: simer@pau.edu

setting which reduces the seed bank of weeds in the soil while the distribution of weeds virtually depends on the tillage operation conducted. Zero tillage/ minimum tillage restricts the tillage operation to the specific site/soil profile for seed drilling, which suppresses the inversion of the lower horizon seed bank during tillage operation and prevents exposure to sunlight for germination. Remnant germinated weeds would majorly be of perennial nature which implicit that weed flora distribution changes from annual to perennial (Jorgensen and Jorgensen 2018). Deep ploughing would invert the soil to deeper horizons and bury the seeds into deeper layers of soil influencing germination and emergence due to reduced solar radiation availability.

Zero tillage is also criticized in certain aspects as the high initial cost of implementation limits its adaptation by the only large farmers. Gullies can form under zero tillage, and potentially get wider with time (Pittelkow *et al.* 2015), but what causes the greatest concern is the weeds. Zero tillage increases the grassy perennial weed population (MacLaren *et al.* 2021), which is to be controlled either manually or chemically. Regular use of atrazine in the maize field increased the number of *Acrachne racemose* and *Brachiaria reptans,* and continuous use of butachlor in rice fields shifted weed flora from *Echinochloa crus-galli* to *Ischaemum rugosum* (Kaur *et al.* 2022). In Australia, zero tillage increased the risk of glyphosate resistance in weeds (Cornish *et al.* 2020). The zero tillage fields also witnessed weed shift from annuals to perennials and more reliance on chemical weed control which resulted in more selection pressure leading to the rapid evolution of herbicide resistance.

Conservation tillage practices in advanced countries

In 1970, North America shared a comparable agricultural stance with present-day India regarding tillage practices. Zero tillage was adopted in North America approximately three decades after its emergence, reflecting a delayed recognition of its significance in India. However, the introduction of zero tillage in the United States has increased the prevalence of herbicide-resistant weeds due to the repeated application of the same herbicide group on untilled land (Dang *et al.* 2020). Currently, the United States contends with approximately 80 herbicide-resistant weeds, totaling nearly 601 unique cases of resistant occurrences nationwide (Heap 2024). Researchers have identified zero tillage as a significant contributor to the phenomenon of weed shift. Studies investigating the causes of weed shift consistently implicate zero tillage/conservation agriculture as a primary factor. Over time, researchers have repeatedly concluded that zero tillage/conservation agriculture plays a pivotal role in augmenting the issue. The adoption of conservation tillage methods has been associated with marked increases in the populations of various weed categories. Conservation tillage practices have substantially altered the weed species spectrum (Winkler *et al.* 2023). A 36-year long-term study on grain sorghum in Texas suggested that no-till has changed the weed dynamics of the field with greater weed densities and a higher proportion of weed seeds in the soil as compared to conventional tillage (Govindasamy *et al.* 2020). These findings underscored the role of zero tillage in shaping weed dynamics and resistance evolution. The future evolution of herbicide resistance cannot be predicted by making a common distinction between target site resistance and non-target site resistance. It is critical to predict which species will next develop into economically and agriculturally significant herbicide-resistant weeds. Evolutionary rescue models theoretically emphasized the significance of population size and persistent genetic variety for evolution in the wake of abrupt and significant environmental change. It appeared that a weed's local abundance accurately predicted the likelihood that it will develop resistance (Délye *et al.* 2013). Conservation tillage agriculture leads to the faster evolution of resistance in weeds which can be an efficient tool for predicting the next evolutionary weeds using models.

Conservation tillage practices in India

India is undergoing a similar transition toward zero tillage/conservation agriculture. Despite being in the early stages, with nearly two decades of research, recent years have witnessed rapid adoption of zero tillage/conservation tillage practices, spurred by diesel prices and production costs. This adoption pattern resembles the historical trajectory observed in the United States of America. Consequently, while zero tillage holds promise for addressing agricultural challenges in India, careful monitoring and mitigation strategies are essential to counteract potential consequences such as the evolution of herbicide-resistant weeds, to ensure the sustainability of the agricultural practices in the region. The expansion of zero tillage is notable in areas with reliable irrigation infrastructure, such as the Indo-Gangetic plains of India, particularly in the rice-wheat cropping system. Adoption of wheat cultivation has seen significant under zero tillage practices, primarily due to the constrained timeframe between wheat harvesting and sowing (Dang *et al.* 2020). Although zero tillage can be traced back to the 1970s, its widespread adoption was hindered by limited mechanization at that time. However, with the advent of mechanization, significant research efforts commenced in the early 2000s, leading to a rapid increase in zero tillage area, reaching 7.6 million hectares by 2010 (Singh *et al.* 2010). However, the expansion of zero tillage also brings concerns regarding weed dynamics and herbicide resistance issues observed in the American context (Chaudhary *et al.* 2021, Heap 2024). Modeling for herbicide resistance evolution can help examine the utmost concerned weed risking to resistance development, which can then be managed with priority using multiple action plans. Reliance on cultural and mechanical control methods proves to be tedious and time-consuming. As a result, chemical methods emerge as quick and economically viable means of weed control. Unfortunately, continuous dependence on a single group of herbicides has led to shifts in weed flora and herbicide resistance (Kaur *et al.* 2022). There are some trends to look over in **Tables 1** and **2** for comparison in the area under zero tillage, major herbicide used, percentage share of pesticide market, area under major crops, weeds resistant to individual herbicide, and site of action. The maximum number of cases of herbicide resistance in the world are against ALS inhibitors (174 cases), photosystem II inhibitors (87 cases), enolpyruvyl shikimate phosphate synthase (59 cases), and ACCase inhibitors (51 cases). A maximum number of cases (601) of unique resistance has been reported in the USA (Heap 2024). In the USA, there have been 286 reported cases of resistance to glyphosate, paraquat, and atrazine. In India, the usage of these herbicides is 6002.74 tons of glyphosate, 2608.00 tons of paraquat, and 1200.92 tons of atrazine (**Table 1**). Thus, the reliance on single chemical weed control in conservation tillage in India necessitates a cautious approach, drawing upon the lessons learned from experiences in the United States to mitigate potential weed management challenges and resistance issues.

Table 1. Comparison between the U.S.A and India concerning (1) Area under zero tillage, (2) Major herbicide used, (3) Percentage share of pesticide market, and (4) Acreage under major crops

Particulars	U.S. A		INDIA		References
The area under zero tillage (in mha)	1973-74 1983-84 1993-94 2003-04 2013-14	2.2 4.8 15.7 25.3 35.6	2001-02 2002-03 2003-04 2004-05 2009-10	0.1 0.3 0.8 1.6 7.6	Derpsch 2003, 2010, Kassam *et al.* 2013, Singh *et al.* 2010)
Major herbicide used (tons)	Glyphosate Paraquat Atrazine	83000 3500 38200	Glyphosate Paraquat Atrazine	6003 2608 1201	Atwood and Jones 2017), Choudhury and Gosh 2018
Percentage share of the pesticide market	Herbicide Insecticide Fungicide Others	58% 25% 16% 2%	Herbicide Insecticide Fungicide Others	16% 60% 18% 6%	Atwood and Jones 2017, Choudhury and Gosh 2018
Acreage under major crops in (mha)	Wheat Maize Rice	15.21 33.47 0.96	Wheat Maize Rice	30.60 9.21 43.79	FAO 2020

Table 2. Number of weeds and unique resistance cases worldwide reported against major herbicides being used in India

Herbicide	HRAC classification	Mode of action	Number of weeds resistant to individual herbicide worldwide	Number of unique cases of resistance to individual herbicide	Number of weeds resistant to the site of action worldwide
Glyphosate	HRAC 9	EPSP synthase inhibitors	58	366	366
Paraquat	HRAC 22	PS I electron diverter	31	75	76
Atrazine	HRAC 5	PS II inhibitors-	67	245	375
Metribuzin		Serine 264 binders	15	30	
Isoproturon			4	17	
Imazethapyr	HRAC 2	ALS inhibitor	43	141	711
Clodinafop-propargyl	HRAC 1	ACCase inhibitor	15	76	271

Source: Heap 2024

Integrated weed management - Prudent way to avoid the evolution of herbicide resistance

Presently, 532 unique cases of herbicide resistance in 273 weed species have been reported globally including 156 dicots and 117 monocots (Heap 2024). There is a chronological increase in unique cases of herbicide-resistant weeds in different countries with maximum cases in the USA followed by Europe and Australia (**Figure 1**). Heap (2024) reported that the maximum number of weed species has evolved resistance against atrazine followed by glyphosate (**Figure 2**). The number of resistant weed species is maximum in wheat followed by maize

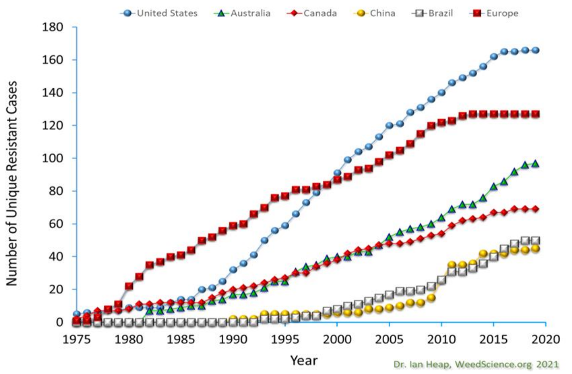

Figure 1. Increase in unique resistant cases of herbicide resistance for selected countries

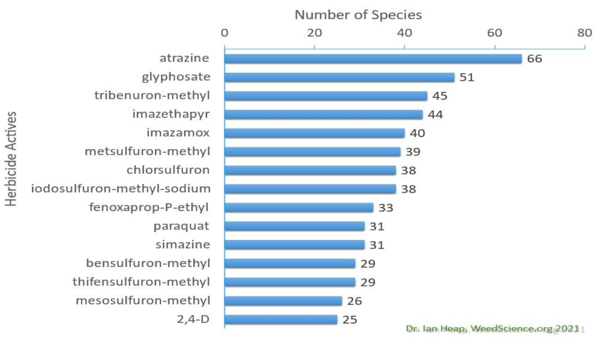

Figure 2. Number of resistant species to individual active substances worldwide

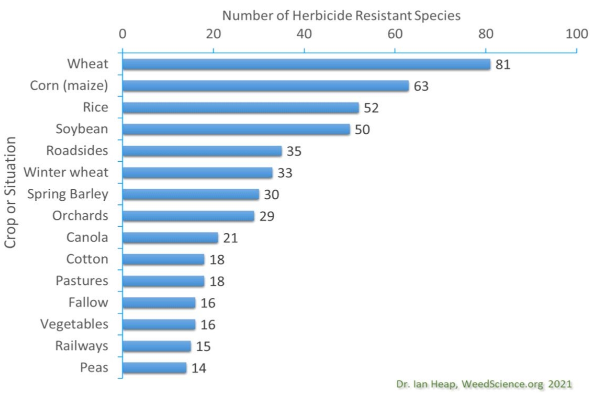

Figure 3. Number of herbicide resistant weed species worldwide in different crops/situation

(**Figure 3**). To delay the evolution of herbicide resistance in weeds and avoid the environmental contamination, the integration of chemical and non-chemical control methods is the best practice. Integrated weed management (IWM) options using competitive crops and good agronomic practices may be used to control weeds. The inclusion of stale seedbed techniques and vigorously growing competitive crops in the rotation will help in suppressing weed growth which will have possible synergistic effects on weed-control efficiency of chemical weed management. The inclusion of cultural weed control strategies such as tillage, sowing time, seeding density, etc. in an IWM program has a significant role in avoiding weed shift and herbicide resistance. The prevention from entry and then establishment using cultural methods, mechanical methods, biological means and chemical tactics are required to be used in an integrated form to neglect the overreliance on single control tactics. Integration of different control measures would minimize environmental hazards and sustainable weed management can be practiced.

Weed seed biology: The biological traits of weeds are to be emphasized for understanding the emergence pattern of weeds. Delayed germination and emergence of weeds prevent the weeds from getting killed (Norsworthy *et al.* 2012). Herbicides including pre- or post-emergence can be applied based on the germination or emergence information of a weed species. If the time of germination of weeds is known, then early sowing of the crop can smother weeds. Remnant weeds can be controlled effectively with a single application of herbicide. Wheat grown in the last week of October can smoother *Phalaris minor* as weed germination starts with the first fortnight of November, up to that period wheat crop established in a better way to provide the smothering effect to the weeds. Remaining *Phalaris minor* plants can be controlled effectively by a single spray of herbicide that can help in delaying herbicide resistance (Yadav *et al.* 2016).

The reproductive behavior of weeds whether annual or perennial also differs in the appearance of resistant genes as the annual population is exposed to the repetitive application due to a shorter life span, which vigorously transfers the resistant genes from resistant to a susceptible population (Lauenroth and Gokhale 2023). The knockdown spraying before seed setting in the annual population would prevent the spreading of resistant seeds of weeds which limits the population of resistant biotypes below a threshold level. While gene transfer and acquisition period of resistant genes differs according to the mode of pollination, either self-pollination or cross-pollination (Délye *et al.* 2013). Uprooting the weeds/rogueing before reproductive stage can reduce the early acquisition of resistance in outcrossed species.

Cultural tactics: Cultural operations during crop production like cultivar selection, tillage operation, seed rate, spacing, planting method, nutrient requirement, irrigation scheduling, harvesting operations, and postharvest operations affect herbicide resistance. Cultivars being aggressive, highly tillered, drooping leaves and a full cover of crop canopy will reduce the population of weed biotypes (Jha *et al.* 2017). Results from the experiment conducted in Western Australia revealed that cereal crops were more efficient in suppressing the population of *Lolium rigidum* than *Lupinus angustifolius* and *Pisum sativum* (Borger *et al.* 2017). Highly vigorous hybrids were more competitive to weeds in Australia than open-pollinated cultivars (Lemerle *et al.* 2013). A higher seed rate of a cultivar would minimize the number of weed biotypes. Ryegrass weed can be suppressed by increasing the seed rate of crop plants due to early canopy cover (Walsh and Powles 2007). A similar experiment in Australia proved the effect of increase in the seed rate of wheat on decline in the population of *Lolium rigidum* (Lemerle *et al.* 2013). Reduction in plant-to-plant spacing would allow spatial competition between weeds and crops as closer spaced crop plants leave minimum area for weeds to emerge, which automatically suppressed the weeds. Narrow row planted wheat at 15-17 cm reduced weed dry matter and density (Yadav and Choudhary 2015). Analogous results were reported in Pakistan where reduced row spacing from 15-23 cm to 11 cm outcompeted *Galium aparine* (Fahad *et al.* 2015). Unidirectional sown wheat has more dense weed flora than bidirectional which ultimately resulted in lower yield (Sardana *et al.* 2017).

Diversification (both crop and herbicide) is the key in delaying evolution of herbicide resistance in weeds. Diversification via crop rotation is the only method that reduces the establishment of weed flora over an area. Rice-wheat crop rotation is a single reason responsible for the hike in the population of *Phalaris minor* in wheat and *Echinochloa crus-galli* in rice fields. Rotation of wheat for three years with berseem fodder will suppress the seed bank of *Phalaris minor* in the field due to the continuous smothering effect of berseem fodder, which prevents light entry into the field for seed germination of weed (Jat *et al.* 2021). Weeds can be suppressed by simply rotating the herbicide with multiple modes of action. Diversification in herbicide will prevent the persistence of single-weed flora. Repetitive application of the same group of herbicides adds resistant seed banks in the soil although repeated use of herbicides of the same group will resist biotypes against herbicide (Norsworthy *et al.* 2012). To minimize herbicide selection pressure in the weed population, herbicide mixture with multiple modes of action for delaying resistance evolution may be used.

Site-specific nutrient application starves the weed species for nutrient uptake and hinders its population, which indirectly reduces the number of resistant biotypes. Drip irrigation for efficient water usage would dehydrate the weeds for water. Admixture seeds act as a primary source for inoculation of resistant seeds to a new location, which is protected by isolated harvesting operations. Sanitized harvesting of crops without admixture of the weed seeds would reduce the entry of resistant biotypes to a new location due to the transfer of planting material. Postharvest burning of straw and chaff also reduces the seed bank in soils in Australia (Walsh and Powles 2007). All cultural operations aimed at suppressing the resistance by reducing the number of weeds to a minimum level as possible, which indirectly suppresses resistance evolution.

Mulching acts as a physical barrier by restricting sunlight required for seed germination. The density and type of mulch material used would affect the suppression of weeds. Straw mulch is the cheapest source of mulch used extensively over a larger area. Hardy weeds like *Cyperus rotundus* and *Cynodon dactylon* have reduced weed biomass by 72% when black polyethylene sheets were used for weed control though it costed more than straw mulch (Webster 2005). Allelopathy is the secretion of agrochemicals into the soil by a living entity to hinder the growth of neighboring individuals. Sunflower, sorghum, marigold, eucalyptus, certain legumes, and the brassicaceae family secretes agrochemicals, which suppress the growth of weeds, and ultimately reduce the population of weed communities in the proximity of crops (Norsworthy *et al.* 2012).

Biological Tactics: Biological predators like insects and diseases can be used as natural bioagents to kill weeds e.g. *Lantana camara*, a bush weed can be suppressed by insect, *Plusia verticillata*. *Zygogramma bicolarata* beetle feeds on flowers and leaves of *Parthenium hysterophorus* which declines the weed population in an environment-friendly way (Hasan *et al.* 2020). Similar studies were conducted in China where *Drechslera monoceras* and

Exserohilum monoceras were checked for their potential to act as a bioagent in controlling *Echinochloa crus-galli* (Hong *et al.* 2002). Powder of dry leaves of *Parthenium hysterophorous* and *Cuscuta spp.* were used to control *Eichhornia crassipes* due to the release of certain secondary metabolites which have an allelopathic effect on the weeds. *Parthenium hysterophorous* can be suppressed by the presence of *Tagetus spp.* (marigold) and *Cassia spp.* through the release of allelochemicals (Patel 2011). *Cyperus rotundus* and *Cynodon dactylon* can be suppressed through the leachates of eucalyptus tree leaves (Mukherjee and Singh 2004). Recently, there is a success story of control of *Salvinia molesta*, a damaging free-floating invasive alien macrophyte by *Cyrtobagous salviniae* weevil in Madhya Pradesh, India. Therefore, biological weed management is a promising option to control the invasive alien weeds in an environment-friendly way.

Chemical tactics: Chemical control, being a sure, quick, and economically viable method of control aims at using chemical-based herbicides to control weeds below the economic threshold level. Due to the sure and quick results of herbicides, they are actively used to control weeds. However, regular use of same group of herbicides resulted in more selection pressure and faster evolution of herbicide resistance in weeds. Moreover, resistance to multiple modes of action was also witnessed due to repetitive application in rice-wheat cropping system (Heap 2024, Dhanda *et al.* 2022). The application of herbicide with multiple modes of action or in a combination of two or more herbicide groups that is admixture composition or rotational use would delay the evolution of herbicide resistance. Sound dependency on not only chemical control tactics but also cultural, biological, and mechanical tactics must be of utmost concern.

Conclusions

There is a rapid increase in conservation tillage in India, particularly in the strategically significant cropping systems of the Indo-Gangetic plains, including Punjab, Haryana, and western Uttar Pradesh. This expansion is accompanied by increased demand for herbicides with modes of action that are already susceptible to resistance. The burgeoning herbicide market in India signals the imminent risk of escalating resistance issues if not addressed by agricultural experts. Proactive measures must be taken soon to address this challenge effectively. Conservation/zero tillage is undoubtedly a necessity in modern agriculture, but its implementation should not merely replicate the practices of other countries. Instead, it should be tailored through targeted and compatible research efforts aimed at mitigating the obstacles posed by herbicide resistance. Agro-experts and researchers must collaborate to develop needed solutions that address the specific challenges posed by herbicide resistance in the Indian context. By doing so, India can navigate the path toward sustainable agriculture while minimizing the risks associated with herbicide resistance in zero tillage systems.

REFERENCES

Atwood D and Jones CP. 2017. Pesticides industry sales and usage 2008-2012. Market estimates. Pp. 1–24. US Environmental Protection Agency, Washington, DC.

Borger CPD, Hashem A and Pathan S. 2017. Manipulating crop row orientation to suppress weeds and increase crop yield. *Weed Science* **58**: 174–178.

Chaudhary A, Chhokar RS, Dhanda S, Kaushik P, Kaur S, Poonia TM, Khedwal RS, Kumar S and Punia SS. 2021. Herbicide resistance to metsulfuron-methyl in *Rumex dentatus* L. in north-west India and its management perspectives for sustainable wheat production. *Sustainability* **13**(12):6947.

Cornish PS, Tullberg JN, Lemerle D and Flower K. 2020. No-till farming systems in Australia. Pp. 511-531. In, Dang YP, Dalal RC and Menzies NW. (Ed.) *No-till Farming Systems for Sustainable Agriculture: Challenges and Opportunities*. doi: 10.1007/978-3-030-46409-7_29/FIGURES/2

Dang YP, Page KL, Dalal RC and Menzies NW. 2020. No-till Farming Systems for Sustainable Agriculture: An Overview. Pp 3-20. In, Dang YP, Dalal RC and Menzies NW. (Ed.) *No-till Farming Systems for Sustainable Agriculture: Challenges and Opportunities*. doi: 10.1007/978-3-030-46409-7_1/FIGURES/4

Délye C, Jasieniuk M and Corre VL. 2013. Deciphering the evolution of herbicide resistance in weeds. *Trends in Genetics* **29**(11): 649–658.

Derpsch R, Friedrich T, Kassam A and Li H. 2010. Current status of adoption of no-till farming in the world and some of its main benefits. *International Journal of Agricultural and Biological Engineering* **3**(1): 1–25.

Derpsch R. 2003. Conservation tillage, no-tillage and related technologies. Pp. 181-190. In, García-Torres L, Benites J, Martínez-Vilela A and Holgado-Cabrera A. (Ed.) *Conservation Agriculture*: *Environment, Farmers Experiences, Innovations, Socio-economy, Policy*. doi: 10.1007/978-94-017-1143-2_23

Dhanda S, Kaur S, Chaudhary A, Jugulam M, Hunjan MS, Sangha MK and Bhullar MS. 2022. Characterization and management of metsulfuron resistant *Rumex dentatus* biotypes in northwest India. *Agronomy Journal* **114**(1): 366–378.

Fahad S, Hussain S, Chauhan BS, Saud S, Wu C, Hassan S, Tanveer M, Jan A and Huang J. 2015. Weed growth and crop yield loss in wheat as influenced by row spacing and weed emergence times. *Crop Protection* **71**: 101–108.

Govindasamy P, Sarangi D, Provin T, Hons F and Bagavathiannan M. 2020. No-tillage altered weed species dynamics in a long-term (36-year) grain sorghum experiment in southeast Texas. *Weed Science 68*(5): 476–484.

Hasan F, Al-Ghanim KA, Al-Misned F and Mahboob S. 2020. Does *Zygogramma bicolorata* Pallister affects the growth, density and reproductive performance of *Parthenium hysterophorus* L.? *Saudi Journal of Biological Sciences* **27**: 1871–1878.

Heap I. 2024. The International Herbicide-Resistant Weed Database. www.weedscience.org (accessed Sunday, 2024)

Hong YK, Cho JM, Lee BC, Uhm JY and Kim SC. 2002. Factors affecting sporulation, germination, and appressoria formation of *Epicoccosorus nematosporus* as a mycoherbicide under controlled environments. *Plant Pathology Journal* **18**: 50–53.

Jat PL, Meena RK, Ram H, Makarana G and Kumar R. 2021. Multiple herbicides resistance in *Phalaris minor*: Extent and management. *Indian Farming* **71**(3): 20–22.

Jha P, Kumar V, Godara RK and Chauhan BS. 2017. Weed management using crop competition in the United States: A review. *Crop Protection* **95**: 31–37.

Jorgensen MH and Jorgensen MH. 2018. The effect of tillage on weed control: an adaptive approach. Pp. 17–25. In, Radhakrishnan R (Ed.) *Biological Approaches for Controlling Weeds*. doi: 10.5772/INTECHOPEN.76704

Kassam A, Kassam A, Friedrich T, Derpsch R and Kienzle J. 2013. Overview of the worldwide spread of conservation agriculture. Pp. 1-11. In *Field Actions Science Reports* Vol. **8**. Available at: https://www.researchgate.net/publication/292477374

Kaur S, Dhanda S, Yadav A, Sagwal P, Yadav DB, and Chauhan BS. 2022. Current status of herbicide-resistant weeds and their management in the rice-wheat cropping system of South Asia. *Advances in Agronomy* **172**: 307–354.

Keil A, Mitra A, McDonald A and Malik RK. 2020. Zero-tillage wheat provides stable yield and economic benefits under diverse growing season climates in the Eastern Indo-Gangetic Plains. *International Journal of Agricultural Sustainability* **18**(6): 567–593.

Kumar RS, Kundu S, Kundu B, Binu NK and Shaji M. 2021. Emerging typology and framing of climate-resilient agriculture in South Asia. Pp.255-287. In, Letcher TM. (Ed.) *The Impacts of Climate Change: A Comprehensive Study of Physical, Biophysical, Social, and Political Issues*. doi: 10.1016/B978-0-12-822373-4.00021-5

Lauenroth D and Gokhale CS. 2023. Theoretical assessment of persistence and adaptation in weeds with complex life cycles. *Nature Plants* **9**: 1267–1279.

Lemerle D, Lockley P, Koetz E and Diffey S. 2013. Herbicide efficacy for control of annual ryegrass (*Lolium rigidum* Gaud.) is influenced more by wheat seeding rate than row spacing. *Crop and Pasture Science* **67**(8): 857–863.

MacLaren C, Labuschagne J and Swanepoel PA. 2021. Tillage practices affect weeds differently in monoculture vs. crop rotation. *Soil and Tillage Research* **205**(104795): 1–11.

Mukherjee D and Singh RP. 2004. The biological control of weeds- A Review. *Agricultural Reviews* **25**(4): 279–288.

Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, Bradley KW, Frisvold G, Powles SB, Burgos NR, Witt WW and Barrett M. 2012. Reducing the risks of herbicide resistance: best management practices and recommendations. *Weed Science* **60**: 31–62.

Patel S. 2011. Harmful and beneficial aspects of *Parthenium hysterophorus*: an update. *3 Biotech* **1**: 1–9.

Pittelkow CM, Linquist BA, Lundy ME, Liang X, Groenigen KJV, Lee J, Gestel NV, Six J, Venterea RT and Kessel CV. 2015. When does no-till yield more? A global meta-analysis. *Field Crops Research* **183**: 156–168.

Sardana V, Mahajan G, Jabran K and Chauhan BS. 2017. Role of competition in managing weeds: An introduction to the special issue. *Crop Protection* **95**: 1–7.

Singh T, Choudhary A and Kaur S. 2023. Weeds can help in biodiversity and soil conservation. *Indian Journal of Weed Science* **55**(2): 133–140.

Singh V, Kumar A, Banga A, Pant G and Pratap V. 2010. Current status of zero tillage in weed management. *Indian Journal of Weed Science* **42**: 1–9.

Sumberg J and Giller KE. 2022. What is 'conventional' agriculture? *Global Food Security* **32**(100617): 1–9.

Thakur M and Kumar R. 2021. Mulching: Boosting crop productivity and improving soil environment in herbal plants. *Journal of Applied Research on Medicinal and Aromatic Plants* **20**(100287): 1–12.

Walsh MJ and Powles SB. 2007. Management strategies for herbicide-resistant weed populations in Australian dryland crop production systems. *Weed Technology* **21**: 332–338.

Wang L, Lu P, Feng S, Hamel C, Sun D, Siddique KHM and Gan GY. 2024. Strategies to improve soil health by optimizing the plant-soil-microbe-anthropogenic activity nexus. *Agriculture Ecosystem and Environment* **359**(108750): 1–16.

Webster TM. 2005. Mulch type affects growth and tuber production of yellow nutsedge (*Cyperus esculentus*) and purple nutsedge (*Cyperus rotundus*). *Weed Science* **53**: 834–838.

Winkler J, Dvoøák J, Hosa J, Barroso PM and Vaverková MD. 2023. Impact of conservation tillage technologies on the biological relevance of weeds. *Land* **12**(121): 1–11.

Yadav DB, Yadav A, Punia SS and Chauhan BS. 2016. Management of herbicide-resistant *Phalaris minor* in wheat by sequential or tank-mix applications of pre- and post-emergence herbicides in north-western Indo-Gangetic Plains. *Crop Protection* **89**: 239–247.

Yadav MK and Choudhary J. 2015. Effect of herbicides and row spacing on weed dynamics and productivity of bread wheat (*Triticum aestivum* L.). *Advance Research Journal of Crop Improvement* **6**: 73–77.