Indian Journal of
Weed Science

Print ISSN 0253-8040
Online ISSN 0974-8164

Volume – 56 | Number – 3
July – September, 2024

Available Online @ www.indianjournals.com

Indian Society of Weed Science
ICAR-Directorate of Weed Research
Jabalpur, Madhya Pradesh 482004, India
Website: www.isws.org.in

Indian Journal of
Weed Science

Volume 56 Number 3 July–September, 2024

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(Founded in 1968)
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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

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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

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

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 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.

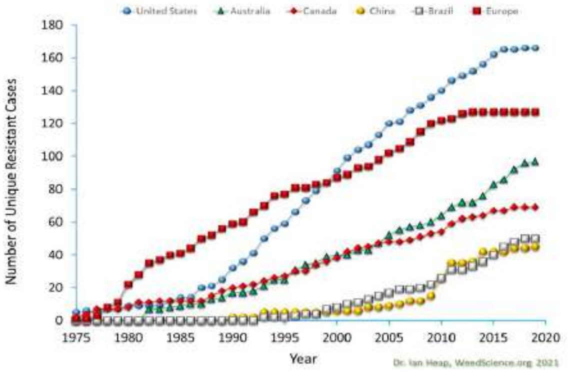

Figure 1. Increase in unique resistant cases of herbicide resistance for selected countries

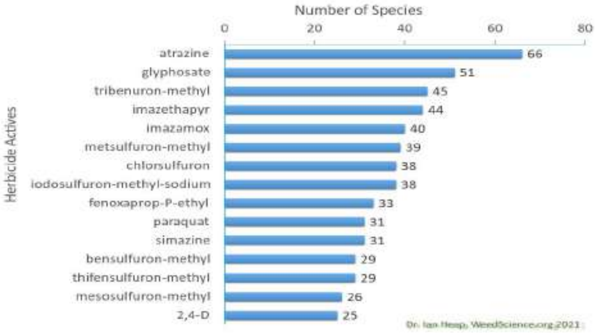

Figure 2. Number of resistant species to individual active substances worldwide

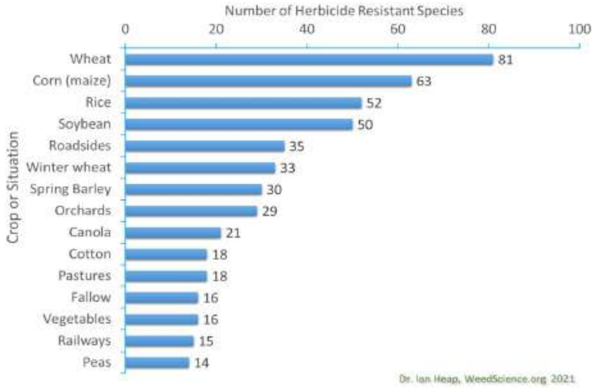

Figure 3. Number of herbicide resistant weed species worldwide in different crops/situation

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.

Indian Journal of Weed Science (2024) **56**(3): 230–236
http://dx.doi.org/10.5958/0974-8164.2024.00038.4

REVIEW ARTICLE

Broomrape management strategies in tobacco - A review

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Received: 1 January 2024 | Revised: 2 August 2024 | Accepted: 5 August 2024

ABSTRACT

Broomrape (*Orobanche* spp.) is a complete root parasite that derives total nourishment from host plants. Tobacco is a common crop that is most seriously infected by *Orobanche*, which causes more than 75% yield loss through reduction in above and below ground biomass, leaf yield and quality. Broomrape's idiosyncratic features, such as prolific seed production (more than 5,00,000 seeds per plant), very small seed size, easy mode of seed dispersal, seed viability and longevity, and seed emergence only when a suitable host is present, make parasite eradication strategies ineffective and expensive. Although several potential control measures have been developed over the past few decades for its management, any approach applied alone is often only partially effective, and the results are sometimes inconsistent owing to variable environmental conditions. In addition, broomrape interactions with tobacco are highly specific and complicate the development of selective control methods that do not affect tobacco. Therefore, the only way to achieve effective control of *Orobanche*, especially in tobacco, is through an integrated approach that combines various measures in a concerted manner. Summer ploughing, growing sesame as trap crop preceding to tobacco, application of neem cake 250 kg/ha at 30 days after planting of tobacco and hand weeding are recommended as integrated approach for broomrape management in FCV tobacco under irrigated conditions.

Keywords: Broomrape, Crop loss, Infestation, Integrated, Management, Parasite, Tobacco

INTRODUCTION

Tobacco is one of the most important high-value cash crops in India and ranks third in world tobacco production. It is grown in most of the agro-climatic zones of the country in more than 15 states, but the major tobacco-growing states are Andhra Pradesh, Gujarat, Karnataka, Uttar Pradesh, West Bengal, and Bihar. Presently, tobacco is cultivated in an area of approximately 4.90 lakh hectares, accounting for 0.24% of the total arable land in the country, covering different types of tobacco, *viz*. FCV tobacco, bidi tobacco, chewing tobacco, hookah tobacco, cheroot tobacco, cigar wrapper tobacco, cigar filler tobacco, oriental tobacco, dark fire cured tobacco etc., with an annual production of 800 million kg (Kasturi Krishna *et al*. 2022).

Tobacco is a unique crop in which quality is as important as yield. Hence, in the cultivation of tobacco, attention is paid to reduce the effects of biotic stresses for production of quality tobacco leaf. However, unlike most crops, tobacco is affected by the parasitic flowering plant *Orobanche*, a complete root parasite, commonly known as broomrape. Broomrape (*Orobanche/Phelipanche* spp.) is an obligate, holo-parasitic angiosperm lacking root system and photosynthetic competence, which derives total nourishment from host plants and attacks the roots of economically important crops, such as tobacco, rapeseed and mustard, brinjal, tomato, sunflower and faba bean in the semi-arid regions of the world (Wickett *et al*. 2011). A review on *Orobanche* with special reference to mustard and tomato was done by Punia (2014, 2015). *O. ramosa* and *O. cernua* are two species that commonly parasitize tobacco. The economic production of tobacco is precluded in soils infested with broomrapes, especially *O. ramosa* and *O. cermua* and hence, many of the traditional and best tobacco soils have been abandoned or planted with other crops in many other countries (Lolas 1994). Hence, it is pertinent to review the studies on management strategies for planning effective, safe and economical method of management.

Orobanche and yield loss in tobacco

Among five species of broomrape, *O. cernua* is the major species causing problem to tobacco in India as reported by Krishnamurthy *et al*. (1977a). Eight *Orobanche* isolates collected from five different FCV tobacco growing areas and one each from burley and *bidi* tobacco growing regions in Andhra Pradesh belong to *Orobanche cernua* with 98-100% sequence match. When the conditions are congenial for its

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growth, it causes a yield loss of more than 75% through reduced crop growth, leaf yield and quality (Krishnamurthy *et al.* 1994)

The parasite emerges usually between December and January months after planting and result into reduction of yield and leaf quality in tobacco (Dakshinamurti *et al.* 1964). It is a serious problem on *Bidi* tobacco in Nipani area of Karnataka and Chewing tobacco in Bihar and Uttar Pradesh. In Karnataka, 90% area under tobacco is infested with this weed and reported 50-60% yield losses in some areas (Dhanapal *et al.* 1998). Yield loss due to *Orobanche* infestation in tobacco growing areas of Tamil Nadu, Gujarat and Maharashtra is also reported to be very high. According to Dhanapal *et al.* (1996) and Qasem (2021), the damage caused by *Orobanche* can range from zero to complete crop failure depending upon the extent of infestation, environmental conditions, soil fertility and crops competitiveness.

It is obvious that 1/5 to 1/8 of the three major nutrients are removed by broomrape. Broomrape contains about 9% reducing sugars and the large depletion of sugars affects tobacco leaf quality (Prasada Rao and Murty 1976). In another study by Murthy and Nagarajan (1986) at Rajahmundry, Andhra Pradesh, broomrape infestation reduced the plant height (52.3%), number of leaves (34.3%), shoot fresh weight (40.3%), shoot dry weight (39.5%), root fresh weight 62.0% and root dry weight (53.7%). It was also reported that *Orobanche* infestation caused reduction in uptake of nutrients N (53.3%), P (77.8%), K (82.6%), Ca (54.9%) and Mg (65.9%). The capacity of infested plants for uptake of nutrients was reduced by 50%. Leaf samples from broomrape infested tobacco plants showed a decrease in P, K, total sugars, reducing sugars, total reducing substances, polyphenols and chloride contents and an increase in total N, Ca, nicotine, total volatile bases and petroleum ether extractives. Physical characters, *viz.* EMC, shattering index and leaf thickness reduced considerably while filling value increased in the broomrape affected tobacco leaf. Nutrient removal by the parasite from the host plant ranged between 20-25% that of healthy plants in case of major nutrients i.e. N, P and K. Further, broomrape was found to contain higher amounts of potassium and protein nitrogen (Murthy *et al.* 1977). Broomrape acts as a strong sink, depriving the host from water, mineral, and organic nutrients with the consequent negative impact on the growth of the host plant (Joel 2000, Abbes *et al.* 2009)

Life cycle of broomrape

Thorough knowledge on life cycle of broomrape is necessary to control the parasite at its vulnerable stage. *Orobanche* infestation and parasitisation processes takes place underground, so damage to the crop occurs prior to the emergence of the parasite and diagnosis of infestation. The germination of broomrape seeds is triggered by the interplay of three factors, *viz.* root exudates of host/ trap crop, low soil temperature and high soil moisture.

After germination in response to specific chemicals released by the host plant, the broomrapes seedlings attach to the host roots by the production of specialized feeding structures, described as 'Haustoria' that form a functional bridge into their hosts. Once vascular connections are formed, the parasite starts extracting water, nutrients, and photosynthates from the host vascular tissues (Fernandez-Aparicio *et al.* 2011). Haustoria penetrate the host tissues until they reach the vascular system for uptake of water, nutrients and assimilates and grow at the expense of the host plant's resources (Joel *et al.* 2007). After the vascular connection between haustorium and root of the host is established, the part of the broomrape seedling that remains outside the host root tissue swells to form the tubercle. In 1 to 2 weeks a shoot bud on tubercle differentiates and develops slowly into a shoot that emerges above the soil surface. The emerged ground shoot elongates to produce the flowering shoot in about 4 to 5 days. The seed ripen after another 20 to 25 days. Thus, the life cycle of parasite is completed in about three months after planting of tobacco (Krishnamurthy *et al.* 1977b). The seed germination stage, infection stage and shoot emergence and succulent stage above ground are considered as the vulnerable stages to combat the parasite.

Spread of *Orobanche* in tobacco growing areas

During field preparation, the *Orobanche* seeds spread by the movement of farm machinery and vehicles from infested fields to the other fields. Due to anticipated economics and limited scope for continued leased in cultivation, farmers cultivating tobacco in leased fields are not showing much attention towards physical removal of *Orobanche* prior to its flowering ,seed shattering and for its proper disposal. In general, after removal of *Orobanche* shoots, farmers are disposing them at field corners/ road side areas/ canals which are places for uncontrolled movement of grazing animals.

In addition, *Orobanche* shoots are good feed stuff to the sheep and goats. The excreta/ manure of those grazing animals act as the reservoir of *Orobanche* seed and also spreads the infestation. Farmers are growing tobacco year after year without following crop rotation and by not growing promising trap crops. As a result, the existing *Orobanche* seed reservoir in the soil is increasing and causing severe damage to the tobacco crop. The use of organic manure from livestock fed with contaminated hay is a cause of further seed dispersal, since the parasite seeds do not lose their viability while passing through animal's digestive systems (Jacobsohn *et al.* 1987).

Management strategies

Over decades, a great deal of research on *Orobanche* in many crops including tobacco yielded vast scientific knowledge on myriad aspects of parasite's life cycle covering seed phase, parasitic phase, emergence and reproductive phase. Based on understanding the points of vulnerability in parasite's life cycle, several management strategies were developed to minimise the loss of yield and quality of the host crops across the world.

a) Management of seed phase of *Orobanche*

Orobanche species are annuals that reproduce by seed. Viability of seeds in the field also varies with *Orobanche* species and environmental conditions. Seed longevity of 12 to 13 years or up to 20 years has been reported in the literature for *O. ramosa* (Puzzilli 1983), and 3 years for *O. Cernua* (Parker and Riches 1983). A simple technique to germinate *Orobanche* in the presence of live host seedlings under controlled conditions was developed by Pathak and Kannan (2014). This seed stage of the parasite is managed by summer ploughing, soil solarisation, crop rotation, intercropping, herbicide application etc.

Cultural practices

Summer ploughing: Summer ploughing at soil depth of more than 20 cm for several years in areas of heavy infestation will reduce *Orobanche* seed bank by exposing the parasite seed to the high temperatures and bring seeds of parasite to a depth of less oxygen availability and resulting in less germination. Deep inversion ploughing after tobacco harvest is the most efficient and cheapest method of control. Trench ploughing45-50 cm deep with a mouldboard plough reduced *O.ramosa* by 80-90% in tobacco fields of Eastern Europe by burying seed to depths where it is unlikely to germinate (Habimana *et al.* 2014). Summer deep ploughing reduced the broomrape incidence upto 59.2% and also increased the yield of in *Bidi* tobacco India (Khot *et al.* 1987).

Soil solarisation: Mulching soil with transparent polyethylene sheets for 4-6 weeks during summer months kill *Orobanche* seeds in the upper soil layers by increasing soil temperature. The temperatures of 45-60°C kill *Orobanche* seeds that are in the imbibed state; therefore soil must be wet at the time of treatment. Soil solarization has eliminated *Oroobanche* and other weeds from the treated plots and black plastic much is effective in controlling *O. Cernua* in tobacco (Meti and Hosmani 1994). Solarisation for 40 days reduced the number and dry weight of broomrape shoots resulting 78% broomrape control in *Bidi* tobacco (Meti 1993). The seed germinability, which was originally 77.5%, decreased as the period of solarisation increased and was completely lost after 7 days of solarisation. The biggest limitation to this method, however, is the high cost of the polyethylene (Krishnamurthy and Raju 1993). Experiments conducted in Vertisols at ICAR-CTRI, Rajahmundry, showed that soil solarisation alone reduced 22% and with mulching it reduced 54% *Orobanche* infestation in tobacco field crop (CTRI 2019).

Crop rotations: Planting non host plants in broomrape infested field is beneficial in terms of preventing new seed production and allowing natural decline of broomrape seed bank in the soil. Rotation with trap crops can stimulate germination of broomrape seeds, but are not themselves parasitized.

Many crops and wild species have been identified in the field and laboratory as trap-crops for *O. ramosa (Phaseolus, Sinapis, Sorghum, Maize, Fenugreek*) and O. *Cernua*, *(Sorghum, Chickpea, Linum, Soybean, Lucerne)*. Flax, fenugreek and Egyptian clover are established to be successful trap crops for *O. crenata (*Haidar and Sidahmad 2000). Trap crops like black gram, green gram, sesame and sun hemp, when grown in broomrape infested fields, have reduced the incidence of the parasite in the succeeding tobacco (Hosmani 1985). In Nipani (Karnataka), sunhemp and green gram proved to be promising trap crops for *Orobanche cernua* control where tobacco is grown in long growing (*Kharif* and *rabi*) seasons (Dhanapal *et al.* 1996). Broomrape infestation in tobacco was significantly lower (1.75%) in succeeding maize when compared to sole tobacco (21.54%) in Vertisols (Kasturi Krishna *et al.* 2007). Trap crops, *viz.* green gram, sesame and sorghum in one year rotation reduced the incidence of *Orobanche* in succeeding tobacco by 22%, 29% and 28.67%, respectively when compared to sole tobacco rotation under Vertisols.

Inter cropping: Intercropping is already used in regions of Africa as a low-cost technology of controlling the broomrapes (Oswald *et al.* 2002). Sowing of fenugreek on both sides of FCV tobacco after establishment recorded only 3.2% *Orobanche* infestation. Trigoxazonane was identified in the root exudates of fenugreek which may be responsible for the inhibition of *O. crenata* seed germination (Evidente *et al.* 2007). Intercropping in berseem with *legumes* (broad bean and pea) reduced the intensity of *Orobanche crenata* (Fernandez-Aparicio *et al.* 2010). Though, lower percentage of infection recorded by planting marigold in between the tobacco plants, it is suppressing the tobacco crop as well (CTRI 2022).

Chemical methods

Herbicides: Different herbicides and fungicides have been tested for control of broom rape in the field but none proved effective or realistic to become a common practice especially for tobacco (Puzzilli 1983). Chlorsulfuron and imazapyr were also tested as pre-emergence herbicides to affect the *Orobanche* seed germination in FCV tobacco and showed 50% control of broom rape with significant adverse effect on tobacco yield. Pre-emergence application of alachlor and pendimethalin reduced the incidence of *Orobanche* by 46.3% and 36.0% when compared to control in FCV tobacco in Vertisols by killing the imbibed seed of the parasite (CTRI 2014-15).

Good control has been reported for MH, glyphosate, sulfosate, imazaquin and imazapyr. Use of plant hole application of neem cake at 200 kg/ha at 30 DAT and post-emergence application of imazethapyr at 30 g/ha at 55 DAT has been suggested to control *Orobanche* in tobacco under Western zone of Tamil Nadu in India (AICRPWC 2013). Application of neem cake at 25-30 days after planting reduced up to 40% incidence of *Orobanche*. It can be applied in the final field preparation in Vertisols (2.5 q/ha) or during fertiliser application in irrigated Alfisols. Punia et al. (2016) have worked on the use of herbicides in tomato and their residual effect on succeeding crops.

b) Management of parasitic phase

Seeds of the different *Orobanche* species do not germinate unless they are found in the vicinity, about 1 to 2 cm, of roots of the suitable host and under appropriate climate conditions (Temperature, moisture and light). Germination is induced in response to stimulation by a chemical released from the roots to host. Germinating *Orobanche* seeds produce a radical, referred to as “germ tube”, which can grow to a length of 3 to 4 mm. On elongation, the radical contacts of host root and attaches to it mainly in the zone of root elongation and absorption. The radical then thickens, by rapid cell division; to form the haustorium. This stage can be managed by early planting dates, fertilisation, mulching, herbicide application *etc*.

Planting date: The degree of infestation by broomrapes is closely related to the date of sowing of the host crop. Early planting reduce the parasite infestation as the crop growth will be completed by the time the parasite infests the crop there by reducing the effect on yield of the crop (Krishnamurthy *et al.* 1994). However, early planted crop *i.e.* tobacco plantings in second fortnight of October to first fortnight of November escaped the parasite competition for acquisition of host nutrients due to the early growth and utilization of nutrient by the host and noticed less damage to the tobacco crop. Delaying the planting date affects *Orobanche* more than its hosts (Habimana *et al.* 2014).

Fertilization: Nutrient status of soil has been observed to affect the infestation of broomrape and its parasitism on host plants. *Orobanche* tends to be associated with less fertile soil conditions. Nitrogen in the ammonium form is more inhibitory than nitrate and reductions in radicle length were observed when ammonium solutions were applied during either preconditioning or germination periods. For germinating seeds, exposures to ammonium sulphate of 4 to 8 h (depending on the species) reduced radicle elongation by half, indicating a relatively rapid inhibition (Westwood and Foy 1999). The activity of glutamate Synthetase is very low in broomrape and therefore carries a reduced ability to detoxify the ammonium.Nitrogen in ammonium form negatively affects broomrape germination and/or elongation of the seedling radical. In addition, manure fertilization augments the killing effect of soil solarization on *O.crenata* seeds (Haidar and Sidahmad 2000).

Mulching: Transparent poly mulch increased the temperature by 10-12-^{0}F in the soil which is not congenial for broomrape seed germination for further infestation to the host plant as low temperatures are prerequisite for its germination. *Orobanche* infestation was not recorded under white polythene mulch but under mulching sheet it was 14% and it was 21% under no mulch (CTRI, 2019). But high cost of polyethylene, appropriate machinery and cloud-free sunny days may restrict its use on larger scale (Foy *et al.* 1989).

Irrigation: Drip irrigation reduced the *Orobanche* infestation and dry weight by 70-76% and appears to be a promising cultural practice in management of *Orobanche ramose* in tobacco under Mediterranean conditions of Greece as reported by Karkanis *et al.* (2007).

Bio-control measures

Biological control is particularly attractive in suppressing root parasitic weeds in annual crops because the intimate physiological relationship with their host plants makes it difficult to apply conventional weed control measures. F. *oxysporum* f.sp. orthoceras, fungus decreased *Orobanche* infestation to tobacco by 75.23% and increased crop yield by 80.5% (Mazaheri *et al*, 1991). Pathogens can be used as sole agents or as part of a complex integrated control strategy (Sauerborn *et al.* 2007). Chandrashekharagowda *et al.* (2018) suggested that AM fungal colonization likely induces resistance to plant parasitism by reducing the exudation of strigolactones from the host roots simultaneously influencing the stimulation of physiological and biophysical attributes of tobacco. The development of fungal inoculate application through drip irrigation system developed in Bari, Italy, opens new horizons in biological control methodology (Hershenhorn *et al.* 2006). Kannan *et al.* (2014) reported natural incidence of the oligophagous fly *Phytomyza orobanchie* on *Orobanche crenata* in brinjal in the farmers' field in India. This fly has also been reported and worked for biological control of *Orobanche* in tobacco worldwide with limited success because of predator and parasites (Habimana *et al.* 2014).

c) Management of emergence and reproductive phase

During the epigeal stage the emerged tubercle above the ground elongates to produce the flowering shoot in about 4 to 5 days. The seed ripen after another 20 to 25 days. Studies of Dinesha *et al.* (2012) on biology of *O. cernua* revealed that broom rape spikes started emerging above ground from 43-58 days after transplanting, flowering was completed in 7-13 days after emergence while stem drying was completed by 26-38 days after emergence of spike and it completed its life cycle by 37-50days after emergence.

Hand weeding: It was the most common method in the past and it is still practised by small farmers where the labour is cheap. It is important that pulled plants are removed from the field and destroyed before seed matures and falls on the ground. Frequency of pulling must be every one week. Weekly pulling of tender *Orobanche* spikes before they set seed, has reduced the original stand by 85% after 2 years and by 96% after 4 years. Periodical hand pulling carried out meticulously by every grower in a large block for at least 4 years will give adequate control of this menace. An alternative to hand-pulling is the "spear "which consists of an iron blade 16 cm long, 8 cm wide and 0.5 cm thick, attached to a bamboo stick about 2 m long which is operated manually to cut unflowered broomrape shoots up to 5 cm deep or more in the soil (Krishnamurthy and Raju 1993)

Oils: Application of 2-3 drops of oil kill the bud portion of young shoots and stem portion before seed portion. Different oils, *viz.* pongamia, rice bran, soybean were tested against broom rape on tobacco and these oils killed the parasite shoots effectively (Krishnamurthy *et al.* 1994). Repeated applications on emerging shoots at an interval of 4-5 days is required for its effective control.Post emergence application of Neem oil and Soybean oil at weekly intervals reduced the incidence of *Orobanche* by 40.6% and 31.5% when compared to control. Neem cake application at 30 days and Neem oil to *Orobanche* spikes reduced the infestation of *Orobanche.*

Considerable work has been done on various aspects of Orobanche in tobacco and in other crops. In spite of the extensive studies on the parasite, its control aspect presents considerable difficulties, still eradication is extremely difficult, practically impossible, mainly because of the large number of seeds produced by a broomrape plant and the long viability of the seeds in the soil. Hence preventing the parasite from spreading to parasite-free areas is the most crucial step in broomrape management.

Phyto-sanitary measures

- Prevent the spread of seeds by restricting the movement of infested soil by farm machinery and vehicles. Clean all the tools and implements after their use in the infested fields.
- Prevent grazing on infested plant material/ *Orobanche* spikes
- Use certified crop seeds collected from non-infested fields and avoid using seeds obtained from infested fields.
- In *Orobanche* sick fields, growing specific host crops for one or two seasons is to be skipped.
- Burning of residue from infested crops can reduce carryover of broomrape seeds back to the soil.
- Prevention of erosion and water runoff from an infested farm to adjacent, non-infested farms

Integrated approach: Farmers rotating the tobacco with recommended trap crops are maintaining their fields with very meagre infestation. In general, farmers who are following crop rotation, balanced fertilization and manual removal of *Orobanche* shoots as and when it appears in the field are facing less problem of infestation. Hence, the only effective way to counteract parasitic weeds problems is to apply an integrated approach (Rubiales and Fernández-Aparicio 2012) through a combination of all possible weed control methods and tools. These include preventive, cultural; mechanical; Physical; biological; and future research and biotechnologies and chemical methods. Several feasible methods/options can be integrated to form a workable integrated weed management (IWM) module including *Orobanche* or certain problematic perennial weeds (Kumar *et al.* 2012) in a specific area or crop for a long-term basis.

Dhanapal (1996) suggest the following package to obtain higher tobacco yields and minimize the *Orobanche cernua* population in the soil for the Nipani tobacco area and areas of similar conditions. 1. Grow trap crops (sunhemp or greengram) in the early spring and incorporate in-situ at 45 days after sowing. 2. Take up general weeding within 45 days after transplanting (DAT). 3. Apply glyphosate 0.50 kg/ha (or less) at 60 DAT.4. Remove the remaining few broomrape spikes by hand or apply plant oils to prevent seed formation.

Kasturi Krishna *et al.* (2019) recommended Summer ploughing, growing sesame in *Kharif* season preceding to tobacco, neem cake 250 kg/ha application at 30 days after planting to tobacco and hand weeding as integrated measures for broomrape management in FCV tobacco under irrigated conditions.

Use of plant hole application of Neem cake at 200 kg/ha at 30 DAT and post-emergence application of Imazethapyr at 30 g/ha at 55 days after planting has been suggested to control *Orobanche* in tobacco under Western zone of Tamil Nadu in India (Chinnusamy 2012).

In highly infested fields of *Orobanche* in tobacco, integration of trap crops of sorghum and sesame, rotation for two years with hand weeding for *Orobanche* management in Vertisol grown tobacco in Andhra Pradesh (Kasturi Krishna *et al.* 2022).

Under Bihar conditions neem cake application at sowing 200 kg/ha followed by metalaxylMZ 0.2% at 20 DAP was recommended for effective management of Orobanche in tobacco (Roy *et al.* 2024)

Conclusions

Several strategies for the control of these parasitic weeds have been studied however, none of them could provide fool-proof protection against *Orobanche* infestation to the host crop. Effective broomrape control strategies should target the underground mechanisms of crop parasitism in order to meet both the short-term productivity expectations of the farmer and reduction of soil bank in the long run. Therefore, an integrated management strategy is the best perspective to control broomrapes combining various methods for control of broomrape menace in tobacco with an aim to reduce seed bank in the soil, infection to host and seed production. Different integrated measures suggested for different tobacco is by researchers and followed in the field are given.

Future research on the critical elements of long-term integrated strategy for *Orobanche* should focus on:

(a) Reducing seed bank in soil while avoiding fresh additions

(b) Identification and timely application of parasite life-cycle phase specific cultural practices and

(c) Community approach to implement integrated strategies for effective control of broomrape.

REFERENCES

AICRPWC. 2013. *Proceedings of Annual Workshop of All India Coordinated Research Project on Weed Control.* CSKHPKVV, Palampur (HP) India.

Abbes Z, Kharra M, Delavault P, Chaïbi W and Simierm P. 2009. Nitrogen and carbon relationships between the parasitic weed *Orobanche foetida* and susceptible and tolerant fababean lines. *Plant Physiology and Biochemistry.* **47**: 153–159.

Chandrashekharagowda B, Jones PN, Shiney A, Matiwade PS, Jagadeesh KS. Suppression of *Orobanche* spp. in tobacco by native Arbuscular Mycorrhizal fungi. 2018. *International Journal of Current Microbiology and Applied Sciences* **7**(4): 1890–1896.

Chinnusamy C. 2012. Management of parasitic weed *Orobanche* in tobacco in Western Zone of Tamil Nadu, pp. 63-67. *Annual Report 2012*, TNAU AICRP-Weed Control, TNAU, Coimbatore.

CTRI, 2015. *Annual Report,* 2014-15. pp 34. Central Tobacco Research Institute, Rajahmundry.

CTRI, 2019. *Annual Report* 2019. pp. 30-31. Central Tobacco Research Institute, Rajahmundry.

CTRI, 2022. *Annual Repor*t 2022. pp. 34-35. Central Tobacco Research Institute, Rajahmundry.

Dakshinamurti V, Govinda Rao P and Reddy GS. 1964. A survey on tokra (*Orobanche cenuaLoefl*) incidence on tobacco in coastal Andhra districts. *Andhra Agricultural Journal* **11** (4): 152–156.

Dhanapal GN, Struik PC and Terborg SJ. 1998. Post-emergence chemical control of nodding broom rape (*Orobanhce cernua* L.) in bidi tobacco (*Nicotianatabacum*) in India. *Weed Technology* **12**: 652–659.

Dhanapal GN, Struik PC, Udayakumar M and Timmermans, PCJM. 1996. Management of broomrape *(Orobanche* spp.): A review. *Journal of Crop Science* **165**: 335–359.

Dhanapal GN. 1996. *Management of broomrape (Orobanche cernua) in tobacco (Nicotiana tabacum)*. Ph.D.Thesis, Wageningen University & Research 183 pp.

Dinesha MS, Dhanapal GN, Prabhudev Dhumgond NS, VigneshV, Madhukumar and Raghavendra K. 2012. Efficiency and economics of broomrape *(Orobanche cernua* Loefl.) control with herbicides in infested tomato *(Lycopersicon esculentum* Mill.) field. *Plant Archives* **12**(2): 833–836

Evidente A, Fernandez-Aparicio M, Andolfi A, Rubiales D and Motta A.2007. Trigoxazonane, a monosubstituted trioxazonane by *Trigonellafoenum-graecum* root exudate, inhibiting agent of *Orobanche crenata* seed germination. *Phytochemistry* **68:** 2487–2492.

Fernandez-Aparicio M, Emeran A and Rubiales D. 2010. Inter-cropping with berseem clover *(Trifolium alexandrinum)* reduces infection by *Orobanche crenata* in legumes. *Crop Protection* **29**(8): 867–871.

Fernandez-Aparicio M, Yoneyama K, and Rubiales D. 2011. The role of strigo lactones in host specificity of *Orobanche* and *Phelipanche* seed germination. *Seed Science Research* **21**: 55–61.

Foy CL, Jain A and Jacobsohn A. 1989. Recent approaches forchemical control of broomrape (*Orobanche* spp.). *Reviewof Weed Science* **4**: 123–152

Habimana SA, Nduwumuremyi JD and Chinama R. 2014. Managementof *Orobanche* in field crops: A review.*Journal of Soil Science and Plant Nutrition* **14**(1): 43–62.

Haidar MA and Sidahmad MM. 2000. Soil solarization and chicken manure for the control of *Orobanche crenata* and other weeds in Lebanon. *Crop Protection* **19**: 169–173.

Hershenhorn J, Dor E, Alperin B, Lat, R, Eizenberg H, Lande T, Acdary, Graph S, Kapulnik Y and Vininger S. 2006. Integrated broomrape control – resistant lines, chemical and biological control and sanitation – can we combine them together? In: *Workshop Parasitic Plant Management in Sustainable Agriculture Final meeting of COST849*; 23-24 November 2006, ITQB Oeiras-Lisbon, Portugal.

Hosmani MM. 1985. *Studies on control of Orobanche and Striga by trap crops*, M.Sc. (Agri) thesis submitted to the University of Agricultural Sciences, Bangalore, Karnatatka State, India

Jacobsohn R, Ben-Ghedalia D and Marton K. 1987. Effect of animal's digestive system on the infectivity of *Orobanche* seeds. *Weed Research* **27**: 87–90.

Joel DM, Hershenhorn J, Eizenberg H, Aly R, Ejeta G, Rich PJ, Ransom JK, Sauerborn J and Rubiales D. 2007. Biology and management of weedy root parasites. *Horticulture Reviews* **33**: 267–349.

Joel DM. 2000. The long-term approach to parasitic weeds control: manipulation of specific developmental mechanisms of the parasite. *Crop Protection* **19**: 753–758.

C. Kannan, Aditi Pathak and Sushilkumar. 2014. Natural incidence of agromyzid fly on broomrape. *Indian Journal of Weed Science* **46**(3):296-297.

Karkanis A, Bilalis D and Efthimiadou A. 2007. Tobacco (*Nicotiana tabaccum*) infection by branched broomrape (*Orobanche ramosa*) as influenced by irrigation system and fertilization, under East Mediterranean conditions. *Journal of Agronomy* **6**: 397–402.

Kasturi Krishna S, Krishna Reddy SV and Naidu VSGR. 2019. Integrated management of *Orobanche* in FCV Tobacco. In: *National symposium on Approaches and strategies for augmenting tobacco farmers income*, organised at CTRI on 19-20th July, 2019, p.54.

Kasturi Krishna S. Krishna Reddy SV, Deo Singh K, Subba Rao R, Harishu Kumar P, and Krishnamurthy V. 2007. Yield, quality and economics of FCV tobacco (*Nicotianatabacum*) in relation to preceding crops and nitrogen in Vertisols of Andhra Pradesh. *Indian Journal of Agronomy* **52**(3): 212–215.

Kasturi Krishna S, Krishna Reddy SV,Kiran Kumar T and Naidu VSGR. 2022. Effect of trap crop rotation cycles on broomrape infestation in FCV tobacco. *Tobacco Research* **48**(1): 23–29.

Khot RS, Bhat BN, KadapaS N and Kambar NS. 1987. Effect of deep tillage in summer on *Orobanche* incidence and yield of Bidi tobacco. *Tobacco Research* **13**(2): 134–138.

Krishnamurthy GVG, Nagarajan K and Chari MS.1994. Broomrape (*Orobanche cenua Loefl*) on tobacco. CTRI, 1994.

Krishnamurthy GVG, Nagarajan K and Ramji L. 1977b. Some studies on *O. cernua* a parasitic weed on tobacco in India. *Indian Journal of Weed Science* **9**(2): 95–106.

Krishnamurthy GVG, Nagarajan K. and Lal R. 1977a. Further studies on the effect of various crops on germination of *Orobanche* seed. *PANS* **23**: 206–208.

Krishnamurthy GVG.and Raju CA.1993. "Mini – spear and Leaf pusher" in broomrape control on air-cured tobacco crops. Paper sent for presentation at the 3rd Int. Workshop on *Orobanche,* Amsterdam, 8-12th Nov. 1993.

Kumar Mukesh, Das T.K, Yaduraju N.T. 2012. An integrated approach for management of *Cyperusrotundus* (purple nutsedge) in soybean - wheat cropping system. *Crop Protection* **33**: 74–81.

Lolas PC.1994. Herbicides for control of broomrape (*Orobanche ramosa*) in tobacco (*Nicotiana tabacum* L.).*Weed Research* **34**: 205–209.

Mazaheri A, Moazami N, Vaziri M, Moayed-Zadeh N.1991. Investigation of *Fusarium oxysporum* a possible biological control of broomrape (Orobanche spp.). In Proceedings of the 5th International Symposium of Parasitic Weeds, Ransom, JK, Musselman LJ, Worsham AD, Parker C, Eds., June 24-30, 1991, Nairobi, Kenya

Meti SS. 1993.*Orobanche* control in bidi tobacco by soil solarisation M.Sc (Agri) Thesis submitted to the University of Agricultural Sciences, Dharwad Karnataka state, India.

Meti SS and Hosmani MM. 1994. Broom rape control in bidi tobacco by soil solarisation. *Tobacco Research* **20**: 60–70.

Murthy KSN, Prasadarao JAV and Prasad SS. 1977. Study on the effect of *Orobanche* infestation on the nutrient uptake and physical and chemical quality characteristics of tobacco.*Tobacco Research* **3**(2): 101–107.

Murthy NS and Nagarajan K. 1986. Effect of *Orobanche* on the morphological characters of tobacco. *Indian Journal Weed Science* **18** (1): 85–89.

Oswald A, Ransom JK, Kroschel J, Sauerborn J. 2002. Intercropping controls Striga in maize based farming systems. *Crop Protection* **21**(5): 367–374.

Pathak Aditi and Kannan C. 2014. A new cost-effective method for quantification of seed bank of *Orobanche* in soil. *Indian Journal of Weed Science* **42**(2): 151-154.

Parker C and Riches CR. 1993. *Parasitic weeds of the world-Biology and Control*. Pp111-164. CAB Intern.

Prasada Rao JAV and Murty KSN. 1976. Preliminary observations on the nutrient removal by *Orobanche* from the host plant. *Tobacco Research* **2**(2): 158.

Punia SS. 2014. Biology and control measures of *Orobanche*. *Indian Journal of Weed Science* **46**(1):36-51.

Punia SS. 2015. Control of broomrape in mustard. *Indian Journal of Weed Science*. **47**(2):170-173.

Punia SS, Duhan Anil, Yadav Dharam Bir and Sindhu VK. 2016. Use of herbicides against Orobanche in tomato and their residual effect on succeeding crop. *Indian Journal of Weed Science*. **48**(4): 404-409.

Puzzilli M. 1983. Tobacco broomrapes and their control and some useful references to other parasite and host species. *Review of Agriculture Subtropicale e Tropicale* **78**: 209-248.

Qasem JR. 2021. Broomrapes (*Orobanche* spp.)the Challenge and Management: A review. *Jordan Journal of Agricultural Sciences* **17**(3): 115–148.

Roy DK, Shivani R and Sumit S.2024. Efficiency and economics of broomrape (*Orobanche* spp) control by different management methods. *Indian Journal of Weed Science* **56**(2): 191–193

Rubiales D and Fernández-Aparicio M. 2012. Innovations in parasitic weeds management in legume crops. A review. In: *Agronomy for Sustainable Development*, Springer Verlag/ EDP Sciences/INRA, 2012, **32**(2): 433-449.

Sauerborn J, Muller-Stover D, and Hershenhorn J. 2007. The role of biological control in managing parasitic weeds. *Crop Protection*. **26**: 246–250

Westwood James H. and Foy Chester L. 1999. Influence of nitrogen on germination and early development of broomrape (Orobanche spp.). *Weed Science* **47:** 2–7.

Wickett NJ, Honaas LA and Wafula EK. 2011. Transcriptomes of the parasitic plant family Orobanchaceae reveal surprising conservation of chlorophyll synthesis. *Current Biology*. **21**(24): 2098–2104.

Indian Journal of Weed Science (2024) **56**(3): 237–242
http://dx.doi.org/10.5958/0974-8164.2024.00039.0

RESEARCH ARTICLE

Bio-efficacy of ready-mix orthosulfamuron 0.6% + pretilachlor 6% GR on transplanted rice

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Received: 9 June 2024 | Revised: 25 August 2024 | Accepted: 27 August 2024

ABSTRACT

A field experiment was conducted at Visva-Bharati University under red and lateritic belt of West Bengal with the objective to evaluate the bio-efficacy of ready-mix orthosulfamuron 0.6% + pretilachlor 6% GR on weeds, yield of puddled transplanted rice (PTR) and its residual effect on succeeding crop. Four doses of ready-mix orthosulfamuron 0.6% + pretilachlor 6% GR at 40 + 400, 50 + 500, 60 + 600 and 70 + 700 g/ha, sole orthosulfamuron 50% WG at 75 g/ha, sole pretilachlor 50% EC at 750 g/ha, ready-mix bensulfuron-methyl 0.6% + pretilachlor 6% GR at 60 + 600 g/ha (check), hand weeding and unweeded control were assigned in randomized complete block design, which were replicated thrice in PTR. At 30 days after application, orthosulfamuron + pretilachlor at 60 + 600 and 70 + 700 g/ha as pre-emergence were found very effective against *Panicum repens* L., *Monochoria vaginalis* (Burm.f.) C. Presl, *Alternanthera philoxeroides* (Mart.) Griseb., *Ludwigia parviflora* Roxb., *Sphenoclea zeylanica* Gaertn., and *Cyperus iria* L. with 95-96% reduction in total weed biomass and comparable with ready-mix bensulfuron-methyl 0.6% + pretilachlor 6% GR at 60 + 600 g/ha (standard check). As compared to ready-mix orthosulfamuron + pretilachlor at 70 + 700 g/ha, sole application of pretilachlor had significantly higher infestation of *P. repens, M. vaginalis, A. philoxeroides* and *L. parviflora*. Similarly, sole orthosulfamuron also recorded higher infestation of all these weeds except *L. parviflora.* There was 9.4-11.0% yield advantage in rice with application of ready-mix formulation of orthosulfamuron + pretilachlor at 60 + 600 and 70 + 700 g/ha compared to sole pretilachlor and orthosulfamuron. None of the herbicides had any adverse effect on the yield of succeeding yellow sarson and on the soil microbial population.

Keywords: Puddled transplanted rice, Soil microflora, Weed management, Yield advantage

INTRODUCTION

Weeds are one of the most important growth-limiting factors in puddled transplanted rice (PTR). Without any weed management practices, the yield reduction may vary from 35.0-38.0% in West Bengal (Duary *et al.* 2015c). In PTR, hand-weeding is the most common method of weed management. However, high wages, scarcity of labour and mimicry of some weeds with rice make this operation difficult and uneconomic. Now the farmers have a variety of herbicides available on the market. The most commonly used pre-emergence herbicides in PTR are pretilachlor, pyrazosulfuron-ethyl and oxadiargyl (Latha and Gopal 2010, Duary *et al.* 2015a). An earlier report suggests that butachlor does not have any effect on *Cyperus* spp., *Cyanotis axillaris* (L.) D. Don ex Sweet and *Commelina benghalensis* L. and pretilachlor is poor against *C. axillaris* (Singh *et al.* 2004). Similarly, pyrazosulfuron alone is unable to control grasses including *Eleusine indica* (L.) Gaertn. (Sunil and Shankaralingappa 2014). Continuous application of a single herbicide leads to shift in weed flora (Duary 2008, Duary *et al.* 2015a and 2015c, Jaiswal *et al.* 2024). In India, *Cyperus difformis* L. and *Echinochloa crus-galli* var. *crus-galli* have been reported to evolve resistance against bispyribac-sodium, a widely and extensive used herbicide in India (Heap 2024). Use of mixtures of herbicides is preferable because the job can be done in a single application, which saves time and overcomes the problem of a shift in weed flora. In recent years, the most common herbicide mixtures that are used in PTR to control weeds are metsulfuron-methyl + chlorimuron-ethyl, pretilachlor + pyrazosulfuron-ethyl, bensulfuron-methyl + pretilachlor and penoxsulam + butachlor (Duary *et al.* 2015a, Yogananda *et al.* 2021, Venkatesh and Parameswari 2022). Even the mixed application of bensulfuron-methyl + pretilachlor was reported to be poor against the *Cynodon dactylon* (L.) Pers. and *Paspalum distichum* L. in West Bengal (Teja *et al.* 2015). It is always desirable to have alternative herbicides along

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with detailed information of their efficacy for recommendation in controlling mixed weed flora. Presently, we have limited information about the relatively new ready-mix herbicide containing orthosulfamuron and pretilachlor. With this perspective, the present experiment was conducted to study the effect of ready-mix application of orthosulfamuron and pretilachlor on weed, productivity of PTR and its residual effect on soil microflora and yield of succeeding crop yellow sarson in the red and lateritic belt of West Bengal.

MATERIALS AND METHODS

A field study was conducted at the Agriculture Farm of the Institute of Agriculture, Visva-Bharati University, West Bengal, India. Rice (*Oryza sativa* L.) was transplanted during the *Kharif* season (July–October 2019 and July–November 2020) and the sowing of succeeding crop, yellow sarson (*Brassica campestris* L. var. *yellow sarson*), was done during *Rabi* season (November–February) in 2019–20 and 2020–21. The field is geographically located at about $23^{0}40.0552$ N latitude and $87^{0}39.6122$ E longitude with an average altitude of 58 m above the mean sea level of sub-humid red lateritic agro-ecological zone of the tropics. The soil of the experiment field was sandy loam (Ultisol) in texture, slightly acidic in reaction with pH 5.9, low in organic carbon (0.5%), low in available N (214.4 kg/ha), medium in available P (19.1 kg/ha) and low in available K (247.7 kg/ha). The experiment was conducted in a randomized complete block design, with eight weed management practices and one control (unweeded control) (**Table 1**) which were replicated thrice. Rice variety "*MTU 1010*" was transplanted at 20 × 15 cm spacing. Succeeding crop yellow sarson variety "*B-9*" was sown with the spacing of 30 × 10 cm. The recommended dose of 80 kg N, 40 kg P and 40 kg K/ha were applied to both the crops. In PTR, to achieve uniform distribution of herbicides, orthosulfamuron + pretilachlor on and bensulfuron-methyl + pretilachlor were mixed with fine sand at 45 kg/ha. A battery-operated knapsack sprayer equipped with a flat fan nozzle was used for foliar sprays of herbicide and the spray volume was 500 L/ha. Herbicides were applied at 3 days after transplanting. As the effect of applied herbicides to rice was studied in succeeding crop no herbicide was given to the succeeding yellow sarson.

The density and biomass of different weed species were recorded separately at 30 days after application (DAA). Weed count was recorded as number of weeds per square meter. The weeds were uprooted, cleaned by washing, placed in sunlight for few hours and were kept in a hot air oven for drying at 70^{0}C for 72 hours or more till constant weights were recorded. The grain of rice and seed of yellow sarson was recorded after proper threshing and drying. Soil samples from the experimental plots were collected from the space in between rows at a depth up to 15 cm at harvesting of the crop. Selective media, namely Pikovskaya's agar medium for PSB (phosphate-solubilizing bacteria), Rose Bengal agar for fungi and Jensen's Agar Medium for actinomycetes were used to enumerate soil microbial population. The data on weed density and biomass was subjected to $\sqrt{x+0.5}$ transformation before statistical analyses. Statistical analysis of experimental data was done using MSTAT – C Computer Software.

RESULT AND DISCUSSION

Weed flora in the experimental field

In rice, *Panicum repens* L. was the dominant grassy weeds (14.4% of total weed density) in the experimental plots. Among the broad-leaved weed flora *Monochoria vaginalis* (Burm.f.) C. Presl (44.0%), *Ludwigia parviflora* Roxb. (15.7%), *Alternanthera philoxeroides* (Mart.) Griseb. (11.9%) and *Sphenoclea zeylanica* Gaertn. (7.5%) were

Table 1. Treatment details

Treatment	Dose (g/ha)	Formulation kg or litre/ha	Time of application (DAT)	Water volume (in litres)
Orthosulfamuron 0.6% + pretilachlor 6% GR	40 + 400	6.67 kg	3	Mixed with sand
Orthosulfamuron 0.6% + pretilachlor 6% GR	50 + 500	8.34 kg	3	
Orthosulfamuron 0.6% + pretilachlor 6% GR	60 + 600	10.00 kg	3	
Orthosulfamuron 0.6% + pretilachlor 6% GR	70 + 700	11.66 kg	3	
Orthosulfamuron 50% WG	75	0.15 kg	3	500
Pretilachlor 50% EC	750	1.50 litre	3	500
Bensulfuron-methyl 0.6% + pretilachlor 6% GR	60 + 600	10.00 kg	3	Mixed with sand
Hand weeding	-	-	-	-
Unweeded control	-	-	-	-

DAT: days after transplanting

dominant. *Cyperus iria* L. (6.2%) was the only sedge weed observed in the experimental field. Similar weed flora in PTR were also reported by Duary *et al.* (2015a, 2015b, 2015c), Teja *et al.* (2015, 2016, 2017).

Effect on grassy weeds

The application of orthosulfamuron 0.6% + pretilachlor 6% GR with different doses significantly reduced the density (**Table 2**) as well as biomass (**Table 3**) of grassy weed *P. repens* as compared to unweeded control. Ready-mix orthosulfamuron 0.6% + pretilachlor 6% GR at 60 + 600 and 70 + 700 g/ha recorded lower *P. repens* density (66-80%) and biomass (65-85%), compared with sole application of orthosulfamuron 75 g/ha and pretilachlor 750 g/ha. The herbicide combination at 60 + 600 and 70 + 700 g/ha of orthosulfamuron 0.6% + pretilachlor 6% GR was comparable with standard check herbicide combination bensulfuron methyl 0.6% + pretilachlor 6% GR at 60 + 600 g/ha. These findings were in conformity with Yadav *et al.* (2018) and Poojitha *et al.* (2023). According to Zahan *et al.* (2017), orthosulfamuron effectively controlled grassy weeds such as *C. dactylon* and *Echinochloa colona* (L.) Link.

Effect on broad-leaved weeds

The ready-mix herbicide orthosulfamuron 0.6% + pretilachlor 6% GR at 60 + 600 and 70 + 700 g/ha was found to be most effective in reducing density (93-96%) and biomass (95-97%) of broad-leaved weeds as compared to unweeded control (**Figure 1**). Whereas only 75-88% reduction in density and 83-89% in biomass of broadleaved weeds were recorded with the sole application of pretilachlor 50% EC and orthosulfamuron 50% WG. Orthosulfamuron 0.6% + pretilachlor 6% GR in all the doses under test had complete control over *A. philoxeroides*, *L. parviflora* and *S. zeylanica* (**Table 2**). But the presence of *A.philoxeroides* was recorded in sole orthosulfamuron 50% WG and pretilachlor 50% EC and *L. parviflora* in pretilachlor 50% EC treated plot. Pretilachlor was found ineffective against *Alternanthera sessilis* (L.) R.Br. ex DC. (Dubey *et al.* 2005) and against *L. parviflora* (Teja *et al.* 2015 and

Table 2. Species wise and total weed density at 30 DAA of herbicide (pooled over two years)

Treatment	Dose (g/ha)	Weed density (no./m^2) at 30 DAA						
		P. repens	*M. vaginalis*	*A. philoxeroides*	*L. parviflora*	*S. zeylanica*	*C. iria*	Total weed
Orthosulfamuron 0.6% + pretilachlor 6% GR	40 + 400	2.58 (6)*	3.51 (12)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	4.32 (18)
Orthosulfamuron 0.6% + pretilachlor 6% GR	50 + 500	2.16(4)	3.37 (11)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	3.95 (15)
Orthosulfamuron 0.6% + pretilachlor 6% GR	60 + 600	1.54(2)	3.08 (9)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	3.38 (11)
Orthosulfamuron 0.6% + pretilachlor 6% GR	70 + 700	1.54(2)	2.23 (5)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	2.64 (7)
Orthosulfamuron 50% WG	75	2.42(6)	3.56 (13)	1.88 (3)	0.71 (0)	0.71 (0)	0.71 (0)	4.63 (21)
Pretilachlor 50% EC	750	3.21(10)	4.42 (19)	2.99 (9)	2.00 (4)	0.71 (0)	0.71 (0)	6.45 (41)
Bensulfuron-methyl 0.6%+ pretilachlor 6% GR	60 + 600	1.87(3)	2.44 (6)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	2.99 (9)
Hand weeding	-	0.71(0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
Unweeded control	-	4.86(23)	8.36 (70)	4.45 (19)	5.03 (25)	3.57 (12)	3.15 (10)	12.61 (159)
LSD (p=0.05)		0.53	0.71	0.36	0.54	0.19	0.19	0.73

*Figures in parentheses are original values. Data were transformed SQRT (x+0.5)

Table 3. Species wise and total weed biomass at 30 DAA of herbicide (pooled over two years)

Treatment	Dose (g/ha)	Weed biomass (g/m^2) at 30 DAA						
		P. Repens	*M. vaginalis*	*A. philoxeroides*	*L. parviflora*	*S. zeylanica*	*C. iria*	Total weed
Orthosulfamuron 0.6% + pretilachlor 6% GR	40 + 400	2.28(4.73)	2.21(4.38)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	3.10(9.10)
Orthosulfamuron 0.6% + pretilachlor 6% GR	50 + 500	2.01(3.54)	1.90(3.13)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	2.68(6.66)
Orthosulfamuron 0.6% + pretilachlor 6% GR	60 + 600	1.12(0.76)	1.79(2.72)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	1.99(3.48)
Orthosulfamuron 0.6% + pretilachlor 6% GR	70 + 700	0.95(0.41)	1.54(1.89)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	1.67(2.30)
Orthosulfamuron 50% WG	75	2.04(3.70)	2.04(3.71)	1.73(2.49)	0.71(0.00)	0.71(0.00)	0.71(0.00)	3.22(9.90)
Pretilachlor 50% EC	750	2.49(5.70)	2.14(4.11)	2.28(4.73)	1.23(1.02)	0.71(0.00)	0.71(0.00)	4.00(15.6)
Bensulfuron-methyl 0.6%+ pretilachlor 6% GR	60 + 600	1.24(1.05)	1.73(2.48)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	2.01(3.53)
Hand weeding	-	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)
Unweeded control	-	4.31(18.26)	4.83(23.0)	3.90(14.73)	3.61(12.5)	2.77(7.48)	2.80(7.35)	9.14(83.3)
LSD (p=0.05)		0.27	0.24	0.17	0.04	0.37	0.04	0.32

*Figures in parentheses are original values. Data were transformed SQRT (x+0.5)

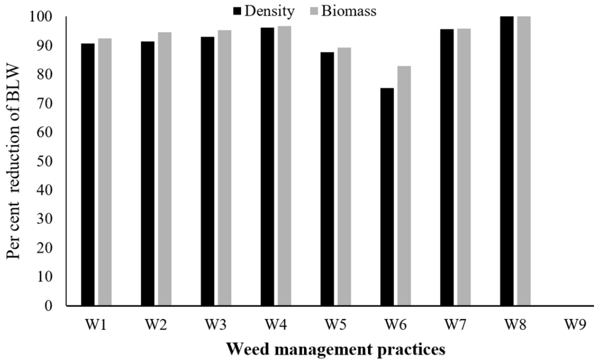
2016).

Effect on sedges

All the plots which were treated with either sole or mixed herbicide recorded complete control of sedges (**Table 2** and **3**). As usual unweeded control recorded the highest density and biomass of *C. iria*. Sole application of bensulfuron methyl or mixture with pretilachlor was very effective against sedges (Singh *et al.* 2005, Poojitha *et al.* 2023).

Effect on total weed

Orthosulfamuron 0.6% + pretilachlor 6% GR at 60 + 600 and 70 + 700 g/ha and bensulfuron methyl 0.6% + pretilachlor 6% were found very effective against the total weed having 93-96% reduction in density and 96-97% in biomass (**Table 2-3 and Figure 2**). While sole application of pretilachlor 50% EC and orthosulfamuron 50% WG recorded only 75-88% reduction in total weed density. Pretilachlor is a cell division inhibitor herbicide and orthosulfamuron inhibits Aceto Lactate Synthase (ALS) enzyme required for production of essential amino acid leucine, isoleucine and valine. Pretilachlor applied alone is more effective against grasses and also some broadleaved. While orthosulfamuron is more effective against sedges, broadleaved and some species of grasses. In the present study mix application of orthosulfamuron and pretilachlor became more effective against complex weed flora as compared to their individual application. Mix application of bensulfuron + pretilachlor was more effective against the weeds as compared to their sole application (Teja *et al.* 2015, Mohapatra *et al.* 2017, Yadav *et al.* 2018).



W1: Orthosulfamuron 0.6% + pretilachlor 6% GR at 40 + 400 g/ha; W2: Orthosulfamuron 0.6% + pretilachlor 6% GR at 50 + 500 g/ha; W3: Orthosulfamuron 0.6% + pretilachlor 6% GR at 60 + 600 g/ha; W4: Orthosulfamuron 0.6% + pretilachlor 6% GR at 70 + 700 g/ha; W5: Orthosulfamuron 50% WG at 75 g/ha; W6: Pretilachlor 50% EC at 750 g/ha; W7: Bensulfuron methyl 0.6% + pretilachlor 6% GR at 60 + 600 g/ha; W8: Hand weeding; W9: Unweeded control.

Figure 1. Effect of weed management practices on reduction in density (%) and biomass (%) of broadleaved weeds (pooled over two years)

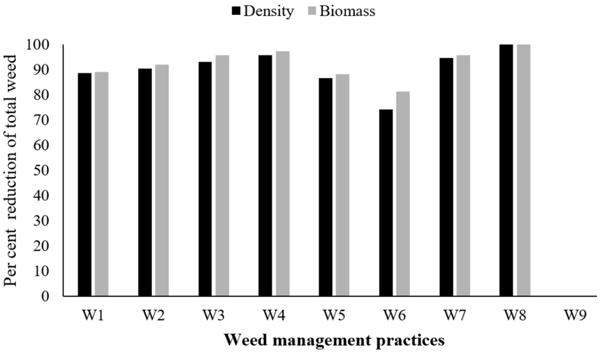


Figure 2. Effect of weed management practices on reduction in density (%) and biomass (%) of total weed (pooled over two years)

Yield of rice

The grain yield was significantly higher in the plots where orthosulfamuron 0.6% + pretilachlor 6% GR was applied at 70 + 700 and 60 + 600 g/ha (4.93 and 4.90 t/ha, respectively) which were comparable with hand weeding (4.86 t/ha) and bensulfuron-methyl 0.6% + pretilachlor 6% (4.84 t/ha). The lowest grain yield (4.03 t/ha) was recorded with unweeded control (**Table 4**). All the treatments except orthosulfamuron + pretilachlor at 40 + 400 g/ha recorded significantly higher grain yield of rice over unweeded control. Increased crop yield under different weed control treatments indicated the effect of weed infestation and competition by weeds in PTR which resulted in significant yield reduction under unweeded control by 18.3%. Ready-mix herbicide orthosulfamuron with pretilachlor both at 60 + 600 and 70 + 700 g/ha provided better weed control and produced 9.4-11.0% higher grain yield of rice as compared to sole application of orthosulfamuron and pretilachlor. The ready-mix herbicide formulation contains multiple active chemicals that are compatible with each other. This compatibility enhances their effectiveness, resulting in reduced density and biomass of complex weed flora. As a result, there is less or no competition, leading to a higher grain yield of rice. Significant response of ready-mix herbicidal treatments on yield may be attributed to favourable environment for crop due to proper weed control. This resulted in reduced competition for space, air, sunlight and nutrients. Duary *et al.* (2015a, 2015b and 2015c) and Teja *et al.* (2015, 2016 and 2017) reported similar higher yield of PTR with ready-mix herbicides in West Bengal. Higher weed biomass led to higher nutrient removal from the soil, resulting in a lower crop yield (Jaiswal *et al.* 2022, Jaiswal and Duary 2023).

Economics of rice

The highest cost of cultivation of rice was incurred in hand weeding and was 19.0-20.8% higher than the herbicide treated plots because of the higher lobour required for weeding (**Table 4**). Ready-mix herbicide orthosulfamuron + pretilachlor both at 60 + 600 and 70 + 700 g/ha fetched the highest net return (60.73-61.16 × 000 ₹/ha) and B:C ratio (1.37 each) and was at par with bensulfuron methyl + pretilachlor. Ready-mix herbicide orthosulfamuron + pretilachlor both at 60 + 600 and 70 + 700 g/ha fetched 17.7-18.5% and 15.2-16.0% higher net return than sole application of orthosulfamuron and pretilachlor, respectively. Better control of weeds with a mixture of different herbicides resulted in higher yield and, therefore, a higher return than the use of a single herbicide (Duary *et al.* 2015a).

Effect of herbicide on follow up crop *yellow sarson*

Follow up effect of orthosulfamuron 0.6% + pretilachlor 6% GR on yellow sarson observed that seed yield of *yellow sarson* did not vary significantly among the treatments (**Table 4**). It indicated that there was no residual toxicity of tested herbicides with different doses in PTR on succeeding yellow sarson. Herbicides pyrazosulfuron + pretilachlor, orthosulfamuron + pretilachlor and pretilachlor applied in PTR had no adverse effect on the yield of succeeding moong bean (*Vigna radiata*) (Venkatesh and Parameswari 2022). Similarly, pretilachlor + pyrazosulfuron-ethyl and bensulfuron-ethyl + pretilachlor applied in PTR did not have any harmful effect on the succeeding chickpea and wheat (Yadav *et al.* 2018).

Soil microbial properties

The impact of the test herbicides on soil micro-flora *viz.* total bacteria, fungi and actinomycetes recorded at harvest during both the years (**Table 5**) revealed that herbicide orthosulfamuron 0.6% + pretilachlor 6% GR did not show any adverse effect on soil bacteria, fungi and actinomycetes in crop rhizosphere. Pretilachlor and pyrazosulfuron did not show appreciable change in soil microbial population after 30 days of incubation (Latha and Gopal 2010). Dharumarajan *et al.* (2009) worked with pretilachlor in PTR and reported that at harvest the residues of this herbicide were below detectable level in soil.

Ready mix herbicide formulation of orthosulfamuron 0.6% + pretilachlor 6% GR at 60 + 600 and 70 + 700 g/ha when compared with sole application of orthosulfamuron 50% WG and pretilachlor 50% EC exhibited higher weed control when worked out against species-wise, category wise as well as total weeds, and registered higher

Table 4. Effect of treatments on yield of rice and residual yellow sarson and economics of rice cultivation (pooled over two years)

Treatment	Dose (g/ha)	Grain yield of rice(t/ha)			Seed yield of yellow sarson (t/ha)			Cost of cultivation (×10^3 ₹/ha)	Net return (×10^3 ₹/ha)	B:C
		2019	2020	Pooled	2019-20	2020-21	Pooled			
Orthosulfamuron 0.6% + pretilachlor 6% GR	40 + 400	3.93	4.78	4.35	1.19	1.27	1.23	43.62	49.85	1.14
Orthosulfamuron 0.6% + pretilachlor 6% GR	50 + 500	4.04	4.94	4.49	1.27	1.20	1.24	43.94	52.76	1.20
Orthosulfamuron 0.6% + pretilachlor 6% GR	60 + 600	4.34	5.46	4.90	1.16	1.11	1.14	44.26	60.73	1.37
Orthosulfamuron 0.6% + pretilachlor 6% GR	70 + 700	4.38	5.49	4.93	1.23	1.14	1.18	44.58	61.16	1.37
Orthosulfamuron 50% WG	75	3.91	4.98	4.44	1.09	1.08	1.09	43.84	51.58	1.18
Pretilachlor 50% EC	750	4.02	4.94	4.48	1.13	1.14	1.13	43.55	52.69	1.21
Bensulfuron-methyl 0.6% + pretilachlor 6% GR	60 + 600	4.19	5.48	4.84	1.04	1.00	1.02	44.34	59.44	1.34
Hand weeding	-	4.25	5.46	4.86	1.16	1.19	1.18	55.10	49.34	0.90
Unweeded control	-	3.64	4.41	4.03	0.99	1.04	1.02	41.90	44.75	1.07
LSD (p=0.05)		0.47	0.42	0.38	NS	NS	NS	-	7.24	0.16

Table 5. Impact of herbicides on total bacteria, fungi and actinomycetes (pooled over two years)

Treatment	Dose (g/ha)	Bacteria (CFU × 10^6 /g of soil)	Fungi (CFU × 10^4/g of soil)	Actinomycetes (CFU × 10^4/g of soil)
Orthosulfamuron 0.6% + pretilachlor 6% GR	40 + 400	15.9	8.0	2.4
Orthosulfamuron 0.6% + pretilachlor 6% GR	50 + 500	16.2	8.0	2.3
Orthosulfamuron 0.6% + pretilachlor 6% GR	60 + 600	14.9	8.0	2.3
Orthosulfamuron 0.6% + pretilachlor 6% GR	70 + 700	16.0	9.1	2.3
Orthosulfamuron 50% WG	75	15.0	7.6	2.4
Pretilachlor 50% EC	750	14.8	7.9	2.3
Bensulfuron methyl 0.6%+ pretilachlor 6% GR	60 + 600	14.9	8.4	2.2
Hand weeding	-	15.5	8.6	2.2
Unweeded control	-	15.4	9.0	2.3
LSD (p=0.05)		NS	NS	NS

grain yield of rice which was comparable with ready mixed herbicide bensulfuron-methyl 0.6% + pretilachlor 6% GR at 60 + 600 g/ha. Thus, ready-mix orthosulfamuron 0.6% + pretilachlor 6% GR at 60 + 600 kg/ha may be recommended for controlling mixed weed flora and obtaining higher grain yield of PTR in lateritic belt of West Bengal.

REFERENCES

Dharumarajan S, Sankar R and Arun S. 2009. Evaluation of bioefficacy and residues of pretilachlor in transplanted rice. *Indian Journal of Weed Science* **41**(1&2): 62–66.

Duary B, Teja KC and Soren U. 2015a. Management of composite weed flora of transplanted rice by herbicides. *Indian Journal of Weed Science* **47**(4): 349–352.

Duary B, Teja KC, Chowdhury SR and Mallick RB. 2015b. Weed growth and productivity of wet season transplanted rice as influenced by sole and sequential application of herbicides. *International Journal of Bio-Resource, Environment and Agricultural Sciences* **1**(4): 187–192.

Duary B. 2008. Recent advances in herbicide resistance in weeds and its management. *Indian Journal of Weed Science* **40**(3&4): 124–135.

Duary B, Mishra MM, Dash R and Teja KC. 2015c. Weed management in lowland rice in India. *Indian Journal of Weed Science* **47**(3): 224–232.

Dubey RP, Moorthy BTS, Gogoi AK. 2005. Bio–efficacy of acetachlor + bensulfuron-methyl against weeds in transplanted rice. *Indian Journal of Weed Science* **37**(3&4): 265–266.

Heap I. 2024. The international survey of herbicide resistant weeds. https://www.weedscience.org/Pages/FAQ.aspx/ [Accessed 7th June 2024].

Jaiswal DK and Duary B. 2023. Weed removal and crop nutrient uptake as affected by tillage and herbicides in direct-seeded rice-yellow mustard cropping sequence. *Indian Journal of Weed Science* **55**(3): 238–243.

Jaiswal DK, Duary B, Kumar RR and Nath CP. 2024. Weed seedbank as influenced by tillage and herbicide in direct seeded rice-mustard cropping sequence in lateritic soil of eastern India. *Weed Research* **64**(3): 197–206.

Jaiswal DK, Duary B, Madhukar B and Jaiswal D. 2022. Influence of rice herbicides on weed growth and nutrient removal under different tillage in rice–yellow sarson cropping sequence. *International Journal of Bio-resource and Stress Management* **13**(12): 1458–1464.

Latha P and Gopal H. 2010. Effect of herbicides on soil microorganisms. *Indian Journal of Weed Science* **42**(3&4): 217–222.

Mohapatra S, Tripathy SK, Nayak BR and Mohanty AK. 2017. Efficacy of pre-emergence herbicides for control of complex weed flora in transplanted rice. *Indian Journal of Weed Science* **49**(3): 216–218.

Poojitha K, Murthy KNK, Sanjay MT and Dhanapal GN. 2023. Weed management efficacy of herbicides and allelochemicals in direct-seeded rice. *Indian Journal of Weed Science* **55**(2): 153–156.

Singh G, Singh VP and Singh M. 2004. Effect of almix and butachlor alone and in combinations on transplanted rice and associated weeds. *Indian Journal of Weed Science* **36**(1&2): 64–67.

Singh VP, Singh G and Singh M. 2005. Effect of bensulfuron-methyl (Londax 60 DF) on sedges and non-grassy weeds in transplanted rice. *Indian Journal of Weed Science* **37**(1&2): 40–44.

Sunil CM and Shankaralingappa BC. 2014. Impact of integrated package of agrotechniques on growth and yield of aerobic rice. *Agricultural Sciences* **5**: 60–65.

Teja KC, Duary B and Dash S. 2016. Sole and combined application of herbicides on composite weed flora of transplanted rice. *Indian Journal of Weed Science* **48**(3): 254–258.

Teja KC, Duary B, Dash S and Swain KC. 2017. Efficacy of herbicides and their combination on weed management in transplanted *Kharif* rice. *Journal of Crop and Weed* **13**(2): 175–179.

Teja KC, Duary B, Kumar M and Bhowmick MK. 2015. Effect of bensulfuron-methyl + pretilachlor and other herbicides on mixed weed flora of wet season transplanted rice. *International Journal of Agriculture, Environment and Biotechnology* **8**(2): 323–329.

Venkatesh B and Parameswari YS. 2022. Weed management measures in transplanted rice and its residual impact on succeeding moong bean (*Vigna radiata*). *Journal of Crop and Weed* **18**(1): 247–249.

Yadav DB, Yadav A, Punia SS, Singh N and Duhan A. 2018. Pretilachlor + pyrazosulfuron-ethyl (ready-mix) against complex weed flora in transplanted rice and its residual effects. *Indian Journal of Weed Science* **50**(3): 257–261.

Yogananda SB, Thimmegowda P and Shruthi GK. 2021. Weed management in wet (drum)-seeded rice under Southern dry zone of Karnataka. *Indian Journal of Weed Science* **53**(2): 117–122.

Zahan T, Rahman MM, Hashem A, Bell RW and Begum M. 2017. Performance of pre- and post-emergence herbicides in strip tillage non-puddled transplanted *Aman* rice. *Bangladesh Journal of Agricultural Research* **42**(4): 631–646.

Indian Journal of Weed Science (2024) **56**(3): 243–250
http://dx.doi.org/10.5958/0974-8164.2024.00040.1

RESEARCH ARTICLE

Sequential herbicidal application on weed community and yield of wheat

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Received: 28 May 2024 | Revised: 24 August 2024 | Accepted: 28 August 2024

ABSTRACT

Effect of time, dosage of herbicide and crop residue were evaluated in Dharwad (Karnataka) on weed flora in wheat during winter (*Rabi*) season of 2020-21 and 2021-22. The experiment used a factorial randomized block design with twelve treatments, including a randomized complete block design to compare controls with treatment combinations. Results revealed that pre-emergence of pendimethalin reduced the number of grasses (3.0/m^2), sedges (1.7/m^2), broad-leaved weeds (4.5/m^2) and total number of weeds (9.2/m^2) at 20 DAS. At 40 and 60 DAS, sequential application of pre-emergence followed by post-emergence reduced the grasses (2.9 and 5.9/m^2), sedges (1.1 and 1.5/m^2), broad-leaved weeds (3.1 and 3.5/m^2), total number of weeds (6.8 and 10.6/m^2) and dry weight of weeds (1.9 and 3.4 g/m^2). Among the dosage, 100% recommended dose of herbicide (RDH) recorded lower grasses, sedges, broad-leaved weeds and dry weight of weeds compared to 75% RDH. Weed population did not differ significantly with application of soybean residue and no residue treatment. Pre-emergence followed by post-emergence at 100% RDH with soybean residue recorded higher grain yield (4.17 t/ha), weed control efficiency (79.7, 92.1 and 84.5%) and lower weed index (4.5%) compared to rest of the treatments. Lower grain yield (2.98 t/ha) and weed control efficiency (65.9, 56.6 and 42.7%) were with pre-emergence at 75% RDH without soybean residue. The results suggested that pre-emergence followed by post-emergence with 100% RDH with soybean residue was the best broad spectrum effective herbicide in order to minimize the diverse weed flora in wheat.

Keywords: 100% RDH, Pre-emergence, Post-emergence, Sequential herbicide, Soybean residue

INTRODUCTION

Weeds compete intensely with wheat crops for resources such as nutrients, water, and light, resulting in decreased wheat yield and reduced produce quality. Research findings from different sources suggest that unmanaged weed proliferation in wheat fields could lead to a decline in grain yield, varying between 15% to 40%, based on the extent, type and duration of weed infestation (Jat *et al.* 2003). Until the late 1990s, farmers predominantly relied on manual and mechanical weeding methods. However, since the 1990s, there has been a notable rise in nominal farm wages, which subsequently led to a higher dependence on herbicides, either applied individually or as part of integrated weed management strategies. While manual weeding remains the safest and most reliable approach to weed control, the challenge lies in ensuring the timely availability of sufficient labour, particularly during critical stages when weeding is required. Additionally, manual weeding has become expensive and time-consuming. As a result, chemical weed control methods are gaining popularity nowadays.

Herbicides represent one of the most effective weed management technologies ever created due to their selectivity, affordability, ease of application, manageable persistence, and adaptable timing for application. These are also environmentally friendly when utilized with the correct dosage, approach, and timing, besides being notably safer compared to other pesticides. However, with the emergence of resistance in significant weeds such as *Phalaris minor* against isoproturon and other suggested herbicides for grassy weeds like fenoxaprop-p-ethyl, it becomes imperative to explore alternative herbicidal options (Kamboj *et al.* 2021). Certain herbicides, like 2,4-D, which are primarily used to manage broadleaved weeds, perform effectively to suppress weeds but frequently cause deformity in wheat leaves and earheads (Balyan *et al.* 1990). Recent compounds of broadleaf herbicides such as metsulfuron-methyl effectively manage broadleaf weeds (Sharma *et al.* 2018) but lack efficacy against grassy weeds. This suggests the necessity of utilizing herbicides with diverse modes of action either in rotation or through sequential application to

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effectively manage the diverse weed population in wheat fields. The combination of various herbicide formulations in tank mixes or pre-mixes, as well as the sequential application of pre- and post-emergence herbicides at different timings, demonstrated efficient weed management (Kaur *et al.* 2017). In present study, the efficiency of combination of pre- and post-emergence herbicides used in sequence against weed flora in wheat was evaluated.

MATERIAL AND METHODS

The study was conducted in the winter (*Rabi*) seasons of 2020–21 and 2021–22 at the Main Agricultural Research Station, University of Agricultural Sciences, Dharwad. The experiment was designed using a factorial randomized block design with 12 treatments. A randomized complete block design was employed to compare the control treatments with the treatment combinations. The treatment details of the experiment are time of application, *viz.*, H_1: Pre-emergence herbicide (pendimethalin), H_2: Pre-emergence (pendimethalin) followed by post-emergence (sulfosulfuron + metsulfuron-methyl), H_3: Post-emergence (sulfosulfuron + metsulfuron-methyl) in factor A, dosage of herbicide, *viz.* D_1: 75% recommended dose of herbicide, D_2: 100% recommended dose of herbicide in factor B and Residue N_1: No residue, N_2: Soybean residue in factor C and the control treatments are W_1: Weed free check and W_2: Weedy check. The soil of the research field was loam in texture pH of 7.4, low in organic carbon (0.47%), available N (158.41 kg/ha), moderate in available P (32.15 kg/ha) and available K (291.52 kg/ha). Wheat (UAS 334) was sown on 27th November 2020 and 14th November in 2021 by using seed rate of 125 kg/ha at 5 cm depth with rows 20 cm apart. The recommended dose of fertilizer was applied at the rate of 120-60-40-20-20 kg N, P, K, $ZnSO_4$ and $FeSO_4$/ha in the form of urea, di-ammonium phosphate, muriate of potash, zinc sulphate and ferrous sulphate, respectively. At the time of sowing, half dose of nitrogen, full dose of phosphorous, potassium, zinc and sulphur were applied as basal dose. Basal application was done in lines 5 cm below the seed rows. The remaining 50 percent of nitrogen was top dressed onto the crop at 30 days after sowing. Pre-emergence herbicide pendimethalin 30% EC 1.0 kg/ha was sprayed uniformly as per the treatment one day after sowing of the crop. The post-emergence herbicide tank mixtures of sulfosulfuron 75% WG 25 g/ha and metsulfuron-methyl 20% WP 4 g/ha was sprayed uniformly as per the treatments at 29 DAS when the weeds attained 2-4 leaf stage. The determined quantity of herbicide was applied to each treatment using a knapsack sprayer, with a spray volume of 750 litres of water per hectare. Three t/ha of soybean residue was chopped and spread immediately after germination in between the plant rows of the wheat crop. In the weed free treatment, there was continuous control of weeds during the entire crop growth period with manual weeding frequently as and when weeds appear in the field. Total number of weeds per square meter was noted in each plot in quadrate of 1 × 1 m^2 at 20, 40 and 60 DAS. A square root transformation $(\sqrt{x+1})$ was used to normalize the distribution of the data in order to determine the number of weeds in the wheat crop. The weeds were uprooted from m^2 area randomly each time and oven dried of weeds at 70°C till a constant weight. These were weighed and expressed in g/m^2 of weed biomass. Weed index was calculated by the formula proposed by Gill and Kumar (1969). The grain yield was calculated and expressed as t/ha. The statistical analysis was carried out using Analysis of Variance (Gomez and Gomez 1984) and mean comparisons were based on the least significant difference (LSD) at 0.05 probability.

RESULTS AND DISCUSSION

Grasses

Significantly reduced number of grasses was registered with the application of pendimethalin (3.0/m^2) and pendimethalin followed by sulfosulfuron + metsulfuron-methyl (3.0/m^2) compared to sulfosulfuron + metsulfuron-methyl (12.3/m^2) at 20 DAS. At 40 and 60 DAS, pendimethalin followed by sulfosulfuron + metsulfuron-methyl (2.9 and 5.9/m^2) noted a substantial decrease in grass weed population. A substantially greater quantity of grass weeds was found in sulfosulfuron + metsulfuron-methyl (9.3 and 12.7/m^2) and was on par with pendimethalin (5.7 and 10.6/m^2). The results are in line with the observations made by Pisal and Sagarka (2013) indicated that pendimethalin effectively managed both monocot and dicot weeds, whereas post-emergence application of 2,4-D amine salt and metsulfuron-methyl efficiently controlled dicot weeds.

Among the dosage of herbicide, grass weed number was significantly lower in 100% RDH (4.5, 4.7 and 7.9/m^2) compared to 75% RDH (6.7, 6.8 and 11.9/m^2) at 20, 40 and 60 DAS. Number of grass weeds did not differ significantly with crop residue application. Weed free check (0.0/m^2) recorded notably lower grass weeds compared to all other interactions and weedy check. While, weedy check

(18.4, 25.0 and 28.8/m^2 at 20, 40, 60 DAS, respectively) registered significantly superior number of grass weeds compared to the remaining treatments.

Sedges

Weed management practices had a significant impact on the number of sedge weeds (**Table 1**). At 20 DAS, significantly lower number of sedge population with pendimethalin (1.7/m^2) and was on par with pendimethalin followed by sulfosulfuron + metsulfuron-methyl (1.9/m^2). Substantially higher number of sedges (4.1/m^2) was noticed in sulfosulfuron + metsulfuron-methyl. At 40 and 60 DAS, sedge population was markedly reduced in pendimethalin followed by sulfosulfuron + metsulfuron-methyl (1.1 and 1.5/m^2) compared to different treatments. Significantly higher sedge weeds were recorded in pendimethalin (3.2 and 4.2/m^2) and was on par with sulfosulfuron + metsulfuron-methyl (2.6 and 3.0/m^2) treatment.

Significantly lower number of sedge weeds was found in 100% RDH (2.1, 1.6 and 2.1/m^2) compared to 75% RDH (2.9, 2.8 and 3.6/m^2) at 20, 40 and 60 DAS. Sedge population did not differ significantly with application of soybean residue and no residue treatment. Among control treatments, weed free check (0.0/m^2) recorded lower sedge number than other treatment combinations. Significantly higher sedges population was observed in weedy check, with counts of 6.3, 8.0, 10.5/m^2 at 20, 40 and 60 DAS, respectively.

Broad-leaved weeds

The number of broad-leaved weeds at 20 DAS varied significantly with the time of herbicide application, the number of broad-leaved weeds was significantly lower in the pendimethalin treatment (4.5/m^2) and comparable to the pendimethalin followed by sulfosulfuron + metsulfuron-methyl treatment (4.6/m^2). Broad-leaved weeds were found in much higher numbers (7.7/m^2) in the sulfosulfuron + metsulfuron-methyl (**Table 2**). At 40 and 60 DAS, pendimethalin followed by sulfosulfuron + metsulfuron-methyl (3.1 and 3.5/m^2) recorded lowest broad-leaved weeds compared to pendimethalin (7.8

Table 1. Number of grasses and sedge weeds at 20, 40 and 60 DAS of wheat as influenced by weed management practices (pooled data of 2 years)

Treatment	Grasses (no./m^2)			Sedges (no./m^2)		
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
Time of application						
H_1: Pre-emergence	2.0 (3.0)	2.6 (5.7)	3.4 (10.6)	1.6 (1.7)	2.1 (3.2)	2.3 (4.2)
H_2: Pre-emergence *fb* post emergence	2.0 (3.0)	1.9 (2.9)	2.6 (5.9)	1.7 (1.9)	1.5 (1.1)	1.6 (1.5)
H_3: Post-emergence	3.6(12.3)	3.2 (9.3)	3.7 (12.7)	2.3 (4.1)	1.9 (2.6)	2.0 (3.0)
LSD (p=0.05)	0.29	0.33	0.47	0.14	0.17	0.22
Dosage of herbicide						
D_1: 75% of herbicide	2.8 (6.7)	2.8 (6.8)	3.5 (11.2)	2.0 (2.9)	1.9 (2.8)	2.1 (3.6)
D_2:100% of herbicide	2.3 (4.5)	2.4 (4.7)	2.9 (7.9)	1.7 (2.1)	1.6 (1.6)	1.8 (2.1)
LSD (p=0.05)	0.24	0.27	0.38	0.12	0.14	0.18
Crop residue						
N_1 = No residue	2.7 (6.4)	2.7 (6.3)	3.4 (10.2)	1.9 (2.6)	1.9 (2.6)	2.0 (3.1)
N_2 = Residue	2.4 (4.8)	2.5 (5.2)	3.1 (8.8)	1.8 (2.3)	1.7(1.9)	1.9 (2.6)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Interaction						
$H_1D_1N_1$	2.6 (5.8)	2.9 (7.7)	4.0 (15.7)	1.9 (2.5)	2.3 (4.3)	2.6 (5.6)
$H_1D_1N_2$	2.2 (3.9)	2.7 (6.3)	3.5 (11.7)	1.7 (1.8)	2.2 (3.8)	2.5 (5.1)
$H_1D_2N_1$	1.8 (2.2)	2.4 (5.0)	3.1 (9.0)	1.6 (1.5)	1.9 (2.6)	2.1 (3.5)
$H_1D_2N_2$	1.5 (1.3)	2.3 (4.5)	2.9 (8.0)	1.5 (1.2)	1.8 (2.3)	1.9 (2.6)
$H_2D_1N_1$	2.4 (5.2)	2.2 (4.0)	3.0 (8.3)	1.9 (2.8)	1.7 (1.8)	1.8 (2.2)
$H_2D_1N_2$	2.2 (3.9)	2.1 (3.5)	2.8 (7.0)	1.8 (2.3)	1.5 (1.3)	1.6 (1.7)
$H_2D_2N_1$	1.9 (2.7)	1.9 (2.8)	2.4 (5.2)	1.6 (1.7)	1.4 (1.0)	1.5 (1.2)
$H_2D_2N_2$	1.6 (1.7)	1.6 (1.7)	2.3 (4.2)	1.5 (1.2)	1.2 (0.5)	1.4 (0.9)
$H_3D_1N_1$	3.8 (13.5)	3.5 (11.0)	3.9 (14.3)	2.4 (4.7)	2.2 (3.8)	2.3 (4.3)
$H_3D_1N_2$	3.5 (11.6)	3.4 (10.7)	3.8 (13.3)	2.2 (3.8)	1.9 (2.6)	2.1 (3.5)
$H_3D_2N_1$	3.7 (12.7)	3.3 (9.7)	3.6 (12.0)	2.3 (4.3)	1.8 (2.3)	1.9 (2.7)
$H_3D_2N_2$	3.5 (11.6)	2.8 (6.7)	3.5 (11.7)	2.2 (3.8)	1.7 (1.8)	1.8 (2.2)
Control						
W_1: Weed free check	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
W_2: Weedy check	4.4(18.4)	5.1(25.0)	5.5 (28.8)	2.7 (6.3)	2.9 (8.0)	3.4 (10.5)
LSD (p=0.05)	0.54	0.62	0.89	0.29	0.37	0.46

Figures are $(\sqrt{x+1})$ transformed values and figures in the parentheses are original values; DAS- Days after sowing and 10.1/m^2) and was on par with sulfosulfuron + metsulfuron-methyl (4.3 and 4.6/m^2). Pendimethalin recorded significantly higher broad-leaved weeds compared to rest of the treatments.

Among the dosage, 100% RDH (4.3, 3.9 and 4.8 /m^2 at 20, 40 and 60 DAS, respectively) was substantially reduced broad-leaved weeds compared to 75% RDH. The treatment of 75% RDH (6.7, 5.9 and 6.9/m^2 at 20, 40 and 60 DAS, respectively) recorded highest broad-leaved weeds. Soybean residue (4.8/m^2) recorded significantly lower broad-leaved weed population compared to no residue (6.2/m^2) treatments at 20 DAS. At 40 and 60 DAS, Application of with and without soybean residue did not affect number of broad-leaved weeds statistically but lower broad-leaved weeds were noticed in soybean residue (4.7 and 5.2/m^2) compared to no residue (5.7 and 6.3/m^2). The weed free check (0.0/m^2) found the lowest number of broad-leaved weeds compared to the other treatments. However, higher broad-leaved weeds population was observed in weedy check (11.5, 15.0 and 17.2/m^2 at 20, 40 and 60 DAS, respectively) compared to all other interactions.

Total number of weeds

Application of herbicides reduced the total number of weeds at 20, 40, 60 DAS compared to the weedy check (36.2, 48.0 and 56.8/m^2). Pre-emergence application of pendimethalin is effective only during the initial days and its efficacy is lost after few days (**Table 2**). Combined application of pendimethalin followed by sulfosulfuron + metsulfuron-methyl reduced the total number of weeds (9.9, 6.8 and 10.6/m^2) compared with single application of pendimethalin (9.2, 16.6 and 25.0/m^2) and sulfosulfuron + metsulfuron-methyl (24.0, 16.6 and 20.2/m^2). Better performance of herbicide mixtures was known in controlling all types of weeds and this was due to synergistic effect of these herbicides when tank mixed. Kaur *et al.* (2019) indicated that the sequential application of pendimethalin 1.0 kg/ha followed by post-emergent herbicides enhanced weed control compared with pre-emergent or post-emergent herbicides alone. Individual herbicide effect was inferior when compared with pre-emergent *fb* post-emergent herbicides.

Table 2. Broad-leaved weeds and total number of weeds at 20, 40 and 60 DAS of wheat as influenced by weed management practices (pooled data of 2 years)

Treatment	Broad-leaved weeds (no./m^2)			Total number of weeds (no./m^2)		
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
Time of application						
H_1: Pre-emergence	2.3 (4.5)	2.9 (7.8)	3.3 (10.1)	3.2 (9.2)	4.2 (16.6)	5.1 (25.0)
H_2: Pre-emergence *fb* post-emergence	2.4 (4.6)	2.0 (3.1)	2.1 (3.5)	3.3 (9.9)	2.8 (6.8)	3.4 (10.6)
H_3: Post-emergence	2.9 (7.7)	2.3 (4.3)	2.4 (4.6)	5.0 (24.0)	4.2 (16.6)	4.6 (20.2)
LSD (p=0.05)	0.29	0.33	0.28	0.31	0.36	0.45
Dosage of herbicide						
D_1: 75% of herbicide	2.8 (6.7)	2.6 (5.9)	2.8 (6.9)	4.2 (16.6)	4.1 (15.8)	4.8 (22.0)
D_2: 100% of herbicide	2.3 (4.3)	2.2 (3.9)	2.4 (4.8)	3.5 (11.2)	3.4 (10.5)	4.0 (15.0)
LSD (p=0.05)	0.24	0.27	0.23	0.25	0.29	0.37
Crop residue						
N_1 = No residue	2.7 (6.2)	2.5 (5.7)	2.7 (6.3)	4.0 (15.0)	3.9 (14.2)	4.6 (20.2)
N_2 = Residue	2.4 (4.8)	2.3 (4.7)	2.5 (5.2)	3.6 (11.9)	3.5 (11.2)	4.2 (16.6)
LSD (p=0.05)	0.24	NS	NS	NS	NS	NS
Interaction						
$H_1D_1N_1$	2.8 (7.0)	3.3 (10.0)	3.7 (12.5)	4.0 (15.0)	4.8 (22.0)	5.8 (32.6)
$H_1D_1N_2$	2.6 (5.7)	3.1 (8.5)	3.5 (11.2)	3.5 (11.2)	4.4 (18.3)	5.3 (27.1)
$H_1D_2N_1$	2.2 (3.8)	2.8 (7.0)	3.2 (9.0)	2.9 (7.4)	3.9 (14.2)	4.7 (21.1)
$H_1D_2N_2$	1.8 (2.3)	2.6 (5.8)	3.1 (8.5)	2.4 (4.7)	3.7 (12.7)	4.5 (19.2)
$H_2D_1N_1$	2.8 (6.7)	2.4 (4.7)	2.4 (5.0)	3.9 (14.2)	3.3 (9.9)	4.0 (15.0)
$H_2D_1N_2$	2.5 (5.3)	2.2 (3.8)	2.2 (4.0)	3.5 (11.2)	3.1 (8.6)	3.7 (12.7)
$H_2D_2N_1$	2.2 (4.2)	1.9 (2.8)	2.1 (3.5)	3.0 (8.0)	2.7 (6.3)	3.3 (9.9)
$H_2D_2N_2$	1.9 (2.8)	1.7 (1.8)	1.7 (1.8)	2.6 (5.7)	2.2 (3.8)	2.8 (6.8)
$H_3D_1N_1$	3.1 (8.8)	2.5 (5.5)	2.6 (5.8)	5.3 (27.1)	4.6 (20.2)	5.0 (24.0)
$H_3D_1N_2$	2.9 (7.3)	2.4 (4.7)	2.4 (5.0)	4.8 (22.0)	4.3 (17.5)	4.7 (21.1)
$H_3D_2N_1$	3.0 (8.2)	2.3 (4.2)	2.3 (4.3)	5.2 (26.0)	4.1 (15.8)	4.5 (19.2)
$H_3D_2N_2$	2.8 (6.7)	2.1 (3.5)	2.1 (3.5)	4.7 (21.1)	3.6 (11.9)	4.2 (16.6)
Control						
W_1: Weed free check	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
W_2: Weedy check	3.5 (11.5)	3.9 (15.0)	4.3 (17.2)	6.1 (36.2)	7.0 (48.0)	7.6 (56.8)
LSD (p=0.05)	0.59	0.61	0.53	0.58	0.67	0.85

Figures are ($\sqrt{x+1}$) transformed values and figures in the parentheses are original values; DAS- Days after sowing

Recommended dosage of herbicide (11.2, 10.5 and 15.0/m^2 at 20, 40 and 60 DAS, respectively) reduced the total number of weed population due to efficient weed control compared with 75% RDH (16.6, 15.8 and 22.0/m^2 at 20, 40 and 60 DAS, respectively) in wheat at all the stages of crop growth. Duary *et al.* (2021) noticed that sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 35 g/ha recorded significantly the lower density of grasses, broad-leaved and total weeds compared with sulfosulfuron-ethyl 75% + metsulfuron-methyl 5% WG 25 g/ha. Total number of weeds showed no notable variance with the utilization of soybean residue practices in wheat crop. Soybean residue appears to be more effective in the absence of herbicide may rather than with the combinations. Abbas *et al.* (2017) found that application of mulches of sunflower, maize, rice and sorghum failed to achieve adequate weed control in wheat under clay-loam soil.

Better initial weed management was achieved with the pre-emergence of pendimethalin at 100% RDH combined with soybean residue (4.7/m^2) resulting in lower total number of weeds at 20 DAS. One of the reasons could be the implementation of the treatment. At 40 and 60 DAS of wheat, maximum control weeds were observed under pre-emergence followed by post-emergence at 100% RDH with soybean residue (3.8 and 6.8/m^2). Combining mulches and herbicides increased *Phalaris minor* mortality up to 98% in wheat crop (Abbas *et al.* 2017). Weed free check showed lower weed number due to continuous hand weeding to keep the field weed free. Weed management was achieved.

Dry weight of weeds

The herbicide application resulted in a notable reduction in the dry weight of weeds compared with weedy check (10.6, 13.2 at 14.8 g/m^2 at 20, 40 and 60 DAS, respectively). At 20 DAS, pendimethalin was efficient in reducing weed dry weight (2.8 g/m^2) compared with sulfosulfuron + metsulfuron-methyl (6.9 g/m^2) and it was on par with pre-emergence followed by post-emergence (3.2 g/m^2) and later dry weight of weeds was increases up to harvest (**Table 3**). This occurred because of the effective

Table 3. Total dry weight of weeds and weed control efficiency at 20, 40 and 60 DAS of wheat as influenced by weed management practices (pooled data of 2 years)

Treatment	Total dry weight of weeds (g/m^2)			Weed control efficiency (%)	
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS
Time of application					
H_1: Pre-emergence	1.9 (2.8)	2.4 (4.7)	2.9 (7.6)	75.2	64.1
H_2: Pre-emergence *fb* post-emergence	2.1 (3.2)	1.7 (1.9)	2.1 (3.4)	68.9	84.6
H_3: Post-emergence	2.8 (6.9)	2.2 (3.8)	2.6 (5.5)	34.4	69.1
LSD (p=0.05)	0.14	0.07	0.12	-	-
Dosage of herbicide					
D_1: 75% of herbicide	2.4 (4.7)	2.2 (3.8)	2.7 (6.3)	54.5	67.4
D_2:100% of herbicide	2.1 (3.2)	1.9 (2.8)	2.4 (4.7)	64.6	77.8
LSD (p=0.05)	0.12	0.05	0.10	-	-
Crop residue					
N_1 = No residue	2.3 (4.2)	2.2 (3.8)	2.6 (5.8)	56.1	70.2
N_2 = Residue	2.1 (3.6)	2.0 (3.2)	2.5 (5.1)	63.0	75.0
LSD (p=0.05)	0.12	0.05	0.10	-	-
Interaction					
$H_1D_1N_1$	2.1 (3.4)	2.6 (5.8)	3.0 (8.5)	65.9	56.6
$H_1D_1N_2$	2.0 (3.1)	2.4 (4.8)	2.9 (7.9)	71.1	61.8
$H_1D_2N_1$	1.8 (2.3)	2.3 (4.1)	2.8 (7.2)	79.6	67.1
$H_1D_2N_2$	1.6 (1.7)	2.2 (4.0)	2.7 (6.6)	84.3	71.1
$H_2D_1N_1$	2.3 (4.3)	1.9 (3.0)	2.4 (5.1)	58.5	78.0
$H_2D_1N_2$	2.2 (3.8)	1.8 (2.4)	2.3 (4.4)	63.9	81.4
$H_2D_2N_1$	1.9 (2.9)	1.7 (1.9)	2.0 (3.3)	73.6	86.7
$H_2D_2N_2$	1.8 (2.1)	1.5 (1.3)	1.8 (2.4)	79.7	92.1
$H_3D_1N_1$	2.9 (7.9)	2.5 (5.1)	2.8 (7.1)	28.4	60.7
$H_3D_1N_2$	2.7 (6.8)	2.3 (4.1)	2.7 (6.5)	39.0	65.9
$H_3D_2N_1$	2.9 (7.5)	2.2 (3.8)	2.5 (5.7)	30.4	71.9
$H_3D_2N_2$	2.6 (6.2)	1.9 (2.8)	2.4 (5.1)	39.9	77.7
Control					
W_1: Weed free check	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	100.0	100.0
W_2: Weedy check	3.3(10.6)	3.72 (13.2)	3.9 (14.8)	-	-
LSD (p=0.05)	0.35	0.28	0.42	-	-

Figures are ($\sqrt{x+1}$) transformed values and figures in the parentheses are original values; DAS- Days after sowing management of weeds during the initial stage through the application of pendimethalin (Kumar *et al.* 2024). At 40 and 60 DAS, combined application of pre-emergence followed by post-emergence recorded lower dry weight of weeds (1.9 and 3.4 g/m^2) over single application of pre-emergence (4.7 and 7.6 g/m^2) and post-emergence (3.8 and 5.5 g/m^2). This may be due to higher efficacy of sulfosulfuron + metsulfuron in controlling both narrow and broad-leaved weeds at later stages (Meena *et al.* 2020). Recommended dosage of herbicide (100% RDH) (3.2, 2.8 and 5.1 g/m^2) was superior at all the stages over 75% RDH (4.7, 3.8 and 6.3 g/m^2) in terms of lowering the weed dry weight at 20, 40 and 60 DAS, respectively. Mekonnen (2022) noticed that rate of herbicides increased, the weeds density decreased in all herbicide treatments resulting in observable reduction in dry biomass. On the contrary, the practice of soybean residue mulching consistently resulted in reduced dry weight of weeds during every growth phase of the crop when compared to the absence of residue application (Meena *et al.* 2022). Combination of pre-emergence followed by post-emergence at 100% RDH with soybean residue reduced weed dry weight (2.1, 1.3 and 2.4 g/m^2 at 20, 40 and 60 DAS, respectively). Higher weed dry weight was observed under pre-emergence at 75% RDH without residue (3.4, 5.8 and 8.5 g/m^2 at 20, 40 and 60 DAS, respectively). This could result from the fact that herbicides were very efficient in suppressing weed biomass. The findings are confirmatory with Abbas *et al.* (2009) who observed significant reduction in weeds dry weight due to decrease in their population under herbicide treatments.

Weed control efficiency

At various phases of crop growth higher weed control efficiency was recorded with pre-emergence followed by post-emergence (68.9, 84.6 and 75.2 % at 20, 40, 60 DAS, respectively). It is due to the fact that pendimethalin and metsulfuron-methyl control both monocot and dicot weeds. Sulfosulfuron ready mixture with metsulfuron-methyl control grasses and broad-leaved weeds and enhance the efficacy of this combination and achieved highest value of WCE (84.6 %) at 40 DAS (**Table 3** and **4**).

The improvement in weed control efficiency with soybean crop residue application was to an extent of 12.29, 6.83 and 7.69 per cent over no mulching at 20, 40 and 60 DAS. This might be due to effective suppression of weeds. Similarly, in the initial stage at 20 DAS, pre-emergence at 100% RDH with soybean residue (84.3%) was better in weed control efficiency compared to the other treatment due to low weed dry weight obtained. At 40 to 60 DAS, pre-emergence followed by post-emergence at 100% RDH with soybean residue had higher weed control efficiency (92.1 and 84.5%). Combined effect indicated that effective management of emerged weeds and reduced carryover of weed seed bank in subsequent seasons. Pre-emergence at 75% RDH without residue recorded lower weed control efficiency. In studies conducted by Chopra *et al.* (2008) more than 80 per cent control of broad-leaved weeds with mixed application of metsulfuron and carfentrazone in wheat. Removing the weeds whenever they appear in the weed free treatment resulted in total control of weeds only by manual weeding. However, this is not feasible due to labour scarcity and un-economical. The lower weed control efficiency was noticed under weedy check treatment, because of higher weed competition stress.

Weed index

Weed index is a measure of crop yield loss due to treatments in comparison to weed free treatment (**Table 4**). Notably, the weedy check exhibited a significantly high weed index, reaching 40.7%. This can be primarily attributed to the intense competition posed by uncontrolled weed growth, which results in a competition for vital resources such as nutrients, moisture and light. This, in turn, leads to diminished growth and suboptimal yield components. Significantly lower weed index (4.5%) was obtained in the pre-emergence followed by post-emergence at 100% RDH with soybean residue. Deshmukh *et al.* (2020) observed that weed index was lower in all the herbicide treatments as compared with weedy check which created favourable conditions for crop growth which ultimately enhanced the grain yield of wheat crop as compared with weedy check treatment.

Grain yield

The application of pendimethalin followed by sulfosulfuron + metsulfuron-methyl resulted in a notably increased grain yield (3.85 t/ha) compared to other treatments (**Table 4**). Pendimethalin (3.21 t/ha) recorded lower grain yield compared to pendimethalin followed by sulfosulfuron + metsulfuron-methyl and sulfosulfuron + metsulfuron-methyl (3.47 t/ha) treatments. Bagri *et al.* (2023) found similar superior wheat grain yields with herbicide combinations compared with herbicides alone. Among the herbicide dosage, 100% RDH (3.69 t/ha) higher grain yield compared to 75% RDH (3.33 t/ha) treatment. The grain yield was higher in soybean residue (3.56 t/ha) compared to no residue (3.46 t/ha) treatment. The mulching effect created favourable conditions,

Table 4. Weed control efficiency at 60 DAS, grain yield and weed index as influenced by weed management practices in wheat (pooled data of 2 years)

Treatment	Weed control efficiency (%) at 60 DAS	Weed index (%)	Grain yield (t/ha) 2020-21	2021-22	Pooled
Time of application					
H_1: Pre-emergence	49.5	26.7	3.16	3.26	3.21
H_2: Pre-emergence *fb* post-emergence	75.2	11.9	3.79	3.91	3.85
H_3: Post-emergence	57.6	20.6	3.39	3.55	3.47
LSD (p=0.05)	-	-	0.07	0.08	0.07
Dosage of herbicide					
D_1: 75% of herbicide	55.3	23.9	3.26	3.39	3.33
D_2:100% of herbicide	66.2	15.6	3.64	3.75	3.69
LSD (p=0.05)	-	-	0.06	0.06	0.06
Crop residue					
N_1 = No residue	58.5	21.0	3.39	3.53	3.46
N_2 = Residue	63.0	18.5	3.51	3.62	3.56
LSD (p=0.05)	-	-	0.06	0.06	0.06
Interaction					
$H_1D_1N_1$	42.7	31.9	2.94	3.02	2.98
$H_1D_1N_2$	46.4	29.4	3.05	3.13	3.09
$H_1D_2N_1$	52.2	23.8	3.27	3.41	3.34
$H_1D_2N_2$	56.5	21.6	3.39	3.49	3.44
$H_2D_1N_1$	66.0	18.0	3.52	3.66	3.59
$H_2D_1N_2$	71.4	16.2	3.60	3.73	3.66
$H_2D_2N_1$	78.8	9.1	3.92	4.03	3.97
$H_2D_2N_2$	84.5	4.5	4.14	4.21	4.17
$H_3D_1N_1$	50.4	25.2	3.17	3.37	3.27
$H_3D_1N_2$	54.6	22.9	3.29	3.44	3.37
$H_3D_2N_1$	60.8	17.9	3.51	3.66	3.59
$H_3D_2N_2$	64.7	16.4	3.59	3.72	3.65
Control					
W_1: Weed free check	100.0	-	4.32	4.42	4.37
W_2: Weedy check	-	40.7	2.62	2.58	2.60
LSD (p=0.05)	-	-	0.14	0.15	0.13

DAS- Days after sowing

including reduced evaporation, enhanced soil moisture content due to soil cover, improved water infiltration and retention, reduced weed growth, and the decomposition of added mulch materials (Zhang and Wu 2011). These factors likely contributed to an increase in the supply of nutrients and moisture, leading to an overall enhancement in crop yields. Among the treatment combination, application of pendimethalin followed by sulfosulfuron + metsulfuron-methyl at 100% RDH with soybean residue (4.17 t/ha) was significantly higher grain yield compared to rest of the interactions. This increase in grain yield can be attributed to the enhancement of yield-related characteristics and the total production of dry matter, with subsequent distribution into various parts of the plant. Lower grain yield was recorded in pendimethalin at 75% RDH without residue (2.98 t/ha) compared to other interactions. This decrease in yield can be attributed to the inferior performance of growth and yield-related parameters. Weed free check (4.37 t/ha) recorded significantly superior grain yield. While, statistically inferior grain yield was noticed in weedy check (2.60 t/ha) compared to all other treatment combinations. Lower yield in weedy check was due to poor plant growth and higher weed density, which could have competed with wheat crop for space, water and nutrients, there by adversely affecting grain yield.

It was concluded that weeds associated with irrigated wheat can be effectively managed through sequence application of pendimethalin followed by sulfosulfuron + metsulfuron-methyl at 100% recommended dose of herbicide with soybean residue and resulted higher grain yield.

REFERENCES

Abbas G, Ali M, Abbas A, Aslam Z and Akram M. 2009. Impact of different herbicides on broadleaf weeds and yield of wheat. *Pakistan Journal of Weed Science Research* **15**: 1–10.

Abbas T, Muhammad AN, Tanveer A, Hafiz HA and Naila F. 2017. Role of allelopathic crop mulches and reduced doses of tank-mixed herbicides in managing herbicide-resistant *Phalaris minor* in wheat. *Crop Protection* **110**: 245–250.

Bagri US, Kasana BS, Mohaniya LS, Bagri PK and Mitoliya V. 2023. Effect of different post-emergence herbicides on weeds and yield of black wheat. *The Pharma Innovation Journal* **12**(5): 4368–4370.

Balyan RS, Malik RK and Bhan VM. 1990. Sensitivity of wheat cultivars to fluroxypyr and 2, 4-D combination. *Indian Journal of Agronomy* **35**: 408–409.

Chopra NK, Chopra N and Singh H. 2008. Bio-efficacy of herbicide mixtures against complex weed flora in wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **53**(1): 62–65.

Deshmukh JP, Kakade SU, Thakare SS and Solanke MS. 2020. Weed management in wheat by pre-emergence and pre-mix post-emergence combinations of herbicides. *Indian Journal of Weed Science* **52**(4): 331–335.

Duary B, Jaiswal DK, Subhaprada D, Sar K and Nirmala P. 2021. Effect of tillage and pre-mix application of herbicides on weed growth and productivity of late-sown wheat. *Indian Journal of Weed Science* **53**(2): 188–190.

Gill GS and Kumar V. 1969. Weed index – A new method for reporting weed control trials, *Indian Journal of Agronomy* **16** (1): 96–98.

Gomez KA and Gomez AA. 1984. Statistical procedures for agricultural research. 2nd Ed. John Willy and Sons, New York (USA), p. 639.

Jat RS, Nepalia V, Chaudhary PD. 2003. Influence of herbicides and method of sowing on weed dynamics in wheat (*Triticum aestivum* L.). *Indian Journal of Weed Science* **35**: 18–20.

Kamboj P, Punia SS and Yadav DB. 2021. Multiple herbicide resistance in *Phalaris minor* Retz. in Haryana, India. *Indian Journal of Weed Science* **53**(4): 411–416.

Kaur M, Punia, SS, Singh J and Singh S. 2019. Pre- and post-emergence herbicide sequences for management of multiple herbicide-resistant littleseed canary grass in wheat. *Indian Journal of Weed Science* **51**(2): 133–138.

Kaur S, Kaur T and Bhullar MS. 2017. Control of mixed weed flora in wheat with sequential application of pre- and post-emergence herbicides. *Indian Journal of Weed Science* **49**(1): 29–32.

Kumar DL, Rathod N and Reddy UG. 2024. Efficacy of pre-emergent herbicides against diverse weed flora in wheat crop in Northern Transition Zone of Karnataka in South India. *Indian Journal of Weed Science* **56**(2): 151–158.

Meena SN, Sharma SK, Singh P, Jadon CK, Jat ML and Meena RL. 2022. Crop-management practices influence weed dynamics, yield and economics of soybean (*Glycine max*). *Indian Journal of Agronomy* **67** (3): 282–286.

Meena V, Kaushik MK, Dotaniya ML and Das H. 2020. Assessing bio-efficacy potential of herbicide combinations for broadspectrum weed control in late-sown wheat. *Indian Journal of Weed Science* **52**(3): 232–236.

Mekonnen G. 2022. Wheat (*Triticum aestivum* L.) yield and yield components as influenced by herbicide application in Kaffa Zone, Southwestern Ethiopia. *International Journal of Agronomy* 1–14.

Sharma, KC, Parmar, PS, Solanki, KS and Singh, U. 2018. Weed control efficiency, productivity and energy relationships of wheat (*Triticum aestivum*) production as influenced by herbicidal weed control in vertisols of central India. *Journal of Pharmacognosy and Phytochemistry* **7**(2): 3715–3720.

Zhang J and Wu LF. 2021. Impact of tillage and crop residue management on the weed community and wheat yield in a wheat–maize double cropping system. *Agriculture* **11** (3): 1–13.

Indian Journal of Weed Science (2024) **56**(3): 251–257
http://dx.doi.org/10.5958/0974-8164.2024.00041.8

RESEARCH ARTICLE

Post-emergence herbicide combinations for wet-seeded rice dominated with grass weed flora

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Received: 20 April 2024 | Revised: 19 September 2024 | Accepted: 22 September 2024

ABSTRACT

The efficacy of herbicide combinations on weed control in wet-seeded rice with grasses as dominant weed flora was evaluated in field experiments conducted at Kerala Agricultural University, India during 2018 and 2019. Experiment comprised of 10 treatments, *viz*. cyhalofop-butyl (CB) 80 g/ha, penoxsulam (PS) + cyhalofop-butyl (6% OD) - commercial formulation 150 g/ha, cyhalofop-butyl 80 g/ha + carfentrazone-ethyl (CE) 200 g/ha, bispyribac-sodium (BS) 25 g/ha, bispyribac-sodium 25 g/ha + cyhalofop-butyl 80 g/ha, bispyribac-sodium 25 g/ha + fenoxaprop-p-ethyl (FPE) 60 g/ha, fenoxaprop-p-ethyl 60 g/ha, stale seedbed (SSB) *fb* chemical weeding with glyphosate 800 g/ha + oxyfluorfen 150 g/ha at 15-20 days after land preparation + cyhalofop-butyl 80 g/ha + carfentrazone-ethyl 200 g/ha, hand weeding twice at 20 and 45 DAS and unweeded control (UWC). The population of grass weeds increased over time, occupying 48.9 and 42.3% of the weed spectra during the initial phase and peaking at 87.40 and 75% towards 60 DAS, respectively during 2018 and 2019. Tank mix application of bispyribac-sodium 25 g/ha + fenoxaprop-p-ethyl 60 g/ha resulted in the lowest density of grass weeds at all stages and registered 100 and 92.97% reduction in weed count over unweeded control at 15 and 45 days after treatment application, respectively. The tank mix of bispyribac-sodium with cyhalofop-butyl and fenoxaprop-p-ethyl improved weed control compared to their individual application. Post-emergence herbicide combinations of bispyribac-sodium + fenoxaprop-p-ethyl, penoxsulam + cyhalofop-butyl (6% OD) and bispyribac-sodium + cyhalofop-butyl registered superior weed control efficiency than the broad-spectrum herbicide bispyribac-sodium and increased the grain yield by 58.84, 56.78, and 56.51%, respectively over the unweeded control.

Keywords: Bispyribac-sodium, Tank mix application, Weed flora, Weed management practices

INTRODUCTION

Rice stands as a critical staple food for over 3.5 billion individuals globally (CGIAR 2020), with the largest concentration residing in Asia. In India, it is grown on an area of about 41.10 million hectares (m ha) with a total production of 135 million tonnes (mt) during 2022-23 (GOI 2023), and in Kerala, it occupies 1.92 m ha area with a production of 5.96 mt (GOK 2023). Direct-seeding of rice (DSR) has been implemented as a substitute for the conventional practice of transplanting rice in numerous Asian countries. Weeds are the major biotic constraint in DSR as the weeds emerge concurrently with rice. The decrease in rice yield caused by uncontrolled weeds dominated by broad-leaved weeds in rainfed lowland rice was approximately 59.75% (Reddy and Ameena 2021).

Though herbicides are effective and economical in controlling weeds in DSR, continuous use of same herbicide or herbicides with a similar mode of action will lead to the development of herbicide resistance and inter and intraspecific shift in weed flora occurs either slowly or rapidly due to herbicide selection pressure (Duary *et al*. 2015). As application of single herbicide cannot deliver proficient weed control in DSR due to diverse weed community, a combination of graminicides with one of the herbicides for the control of sedges and broad-leaved weeds was found to be better for broad-spectrum weed control in DSR (Karim *et al*. 2004). Hence, there is a need to evaluate the performance of available herbicides and their combinations for the successful management of complex weed flora in DSR especially in the context of differential response of herbicides to weeds belonging to same family. With this background, the present study was carried out to evaluate the efficacy of tank mixtures of different herbicides for the control of a diverse weed flora in DSR.

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MATERIALS AND METHODS

The field study was carried out in the paddy fields of Integrated Farming System Research Station, Karamana, Thiruvananthapuram of Kerala Agricultural University, Thrissur, Kerala, India during the *Kharif* seasons (June-September) of 2018 and 2019. The soil of the experimental field was sandy clay loam with a pH of 5.20. The available N, P and K content was 200.7, 30.5 and 414.25 kg/ha, respectively. The experiment was conducted in a randomized block design (RBD) with three replications. Nine weed control treatments, *viz*. cyhalofop-butyl (CB) 80 g/ha, penoxsulam (PS) + cyhalofop-butyl (6% OD) - commercial formulation 150 g/ha, cyhalofop-butyl 80 g/ha + carfentrazone-ethyl (CE) 200 g/ha, bispyribac-sodium (BS) 25 g/ha, bispyribac-sodium 25 g/ha + cyhalofop-butyl 80 g/ ha, bispyribac-sodium 25 g/ha + fenoxaprop-p-ethyl (FPE) 60 g/ha, fenoxaprop-p-ethyl 60 g/ha, stale seedbed (SSB) *fb* chemical weeding with glyphosate 800 g/ha + oxyfluorfen 150 g/ha at 15-20 days after land preparation + cyhalofop-butyl 80 g/ha + carfentrazone-ethyl 200 g/ha, hand weeding twice at 20 and 45 DAS were tried out and an unweeded control (UWC) was included as control for comparison. The rice variety '*Uma*' (*MO 16*), a medium duration (120-135 days) was used as the experimental variety. The fertilizers were applied at 90: 45: 45 kg/ha N: P: K as per the recommendations of the Kerala Agricultural University (KAU, 2016). The full dose of phosphatic fertilizer was given as basal. One-third dose each of nitrogen was given as top dressing at 15 DAS, active tillering (35 DAS) and panicle initiation stages (60 DAS). Potassium was applied as equal doses at seedling stage (15 DAS) and the panicle initiation stage (60 DAS). All the herbicides were applied as post-emergence at 18 DAS, when weeds reached 3–4 leaf stage.

Weed dry weight were recorded at 15, 30, 45 days after treatment application (DATA). The weed control efficiency was worked out as per standard formula and grain yield was recorded.

RESULTS AND DISCUSSION

Weed flora

Fifteen species of weeds were observed in the wet-seeded rice (WSR). The weed flora in the experimental field was very diverse and composed of grass weeds, broad-leaved weeds, sedges and ferns. The grass weeds comprised of *Leptochloa chinensis*, *Echinochloa colona*, and *Isachne miliacea.* The main broad-leaved weeds were *Sphenoclea zeylanica*, *Bergia capensis*, *Monochoria vaginalis*, *Limnocharis flava*, *Ludwigia perennis*, *Alternanthera philoxeroides* and *Lindernia parviflora*. The sedges present were *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea. Marsilea quadrifolia* was the only fern species observed in the experimental field.

The relative proportion of weeds revealed that grass weeds were the most dominant weed flora in WSR in both 2018 and 2019, followed by BLWs and sedges. (**Figure 1**). Among the grass weeds, *L. chinensis* was the most abundant, accounting for more than 40% of the total population in both years, followed by. *E. colona* and *I. miliacea.* At 15 DATA, grass weeds constituted 46% and broad-leaved weeds comprised 12% of the population during 2018, whereas they were 62 and 26%, respectively, during 2019 at UWC (weedy check). Out of this, *L. chinensis* constituted 56% in 2018 and 65% in 2019. Ferns accounted for 32.60% of the UWC at 15 DATA during 2018.

The population of grass weeds was increased by 30 DATA and encompassed 67 and 68% of total population during 2018 and 2019 of which, *L. chinensis* contributed 67 and 61% of total grass populace, respectively. The dominance of grass weeds in WSR could be attributed to its persistent non-dormant weed seed bank and favourable soil conditions in wet seeding. Weed management practices had a significant effect on the absolute density of grass weeds, BLWs, and sedges at 15, 30, and 45 DATA during both years.

Absolute density of weeds

In general, the population of grass weeds increased in all treatments from 15 to 45 DATA in both 2018 and 2019. Grass weed population increased and peaked at 87.40 and 75% towards 60 DAS, occupying 48.9 and 42.3% of the weed spectra during the initial phase.

Tank mix application of BS 25 g/ha + FPE 60 g/ ha had the lowest absolute density of grass weeds at all stages and was statistically equivalent to hand weeding twice at 20 and 45 DAS at 45 DATA. (**Table 1**). The combination registered 100 and 92.97% reduction in weed count over UWC at 15 and 45 DATA in WSR. The lower grass weed count in the treatment could be attributed to the combined efficiency of the mix in broad spectrum control of grass weeds. FPE 60 g/ha was also effective against grass weeds, with 97.17 and 91.24% reductions over UWC at 15 and 45 DATA, respectively. BS 25 g/ha + FPE 60 g/ha registered lower count of grass weeds compared to the sole application and could be considered as an additive selection for control of grass weeds.

The treatments consisting of BS 25 g/ha + FPE 60 g/ha and SSB *fb* chemical weeding with glyphosate 800 g/ha + oxyfluorfen 150 g/ha at 15 - 20 days after land preparation *fb* CB 80 g/ha + CE 200 g/ha showed an absolute density of zero for grass weeds at 15 DATA during both years of the study. The success of the SSB followed by chemical weeding treatment may be attributed to the effectiveness of the stale seedbed method in preventing the germination and establishment of dominant grass weeds like *L. chinensis* and *E. colona*, as well as the application of glyphosate, which eradicated established weeds, and oxyfluorfen, which prevented the growth of new weeds. However, the population of grass weeds under the SSB followed by chemical weeding treatment increased from 15 to 45 DATA, which recorded counts of 20 and 24/m^2, during 2018 and 2019, respectively, at 45 DATA.

The application of CB 80 g/ha alone was found to be more effective in controlling grass weeds than its combination with BS 25 g/ha and CE 200 g/ha. The combination treatments resulted in reductions of 50.09 and 24.61% at 15 DATA, and 36.03 and 10.56% at 45 DATA, respectively, as shown in Table 1. This might be due to the antagonistic effect of the herbicides with different modes of action used in the combination, as noted by Matzenbacher *et al.* (2015) who found that mixing acetyl-CoA carboxylase (ACCase) inhibitors with ALS (Aceto Lactate Synthase) inhibitors can result in antagonism. The treatment also performed better than the application of the broad-spectrum herbicide, BS 25 g/ha, and provided very good control of grass weeds in the study area. FPE 60 g/ha, PS + CB (6% OD) 150 g/ha, and CB 80 g/ha + CE 200 g/ha were also found to provide very good control of grass weeds during both seasons at 15 DATA. However, the higher count of grass weeds observed in the PS + CB (6% OD) 150 g/ha treatment during the later stages of the study was attributed to the uncontrolled population of *L. chinensis*.

Throughout both years of the study, UWC exhibited the greatest absolute density of grass weeds at all stages, followed by plots treated with BS 25 g/ha. The increased number of grass weeds in the BS treatment can be attributed to the higher count of *L. chinensis*, indicating that BS is ineffective in controlling this particular weed, despite its effectiveness against all other types of grass weeds. However, when BS was combined with FPE and CB, it resulted in reductions of 35-50% and 11-40%, respectively, in the population of *L. chinensis* compared to its individual application.

In the experimental site, which was mainly dominated by grass weeds, the presence of BLWs was generally low. The application of BS 25 g/ha was found to be effective in managing BLWs in both years of the study, resulting in the lowest count of BLWs under this treatment (**Table 1**). When BS 25 g/ha was combined with FPE 60 g/ha, the density of BLWs was significantly reduced in both years, with a reduction of 73.39% at 15 DATA compared to the sole application of BS 25 g/ha. This improvement might be due to the synergistic effect of FPE and BS in managing BLWs, even though FPE is primarily a grass killer. Although the pre-mix formulation of PS + CB 150 g/ha (6% OD) was effective in controlling a broad range of BLWs, it was found to be ineffective against *L. perennis* in WSR. This result was supported by the findings of Menon *et al.* (2016).

The combination of SSB and chemical weeding exhibited effective control of BLWs at the early stages of the crop by inhibiting the germination and emergence of BLW seeds. The application of pre-emergent herbicide controlled the emerged seeds, and glyphosate application after emergence helped in controlling the germinated ones. Staling stimulated the emergence of BLWs, which are mostly seed propagated, and multiple modes of action maximized the efficiency of chemical weeding. However, this treatment was not effective in controlling BLWs at later stages due to the excessive growth of *M. vaginalis* and *L. flava* under flooding.

The use of CB 80 g/ha and FPE 60 g/ha resulted in the highest count of broad-leaved weeds, which was similar to that of the untreated control, indicating the ineffectiveness of these treatments in controlling broad-leaved weeds.

The absolute density of sedges was significantly affected by the weed management treatments. Similar to the grass weeds, SSB followed by chemical weeding was effective in controlling sedges, with a count of zero at 15 DATA in both years (**Table 1**). However, the treatment was not able to maintain control of sedges in the later stages, resulting in higher absolute density.

Tank mixing BS 25 g/ha with FPE 60 g/ha resulted in consistently lower sedge counts at all stages observed. PS + CB (6% OD) 150 g/ha and BS 25 g/ha showed the best control of sedges with reductions of 91.35 and 100%, respectively at 15 DATA. The sole application of BS 25 g/ha and FPE 60 g/ha resulted in higher sedge counts compared to the tank mix combination of BS 25 g/ha + FPE 60 g/ha, highlighting the importance of applying herbicides in combination for effective weed management.

The sedge population was completely controlled by hand weeding twice at 20 and 45 DAS, with no sedges detected in the UWC at 15 DATA. This is consistent with the findings of Mubeen *et al.* (2014), who reported that HW reduced weed density by 90%, particularly for grass weeds. However, in the study, no sedges were detected in the UWC towards the end of the crop, which may be due to the early completion of their growth and life cycle.

The untreated plots had a higher count of weeds throughout the crop growth, but a decreasing trend was observed towards the later stages. This decrease could be attributed to the completion of the life cycle of some weeds and the competition from other weeds that emerged earlier.

Weed dry matter production

The results of data analysis showed that the treatments significantly affected the total dry matter production (DMP) of weeds at 15, 30, and 45 DATA. The tank mix application of BS 25 g/ha + FPE 60 g/ha had the lowest weed DMP, which was significantly lower than the individual application of each herbicide. When compared to BS 25 g/ha, FPE 60 g/ha, and the UWC at 15, 30, and 45 DATA, the combination reduced weed DMP by 83.09, 83.89, and 96.55%; 86.38, 93.18 and 98.20%; and 73.26, 86.49 and 89.70%, respectively (as shown in **Figure 2**). The lower weed DMP in the combination treatments can be attributed to the synergistic effects of herbicide combinations. Although BS 25 g/ha effectively controlled grass weeds, broad-leaved weeds (BLWs), and sedges, its ineffectiveness on the aerobic grass *L. chinensis* resulted in high weed DMP. Previous studies by Jacob (2014) and Sekhar *et al.* (2020) also reported that BS was ineffective in controlling *L. chinensis*. However, the combination of BS with FPE and CB proved to be efficient in controlling *L. chinensis*, highlighting the importance of using herbicide combinations to manage complex weed flora in the WSR.

Chemical weeding of stale seedbeds at 15 DATA resulted in zero weed DMP up to 35 DAS. However, weed DMP increased at later stages, which might be due to the lower efficiency of CB 80 g/ha + CE 200 g/ha in managing late-emerging *M. vaginalis* and *L. flava*. Among the herbicidal treatments, CB 80 g/ha had the highest weed DMP, followed by sole application of FPE 60 g/ha and BS 25 g/ha. The weed DMP increased by 1.6-6.5 times in plots that received single herbicide applications compared to those that received tank mix or ready mix applications. On the other hand, CB 80 g/ha + CE 200 g/ha resulted in higher weed DMP at later stages and was statistically

Table 1. Effect of treatments on absolute density of grasses, broad-leaved weeds and sedges

Treatment	Absolute density (no./m^2)											
	2018						2019					
	Grasses		Broad-leaved weeds		Sedges		Grasses		Broad-leaved weeds		Sedges	
	15 DATA*	45 DATA	15 DATA	45 DATA	15 DATA	45 DATA	15 DATA	45 DATA	15 DATA	45 DATA	15 DATA	45 DATA
Cyhalofop-butyl	1.64 (2.7)	6.21 (38.7)	9.35 (90.7)	8.24 (68.0)	4.46 (21.3)	5.58 (33.3)	1.77 (2.7)	4.47 (20.0)	8.27 (68.0)	11.13 (129.3)	5.92 (34.7)	5.56 (30.7)
Penoxsulam + cyhalofop-butyl (6% OD) – ready mix formulation	2.38 (6.7)	5.41 (29.3)	1.17 (1.3)	5.02 (25.3)	1.44 (2.7)	0.70 (0.0)	2.41 (5.3)	6.27 (40.0)	3.71 (13.3)	3.50 (12.0)	1.34 (1.3)	0.70 (0.0)
Cyhalofop-butyl + carfentrazone-ethyl	1.91 (4.0)	6.53 (42.7)	4.76 (22.7)	2.92 (10.7)	2.31 (5.3)	5.33 (37.3)	2.41 (5.3)	4.70 (22.7)	5.33 (28.0)	6.15 (42.7)	1.77 (2.7)	1.66 (2.7)
Bispyribac-sodium	6.70 (46.7)	9.66 (93.3)	2.51 (6.7)	2.27 (5.3)	2.12 (4.0)	0.70 (0.0)	6.03 (36.0)	9.46 (90.7)	2.87 (8.0)	0.70 (0.0)	1.64 (2.7)	0.70 (0.0)
Bispyribac-sodium + cyhalofop-butyl	2.12 (5.3)	7.56 (57.3)	2.77 (8.0)	6.32 (40.0)	1.17 (1.3)	4.21 (21.3)	2.41 (5.3)	4.86 (24.0)	0.70 (0.0)	2.29 (6.7)	1.77 (2.7)	0.70 (0.0)
Bispyribac-sodium + fenoxaprop-p-ethyl	0.70 (0.0)	3.24 (10.7)	1.17 (1.3)	3.15 (10.7)	0.70 (0.0)	0.70 (0.0)	0.70 (0.0)	3.21 (10.7)	1.77 (2.7)	0.70 (0.0)	0.70 (0.0)	0.70 (0.0)
Fenoxaprop-p-ethyl	1.64 (2.7)	3.43 (12.0)	7.40 (54.7)	7.23 (53.3)	3.82 (14.7)	2.91 (8.0)	2.12 (4.0)	3.82 (14.7)	10.08 (101.3)	10.82 (120.0)	5.58 (30.7)	3.53 (13.3)
Stale seedbed *fb* glyphosate + oxyfluorfen *fb* cyhalofop-butyl + carfentrazone-ethyl	0.70 (0.0)	4.46 (20.0)	0.70 (0.0)	6.54 (44.0)	0.70 (0.0)	10.21 (104.0)	0.70 (0.0)	4.88 (24.0)	0.70 (0.0)	6.25 (40.0)	0.70 (0.0)	5.07 (25.3)
Unweeded control	10.60 (113.3)	12.16 (148.0)	5.45 (29.3)	4.16 (17.3)	4.80 (22.7)	0.70 (0.0)	11.03 (121.3)	12.46 (156.0)	6.95 (49.3)	6.76 (52.0)	4.93 (24.0)	0.70 (0.0)
Hand weeding twice at 20 and 45 DAS**	1.64 (2.7)	3.45 (12.0)	1.91 (4.0)	5.65 (32.0)	0.70 (0.0)	0.70 (0.0)	1.34 (1.3)	3.04 (9.3)	2.65 (6.6)	2.12 (5.3)	0.70 (0.0)	1.34 (1.3)
LSD (p=0.05)	2.01	0.56	1.90	1.61	1.48	2.73	0.27	1.28	0.91	2.86	0.54	0.99

*DAS - Days after sowing

comparable to BS due to the combination's inability to control *M. vaginalis* and *F. miliacea*.

Hand weeding performed twice at 20 and 45 DAS resulted in a significant reduction in weed DMP, by 96.80, 98.56, and 92.84%, respectively, when compared to the UWC at 15, 30, and 45 DATA (**Figure 2**). However, there was an increase in weed DMP for most of the herbicidal treatments at 45 DATA, and a fivefold increase was observed in the un-weeded control from 15 to 30 DATA. Although the weed DMP was lower at 45 DATA than at 30 DATA during both years, the reduction in DMP per unit area towards the later stages may have been due to the decreased weed count in the unweeded control.

Weed control efficiency

Among the weed management practices, higher WCE of 96.80, 98.56 and 92.84% were recorded in HW twice at 20 and 45 DAS, respectively at 15, 30 and 45 DATA. In WSR, tank mix application of BS 25 g/ha + FPE 60 g/ha was just as effective as HW treatments applied twice at 20 and 45 DAS, with WCE of 96.55, 98.20, and 89.70% at 15, 30 and 45 DATA (**Figure 3**). This was possibly due to the effective management of a wide range of weeds through the combined action of herbicides with different modes of action. Blouin *et al.* (2010) reported similar results, stating that mixtures of ALS inhibitor herbicides with FPE at optimal doses resulted in better weed control in rice.

The combination of BS 25 g/ha with FPE 60 g/ha or CB 80 g/ha, as well as ready mix combination of PS + CB (6% OD) 150 g/ha, resulted in better weed control compared to the individual application of these herbicides. The WCE for the individual application of herbicides ranged from 79.05 to 81.46%, 67.92 to 85.86%, and 18.92 to 61.39% at 15, 30 and 45 DATA, respectively. However, when the herbicides were combined, the WCE ranged from 83.01 to 100%, 80.85 to 98.20%, and 50.73 to 89.70%, respectively. These findings suggest that tank mixing BS 25 g/ha with FPE 60 g/ha or CB 80 g/ha and applying a ready mix of PS and CB (6% OD) 150 g/ha may have a synergistic effect in controlling a wide range of weeds, resulting in a lower total weed biomass and higher WCE. The most significant impact was observed when BS 25 g/ha was mixed with FPE 60 g/ha, which provided excellent control of a broad spectrum of weeds.

At 15 DATA, the highest WCE of 100% was achieved with SSB *fb* chemical weeding, possibly because there was very little weed dry matter accumulation in the early stages. The use of herbicide combinations resulted in a WCE improvement of 26.79 to 33.87% over the application of BS alone, which only registered a 61.39% WCE at 45 DATA.

FPE 60 g/ha and CB 80 g/ha had the lowest total weed control among the treatments, as they were not effective in controlling BLWs and sedges. On the other hand, tank mix applications of CB 80 g/ha or FPE 60 g/ha with BS 25 g/ha improved the control of *E. colona, M. vaginalis, C. iria*, and *F. miliacea* compared to sole application, resulting in an enhanced WCE in herbicide combinations. These findings suggest that herbicide combinations are necessary for broad-spectrum weed control in WSR.

Grain yield

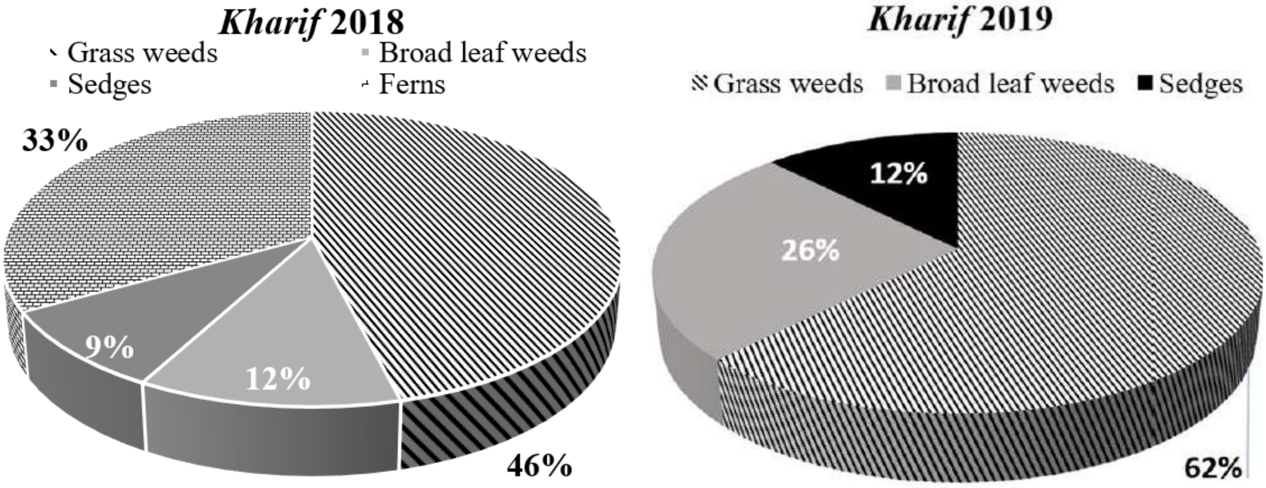
Grain yield was significantly influenced by weed management treatments during both years (**Table 2**). All the tested herbicides and the herbicide combinations were observed to improve the grain and straw yield compared to unweeded control during both the years.

The maximum grain yield (4.93 and 5.47 t/ha) and straw yield (6.84 and 6.79 t/ha) was attained by HW twice at 20 and 45 DAS during both 2018 and 2019, and recorded 60.19% increase in grain yield over unweeded control in WSR. Herbicide

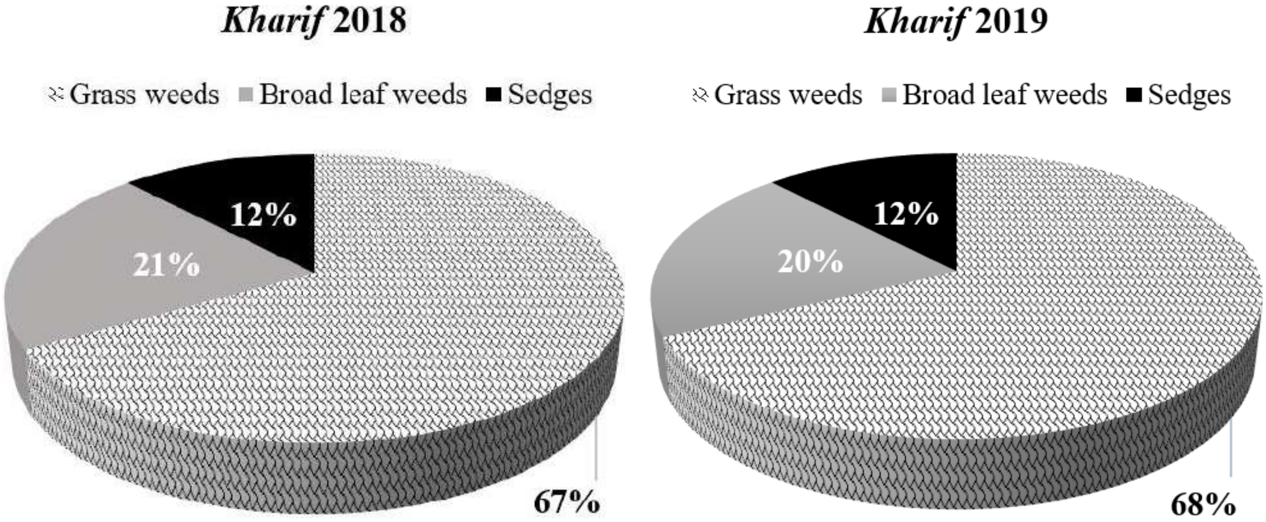
Table 2. Effect of weed management practices on grain yield and straw yield

Treatment	Grain yield (t/ha)		Straw yield (t/ha)	
	2018	2019	2018	2019
Cyhalofop-butyl	3.26	2.17	4.51	3.58
Penoxsulam + cyhalofop-butyl (6% OD) – ready mix formulation	4.55	5.03	6.06	6.27
Cyhalofop-butyl + carfentrazone-ethyl	3.68	4.20	4.99	5.65
Bispyribac-sodium	3.76	4.19	5.64	5.26
Bispyribac-sodium + cyhalofop-butyl	4.37	5.14	5.92	6.09
Bispyribac-sodium + fenoxaprop-p-ethyl	4.76	5.30	6.12	6.37
Fenoxaprop-p-ethyl	3.20	3.12	4.52	4.30
Stale seedbed *fb* glyphosate + oxyfluorfen *fb* cyhalofop-butyl + carfentrazone-ethyl	4.02	4.74	5.52	5.89
Unweeded control	2.13	2.01	3.88	3.42
Hand weeding twice at 20 and 45 DAS*	4.93	5.47	6.84	6.79
LSD (p=0.05)	0.881	0.911	0.843	0.755

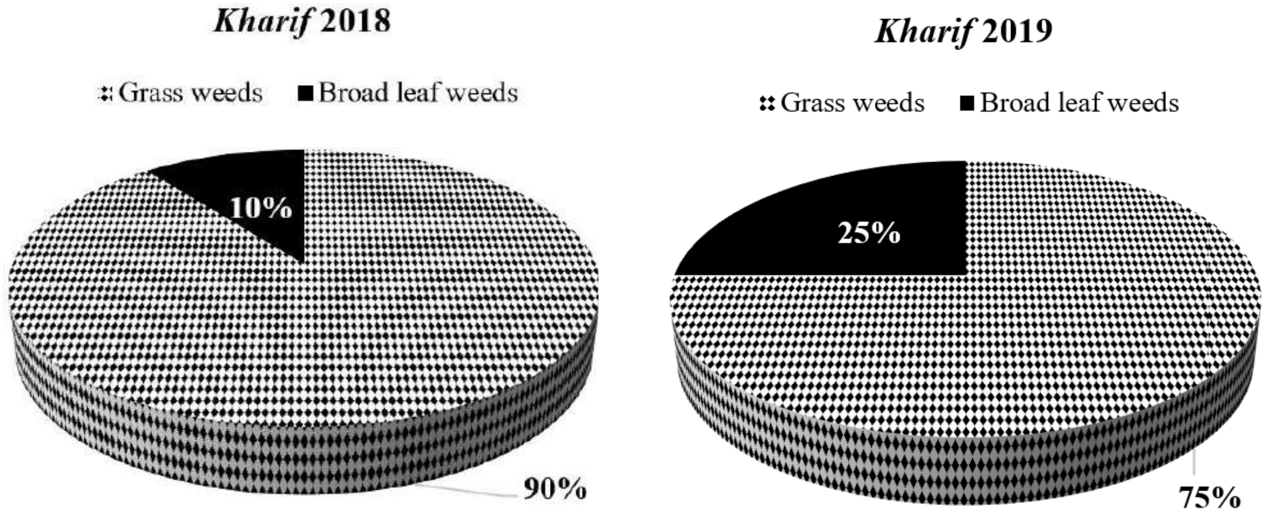
*DAS - Days after sowing



15 days after treatment application



30 days after treatment application



45 days after treatment application

Figure 1. Weed spectrum in un-weeded control

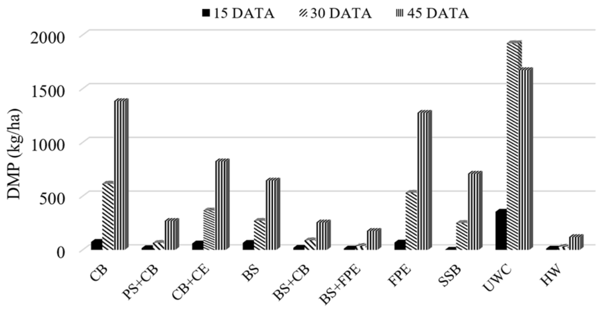


Figure 2. Effect of weed management practices on weed dry matter production (pooled)

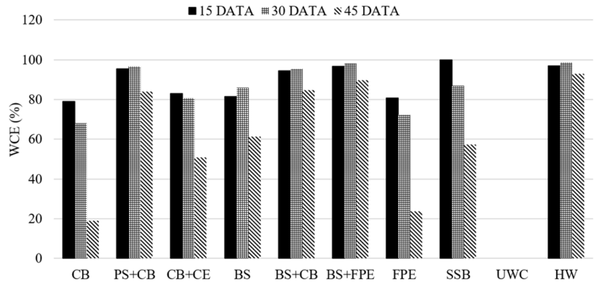


Figure 3. Effect of weed management practices on weed control efficiency (pooled)

combinations of BS 25 g/ha + FPE 60 g/ha, PS + CB (6% OD) 150 g/ha and BS 25 g/ha + CB 80 g/ha produced superior grain yield (5.03, 4.79 and 4.76 t/ha, respectively) and straw yield (6.25, 6.18 and 6.00 t/ha, respectively) which were statistically similar to the hand weeded weed free check.

Un-weeded control recorded the least values in grain yield and straw yield, which reduced grain yield by 56.77 and 63.13%, respectively, in WSR during 2018 and 2019, compared to the treatment with highest grain yield (**Table 2**). The heavy and unhampered infestation of weeds contributed to very severe competition and inopportune exploitation of growth factors, which might have resulted in lower yields and yield attributes in un-weeded control. Reddy (2020) also reported a grain yield reduction of 59.03% in weedy check in WSR. Herbicide combinations produced higher grain yields than single herbicide applications, increasing grain yield by 16-28% compared to sole application of BS and 56-59% compared to un-weeded control (**Table 2)** Higher yield attributes in herbicide combinations compared to sole application during both years due to enhanced control of complex weed flora, could be leading to lower crop-weed competition. Vigorous stands offer rice plants an advantage to outcompete weeds, which ultimately translates into better growth, allometry, yield components and finally increased yield.

It was concluded that post-emergence herbicide combinations of bispyribac-sodium + cyhalofop-butyl, penoxsulam + cyhalofop-butyl and bispyribac-sodium + fenoxaprop-p-ethyl were more effective in controlling complex weed flora in WSR besides higher grain yield.

REFERENCES

Blouin DC, Webster EP and Bond JP. 2010. On a method of analysis for synergistic and antagonistic joint-action effects with fenoxaprop mixtures in rice (*Oryza sativa*). *Weed Technology* 24: 583–589.

CGIAR [Consultative Group for International Agricultural Research]. 2020. Ricepedia [on-line]. Available: http://ricepedia.org/rice-as-food/theglobal-staple-rice-consumers.

Duary B, Mishra MM, Dash R and Teja KC. 2015. Weed management in lowland rice. *Indian Journal of Weed Sci*ence 47: 224–232.

GOI [Government of India]. 2023. Data bank of Crops Unit-I, Crop division, Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare.

GOK [Government of Kerala]. 2023. https://www.ecostat.kerala.gov.in/publication-detail/final-estimates-of-areaproduction-and-yield-of-crops-2022-23

Jacob G. 2014. *Herbicidal management of Chinese sprangletop (Leptochloa chinensis (L.) Nees.) in direct seeded rice*. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, 96p.

Karim RSM, Man AB and Sahid IB. 2004. Weed problems and their management in rice fields of Malaysia: an overview. *Weed Biology and Management* 4(4): 177–186.

KAU [Kerala Agricultural University]. 2016. *Package of Practices Recommendations: Crops 2016* (15th Ed.), Kerala Agricultural University, Thrissur, 393p.

Matzenbacher FO, Kalsing A, Dalazen G, Markus C and Merotto A. 2015. Antagonism is the predominant effect of herbicide mixtures used for imidazolinone resistant barnyardgrass (*Echinochloa crusgalli*) control. Planta daninha [e-journal].

Menon MV, Bridgit TK and Girija T. 2016. Efficacy of herbicide combinations for weed management in transplanted rice. *Journal of Tropical Agriculture* 54(2): 204–208.

Mubeen K, Jhala AJ, Hussain M, Siddiqui MH, Zahoor F, Shehzad M and Mehmood K. 2014. Effects of seeding time and competition period on weeds, growth and yield of direct seeded fine rice (*Oryza Sativa* L.). *Academic Journal of Interdisciplinary Studies* 3(5): 55–64.

Reddy MSSK. 2020. *Biology and management of goose weed (Sphenoclea zeylanica Gaertner) in wetland rice*. M.Sc.(Ag.) thesis, Kerala Agricultural University, Thrissur, 169p.

Reddy MSSK and Ameena M. 2021. Efficacy of pre- and post-emergence ready-mix herbicides in rainfed lowland wet-seeded rice. *Indian Journal of Weed Science*. 53(1): 88–91.

Sekhar L, Ameena M and Jose N. 2020. Herbicides and herbicide combinations for management of *Leptochloa chinensis* in wet-seeded rice. *Indian Journal of Weed Science*. 52(3): 211–216.

Indian Journal of Weed Science (2024) **56**(3): 258–262
http://dx.doi.org/10.5958/0974-8164.2024.00042.4

RESEARCH ARTICLE

Effect of herbicides against *Phalaris minor* and other weeds in wheat under middle Gujarat condition

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Received: 4 July 2024 | Revised: 24 September 2024 | Accepted: 27 September 2024

ABSTRACT

Phalaris minor Retz. now became a problematic weed of wheat in middle Gujarat condition due to its morphological similarity with wheat and continuous use of broad-spectrum herbicide. To combat this problem, an experiment was conducted during winter (*Rabi*) season of 2021-22 and 2022-23 on loamy sand soil at the farm of AICRP-Weed Management, Anand Agricultural University (Gujarat). The study aimed to find out instead of studied effect of herbicides against *P. minor* and other weeds in wheat. Results revealed that pre-mix (PM) application of clodinafop-propargyl 15% + metsulfuron-methyl 1% WP (PM) 60 + 4 g/ha as post-emergence (PoE) or sulfosulfuron 75% + metsulfuron-methyl 5% WG (PM) 30 + 2 g/ha PoE and sequential application of pendimethalin 30% EC 500 g/ha as pre-emergence (PE) *fb* clodinafop-propargyl 15% WP 60 g/ha PoE or sulfosulfuron 75% WP 30 g/ha PoE or hand weeding at 20 and 40 days after sowing (DAS) provide effective control of *P. minor* with broad-spectrum weed control resulted in higher grain yield and benefit-cost ratio.

Keywords: Crop yield, Herbicides, *Phalaris minor*, Pre-mix, Weed control efficiency, Wheat

INTRODUCTION

Wheat (*Triticum aestivum* L.), a member of the Poaceae family, is a staple food and the primary cereal crop grown worldwide. Wheat plays a significant role as a key *Rabi* crop in India and is an essential cereal and staple food, ranking second in importance only after rice. The major wheat growing states in India are Uttar Pradesh, Madhya Pradesh, Punjab, Haryana, Bihar, Rajasthan and Gujarat. Wheat cultivation in Gujarat was 10.46 lakh hectares in 2021-22, with a production of 33.24 lakh tonnes and average productivity of 3179 kg/ha (Anon., 2021). Weeds pose a substantial threat to agricultural production, impacting both crop yields and biodiversity. These invasive plants, if not managed effectively, can lead to significant crop losses and environmental degradation. Wheat crop is generally infested with both grassy and broad-leaf weeds depending upon environmental conditions like humidity, temperature and moisture availability, type of soil, cultural practices, varieties used and crop rotation adopted.

Phalaris minor Retz. is an annual grassy weed (family: Poaceae), locally, it is called Dumbisitti, Gullidanda, Sitti, Kanki and Mandusi. It is a monocot, self-pollinated, C_3 weed (2n = 28), associated with wheat crop (Chhokar *et al.* 2018). During the initial growth stages, plants of *P. minor* are morphologically similar to wheat plants and thus, escape during hand weeding which is done mainly in between the crop rows. In wheat, chemical weed control is a preferred practice due to the scarce and costly labour as well as the lesser feasibility of mechanical or manual weeding to manage such a mimic weed. Combinations of herbicides are preferable since they require lower dosage/ rates and leave less residue in the soil, which will biodegrade in a shorter time, improve the succeeding crop safety and smart strategy for controlling both monocot and dicot weeds in wheat fields. It improved the efficiency of the herbicide and increased activity on the targeted weed species while lowering crop toxicity. The problem of *P. minor* is increasing year after year which leads to huge reduction in wheat yield particularly in wheat growing area of Ahmedabad, Kheda, Anand, Gandhinagar and Sabarkantha district of Gujarat state (Anon. 2011). Looking to this an experiment was planned to study the effect of herbicides against *P. minor* and other weeds in wheat (*Triticum aestivum* L.) under middle Gujarat condition.

MATERIALS AND METHODS

Field experiment was carried out during winter (*Rabi*) season of the year 2021-22 and 2022-23 on

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loamy sand soil at the farm of AICRP-Weed Management, B. A. College of Agriculture, Anand Agricultural University, Anand (Gujarat). The experiment was laid out in randomized block design with three replications and twelve treatments, *viz*. pendimethalin 30% EC 500 g/ha PE *fb* clodinafop-propargyl 15% WP 60 g/ha PoE, flumioxazin 50% SC 125 g/ha PE *fb* clodinafop-propargyl 15% WP 60 g/ha PoE, pyroxasulfone 85% WG 127.5 g/ha PE *fb* clodinafop-propargyl 15% WP 60 g/ha PoE, pendimethalin 30% EC 500 g/ha PE *fb* sulfosulfuron 75% WP 30 g/ha PoE, pendimethalin 30% EC + metribuzin 70% WP (TM) 500 + 140 g/ha PE, clodinafop-propargyl 15% + metsulfuron-methyl 1% WP (PM) 60 + 4 g/ha PoE, sulfosulfuron 75% + metsulfuron-methyl 5% WG (PM) 30 + 2 g/ha PoE, mesosulfuron-methyl 3% + iodosulfuron-methyl sodium 0.6% WDG (PM) 12 + 2.4 g/ha PoE, metribuzin 42% + clodinafop-propargyl 12% WG (PM) 140 + 40 g/ha PoE, metribuzin 42% + clodinafop-propargyl 12% WG (PM) 210 + 60 g/ha PoE, hand weeding at 20 and 40 DAS and un-weeded check. Pre-emergence and post-emergence herbicides were applied as per the treatments using a knapsack sprayer equipped with a flat fan nozzle, using 500 liters of water per hectare. The recommended seed rate of 120 kg/ha for wheat cv. "*Gujarat Wheat 451*" was sown keeping the distance of 22.5 cm row spacing by manually in previously open furrows with the help of kudali. Later the seeds were covered manually. The recommended dose of nitrogen and phosphorus (120-60 kg N and P/ha) was applied through urea and SSP, respectively. The entire dose of phosphorus and half dose of nitrogen were applied to all the plots as basal dose in furrow prior to sowing. The remaining half dose of nitrogen was applied at 30 DAS. Irrigation was given after sowing of wheat and pre-emergence herbicides were applied after next day of first irrigation and post-emergence herbicides were applied at 30 DAS. The phytotoxicity of herbicides was noted at 10 and 20 days after herbicide application (DAHA), using a phytotoxicity scoring chart on a scale from 0 to 10 in each plot. At the maturity of crop, border lines were harvested first and were removed from the experimental area. Then the net plot area was harvested separately. Weed parameters taken randomly from 0.25 m^2 quadrant from net plot area from each treatment and converted into m^2 area. The monocot weeds including *P. minor*, monocot and dicot weeds were separated and counted separately from each plot at 25, 50 DAS and at harvest. Data on various observations recorded during the experimental period was statistically analysed as per the standard procedure and weed data were transformed by square root transformation ($\sqrt{(x+1)}$) and transformed data were subjected to ANOVA analysis (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Weed flora

Major weed flora observed on un-weeded check plot comprised of *P. minor, Setaria tomentosa, Dactyloctenium aegyptium, Digitaria sanguinalis* and *Eleusine indica* among monocot weeds, while *Chenopodium album, Chenopodium murale, Digera arvensis* and *Melilotus indica* among dicot weeds in loamy sand soil during both years of the experimentation.

Effect on weeds

Results indicated that weed control treatment showed significantly lower density and dry weight of *P. minor*, monocot and dicot weeds recorded at 25 DAS in twice hand weeding at 20 and 40 DAS and treatment received pre-emergence herbicides as compared to treatment with post-emergence herbicides and un-weeded check (**Table 1**). Among all the pre-emergence treatments, application of pendimethalin 30% EC 500 g/ha, flumioxazin 50% SC 125 g/ha and pyroxasulfone 85% WG 127.5 g/ha recorded significantly lower density and dry biomass of *P. minor* as compared to un-weeded check at 25 DAS. Similarly, Kaur *et al*. (2019) also found that pre-emergence application of pyroxasulfone at 127.5 g/ha recorded effective control of *P. minor* in wheat. However, application of metribuzin 42% + clodinafop-propargyl 12% WG (PM) 210 + 60 g/ha PoE provided 100% control of *P. minor* at 50 DAS but it was showed phytotoxic effect on wheat crop. Application of either flumioxazin 50% SC 125 g/ha PE *fb* clodinafop-propargyl 15% WP 60 g/ha PoE or pyroxasulfone 85% WG 127.5 g/ha PE *fb* clodinafop-propargyl 15% WP 60 g/ha PoE or pendimethalin 30% EC 500 g/ha PE *fb* sulfosulfuron 75% WP 30 g/ha PoE or pendimethalin 30% EC 500 g/ha PE *fb* clodinafop-propargyl 15% WP 60 g/ha PoE or clodinafop-propargyl 15% + metsulfuron-methyl 1% WP (PM) 60 + 4 g/ha PoE effectively reduced the density and dry biomass of *P. minor* at 50 DAS. Among herbicidal treatments, pendimethalin 30% EC + metribuzin 70% WP (TM) 500 + 140 g/ha PE found less effective against *P. minor* but effectively reduced the density and dry biomass of dicot weeds at 50 DAS. Sequential application of clodinafop-propargyl 15% WP 60 g/ha PoE provided effective control of monocot weed. The application of premix herbicides such a metribuzin 42% + clodinafop-propargyl 12%

WG 210 + 60 g/ha PoE, mesosulfuron-methyl 3% + iodosulfuron-methyl sodium 0.6% WDG 12 + 2.4 g/ha PoE, clodinafop-propargyl 15% + metsulfuron-methyl 1% WP 60 + 4 g/ha PoE and sulfosulfuron 75% + metsulfuron-methyl 5% WG 30 + 2 g/ha PoE effectively reduced the density and dry biomass of monocot and dicot weeds at 50 DAS than other treatments. Similar results were also reported by Sharma *et al.* (2003), Bharat and Kachroo (2007) and Tomar and Tomar (2014).

In relation to weed control efficiency (WCE), sequential application of pendimethalin 30 % EC 500 g/ha PE *fb* either clodinafop-propargyl 15% WP 60 g/ha or sulfosulfuron 75% WP 30 g/ha as well as all the treatment of premix herbicides, provided more than 89% control of *P. minor* and more than 81% monocot (including *P. minor*) and dicot weeds at 50 DAS. Pre-emergence application of pendimethalin 30% EC + metribuzin 70% WP (TM) 500 + 140 g/ha found effective against *P. minor* (94% WCE) only at 25 DAS but at 50 DAS it was failed to control the *P. minor* and recorded only 22% WCE. However, it provided more than 85% weed control efficiency of dicot weed at 50 DAS. Hand weeding twice effectively manages weeds and reduces their dry weight, resulted in higher WCE of *P. minor*, monocot and dicot weed at 50 DAS.

Phytotoxicity

Data presented in **table 2** indicated that visual phytotoxicity symptoms of chlorosis on wheat crop was observed in mesosulfuron-methyl 3% + iodosulfuron-methyl sodium 0.6% WDG (PM) at 12 + 2.4 g/ha PoE at 10 days after application but it was recovered with crop growth. However, application of metribuzin 42% + clodinafop-propargyl 12% WG (PM) PoE at both the rate i.e., 140 + 40 g/ha and 210 + 60 g/ha PoE showed chlorosis symptoms on wheat crop (3 and 4 score, respectively) at 10 days after application and even at 20 days after application phytotoxicity was observed upto 1 score. Additionally, this herbicide combination shows wilting (score 1) at 10 days after application but it recovered at 20 days after application. Combined application of metribuzin and clodinafop aggravates phytotoxic effects, leading to control of weeds but also damage the wheat crop. Results of metribuzin phytotoxic effect are in conformity with the finding of Sidhu *et al.* (2014), Sharma *et al.* (2018) and Qazizada *et al.* (2022).

Table 1. Density and dry biomass of *Palmaris minor*, monocot and dicot weeds as influenced by different weed management practices (two years pooled data)

Treatment	Weed density (no./m^2)						Weed dry biomass (g/m^2)					
	P. minor		Monocot		Dicot		*P. minor*		Monocot		Dicot	
	25 DAS	50 DAS	25 DAS	50 DAS	25 DAS	50 DAS	25 DAS	50 DAS	25 DAS	50 DAS	25 DAS	50 DAS
Pendimethalin 500 g/ha PE *fb* clodinafop-propargyl 60 g/ha PoE	3.72 (14.0)	2.51 (6.2)	5.19 (26.3)	3.38 (10.5)	3.17 (10.7)	3.95 (15.2)	1.58 (1.5)	2.34 (5.00)	2.07 (3.3)	3.25 (9.7)	1.65 (2.0)	3.63 (12.4)
Flumioxazin 125 g/ha PE *fb* clodinafop-propargyl 60 g/ha PoE	4.93 (24.7)	1.74 (2.2)	6.41 (41.3)	1.74 (2.2)	2.92 (8.0)	3.96 (15.2)	2.07 (3.5)	1.79 (2.3)	2.77 (6.9)	2.24 (4.1)	1.42 (1.1)	3.22 (9.5)
Pyroxasulfone 127.5 g/ha PE *fb* clodinafop-propargyl 60 g/ha PoE	5.20 (28.7)	2.13 (4.0)	7.02 (49.7)	2.63 (6.0)	4.35 (18.7)	5.97 (35.7)	2.10 (3.8)	2.11 (3.7)	2.66 (6.5)	3.18 (9.2)	1.57 (1.5)	4.35 (18.2)
Pendimethalin 500 g/ha PE *fb* sulfosulfuron 30 g/ha PoE	3.73 (14.7)	2.41 (5.5)	5.31 (27.8)	3.48 (12.0)	3.26 (11.5)	3.94 (14.7)	1.58 (1.6)	2.35 (5.1)	2.00 (3.1)	3.23 (9.6)	1.67 (2.0)	3.62 (12.6)
Pendimethalin + metribuzin (TM) 500 + 140 g/ha PE	3.83 (14.7)	5.52 (31.3)	5.22 (26.8)	5.91 (36.3)	3.13 (9.8)	4.97 (25.3)	1.57 (1.5)	8.25 (70.5)	1.89 (2.6)	8.91 (81.2)	1.60 (1.7)	4.02 (16.1)
Clodinafop-propargyl + metsulfuron-methyl (PM) 60 + 4 g/ha PoE	9.81 (101.3)	2.74 (7.0)	13.85 (193.7)	4.32 (18.0)	7.32 (55.3)	3.20 (10.0)	4.33 (18.8)	2.61 (5.9)	6.11 (36.5)	3.68 (12.9)	3.79 (13.7)	2.15 (3.7)
Sulfosulfuron + metsulfuron-methyl (PM) 30 + 2 g/ha PoE	10.37 (110.7)	3.35 (10.7)	14.55 (212.2)	5.70 (32.0)	7.46 (56.3)	2.68 (6.7)	4.15 (16.9)	3.12 (8.8)	5.90 (34.2)	3.94 (14.9)	3.59 (12.1)	2.46 (5.1)
Mesosulfuron-methyl + iodosulfuron-methyl sodium (PM) 12 + 2.4 g/ha PoE	10.18 (108.0)	2.41 (5.0)	14.15 (200.3)	5.24 (26.7)	7.80 (63.3)	3.37 (11.3)	4.63 (21.1)	3.21 (9.9)	6.19 (37.5)	4.29 (17.6)	3.86 (14.3)	3.55 (11.8)
Metribuzin + clodinafop-propargyl (PM) 140 + 40 g/ha PoE	10.01 (105.3)	2.11 (3.7)	13.96 (196.3)	3.07 (10.3)	7.86 (63.0)	1.00 (0.0)	4.77 (22.6)	3.05 (8.5)	6.58 (42.8)	3.54 (12.1)	3.84 (14.1)	1.00 (0.0)
Metribuzin + clodinafop-propargyl (PM) 210 + 60 g/ha PoE	10.19 (108.0)	1.00 (0.0)	14.61 (214.3)	1.00 (0.0)	7.57 (57.7)	1.00 (0.0)	4.78 (23.3)	1.00 (0.0)	6.47 (41.2)	1.00 (0.0)	3.60 (12.2)	1.00 (0.0)
Hand weeding at 20 and 40 DAS	1.00 (0.0)	4.63 (21.0)	1.00 (0.0)	6.13 (37.8)	1.00 (0.0)	3.87 (14.2)	1.00 (0.0)	1.98 (3.1)	1.00 (0.0)	2.33 (4.5)	1.00 (0.0)	1.70 (1.9)
Un-weeded check	10.74 (118.7)	7.82 (64.7)	14.96 (223.7)	11.73 (143.7)	8.09 (66.7)	8.93 (79.3)	4.88 (23.5)	9.28 (87.6)	6.96 (47.7)	10.36 (111.0)	3.98 (15.2)	11.09 (123.9)
LSD (p=0.05)	2.31	1.61	1.56	1.56	2.04	1.75	0.67	1.49	0.56	2.32	0.69	1.26

*Figures in parentheses are means of original values. Data subjected to transformation [$\sqrt{(x+1)}$]

Effect on crop

Effect of different weed management practices did not exert any significant effect on plant population recorded at 15 DAS during both years of the study. Different pre-emergence herbicides did not induce any phytotoxicity. Therefore, plant populations were comparable with all herbicidal treatments, including manual weeding and weedy check treatment. Grain and straw yield of wheat (**Table 3**) was recorded significantly higher under pendimethalin 30% EC 500 g/ha PE *fb* clodinafop-propargyl 15% WP 60 g/ha PoE which was followed by clodinafop-propargyl 15% + metsulfuron-methyl 1% WP (PM) 60 + 4 g/ha PoE, sulfosulfuron 75% + metsulfuron-methyl 5% WG (PM) 30 + 2 g/ha PoE and hand weeding at 20 and 40 DAS during both years of the study. The higher yield might be due to better control of both monocot and dicot weeds including *P. minor* due to sequential and pre-mix application herbicide provided congenial conditions for better growth and development of crop which resulted in higher yield. In this line of work, Hundal and Dhillon (2018) observed that sequential application of pendimethalin 750 g/ha PE *fb* clodinafop 60 g/ha PoE provided effective broad-spectrum weed control. This reduced crop-weed competition, thereby creating congenial conditions for better growth and development, which resulted in higher grain yield of wheat. The results are in accordance with the results reported by Chaudhari *et al.* (2017), Patel *et al.* (2021) and Kumar *et al.* (2023). Further, it was observed that application of metribuzin 42% + clodinafop-propargyl 12% WG (PM) PoE at both the rate i.e., 140 + 40 g/ha and 210 + 60 g/ha PoE provided effective control of weeds,

Table 2. Weed control efficiency and phytotoxicity as influenced by different weed management practices (two years pooled data)

Treatment	Weed control efficiency (%)						Phytotoxicity scoring (0-10)			
	P. minor		Monocot weed		Dicot weed		Chlorosis (DAHA)		Wilting (DAHA)	
	25 DAS	50 DAS	25 DAS	50 DAS	25 DAS	50 DAS	10	20	10	20
Pendimethalin 500 g/ha PE *fb* clodinafop-propargyl 60 g/ha PoE	93.6	94.9	93.0	90.2	88.8	89.7	0	0	0	0
Flumioxazin 125 g/ha PE *fb* clodinafop-propargyl 60 g/ha PoE	85.7	97.5	85.5	96.1	91.4	91.7	0	0	0	0
Pyroxasulfone 127.5 g/ha PE *fb* clodinafop-propargyl 60 g/ha PoE	85.7	96.1	86.3	89.9	90.0	85.0	0	0	0	0
Pendimethalin 500 g/ha PE *fb* sulfosulfuron30 g/ha PoE	93.9	94.8	93.6	90.7	88.2	89.5	0	0	0	0
Pendimethalin + metribuzin (TM) 500 + 140 g/ha PE	94.0	22.2	94.4	26.0	89.9	85.7	0	0	0	0
Clodinafop-propargyl + metsulfuron-methyl (PM) 60 + 4 g/ha PoE	-	93.0	-	85.0	-	97.0	0	0	0	0
Sulfosulfuron + metsulfuron-methyl (PM) 30 + 2 g/ha PoE	-	89.6	-	83.9	-	95.8	0	0	0	0
Mesosulfuron-methyl + iodosulfuron-methyl sodium (PM) 12 + 2.4 g/ha PoE	-	89.4	-	81.2	-	90.3	1	0	0	0
Metribuzin + clodinafop-propargyl (PM) 140 + 40 g/ha PoE	-	90.3	-	89.2	-	100.0	3	1	1	0
Metribuzin + clodinafop-propargyl (PM) 210 + 60 g/ha PoE	-	100.0	-	100.0	-	100.0	4	1	1	0
Hand weeding at 20 and 40 DAS	100.0	96.7	100.0	95.7	100.00	98.3	-	-	-	-
Un-weeded check	-	-	-	-	-	-	-	-	-	-

Table 3. Yield and economics of wheat as influenced by different weed management practices (two years pooled data)

Treatment	Plant Population (per meter row length) at 15 DAS		Grain yield (t/ha)		Straw yield (t/ha)		B C ratio	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Pendimethalin 500 g/ha PE *fb* clodinafop-propargyl 60 g/ha PoE	58.1	53.9	5.29	4.88	7.44	7.19	2.91	2.70
Flumioxazin 125 g/ha PE *fb* clodinafop-propargyl 60 g/ha PoE	55.2	53.6	4.59	4.17	6.44	6.18	2.40	2.20
Pyroxasulfone 127.5 g/ha PE *fb* clodinafop-propargyl 60 g/ha PoE	53.0	54.5	5.02	4.28	7.09	6.20	2.52	2.16
Pendimethalin 500 g/ha PE *fb* sulfosulfuron30 g/ha PoE	56.7	53.7	4.63	4.58	6.42	6.19	2.50	2.47
Pendimethalin + metribuzin (TM) 500 + 140 g/ha PE	56.3	51.6	2.87	2.43	6.09	5.83	1.73	1.50
Clodinafop-propargyl + metsulfuron-methyl (PM) 60 + 4 g/ha PoE	59.7	57.0	5.26	4.83	7.28	7.16	2.92	2.71
Sulfosulfuron + metsulfuron-methyl (PM) 30 + 2 g/ha PoE	58.5	56.7	5.23	4.54	7.24	7.03	2.93	2.58
Mesosulfuron-methyl + iodosulfuron-methyl sodium (PM) 12 + 2.4 g/ha PoE	59.9	56.9	4.45	3.95	6.43	6.15	2.51	2.25
Metribuzin + clodinafop-propargyl (PM) 140 + 40 g/ha PoE	58.9	56.6	3.64	2.99	6.18	6.17	2.13	1.81
Metribuzin + clodinafop-propargyl (PM) 210 + 60 g/ha PoE	59.0	55.0	3.55	2.87	5.93	6.09	2.05	1.72
Hand weeding at 20 and 40 DAS	58.3	54.4	5.18	4.83	7.21	7.12	2.54	2.38
Un-weeded check	59.3	56.1	1.94	1.75	3.07	2.87	1.19	1.08
LSD (p=0.05)	NS	NS	0.62	0.60	0.98	0.97	-	-

but due to phytotoxic effect on crop leads to reduction in grain and stover yield of wheat. The lowest yields of wheat with the highest yield reduction of grain yield to the extent of 63.41 and 64.04% was recorded during 2021-22 and 2022-23, respectively under un-weeded check due to severe crop-weed competition throughout the crop growth stages.

Economics

The economics analysis of the weed management practices revealed that higher benefit cost ratio was recorded under premix application of clodinafop-propargyl 15% + metsulfuron-methyl 1% WP (PM) 60 + 4 g/ha PoE followed by sulfosulfuron 75% + metsulfuron-methyl 5% WG (PM) 30 + 2 g/ha PoE and sequential application of pendimethalin 30% EC 500 g/ha PE *fb* clodinafop-propargyl 15% WP 60 g/ha PoE during both the years of experimentation.

Conclusion

The finding of the present study indicated that post-emergence application of either of clodinafop-propargyl 15% + metsulfuron-methyl 1% WP (PM) 60 + 4 g/ha or sulfosulfuron 75% + metsulfuron-methyl 5% WG (PM) 30 + 2 g/ha PoE provides effective control of *P. minor* with broad-spectrum weed control resulting higher grain yield and benefit-cost ratio. Similar effectiveness was observed under sequential application of pendimethalin 30% EC 500 g/ha PE *fb* clodinafop-propargyl 15% WP 60 g/ha PoE or sulfosulfuron 75% WP 30 g/ha PoE and hand weeding at 20 and 40 DAS. Therefore, for long-term management, these options can be used in a yearly rotation.

REFERENCES

Anonymous. 2011. *Annual Report-2011*. AICRP on Weed Management, BACA, AAU, Anand, pp. 23.

Anonymous. 2021. *District wise area, production and yield of food and non-food crops in Gujarat state*. Published by Directorate of Agriculture, Gandhinagar, page 27. Retrieved from https://dag.gujarat.gov.in

Bharat R and Kachroo D. 2007. Effect of different herbicides on mixed weed flora, yield and economics sf wheat (*Triticum aestivum*) under irrigated conditions of Jammu. *Indian Journal of Agricultural Sciences* **77**(6): 383–386.

Chaudhari DD, Patel VJ, Patel HK, Mishra A, Patel BD and Patel RB. 2017. Assessment of pre-mix broad spectrum herbicides for weed management in wheat. *Indian Journal of Weed Science* **49**(1): 33–35.

Chhokar RS, Chaudhary A and Sharma RK. 2018. Herbicide resistant weeds in India and their management. pp. 288–308.In: Sushilkumar and Mishra JS (Eds.) *Fifty Years of Weed Science Research in India*. Indian Society of Weed Science.

Gomez KA and Gomez AA. 1984. *Statistical Procedures for Agricultural Research (2ed.).* John Wiley and Sons, New York, 680 p.

Hundal RK and Dhillon BS. 2018. Control of *Phalaris minor* with sequential application of pre-and postemergence herbicides and herbicide combinations in wheat. *Indian Journal of Weed Science* **50**(4): 351–354.

Kaur T, Bhullar MS and Kaur S. 2019. Control of herbicide resistant *Phalaris minor* by pyroxasulfone in wheat. *Indian Journal of Weed Science* **51**(2): 123–128.

Kumar M, Kumar R, Patel VK and Prajapati AK. 2023. The effect of weed management practices on the growth, yields and productivity of wheat (*Triticum aestivum* L.). *International Journal of Plant & Soil Science* **35**(19): 644–652.

Patel VY, Patel BD, Patel VJ, Viradiya MB and Sodavadiya HB. 2021. Management of complex weed flora through herbicide combinations in irrigated wheat (*Triticum aestivum* L.). *International Journal of Current Microbiology and Applied Sciences* **10**(1): 3437–3444.

Qazizada GS, Todar Mal SK and Kumar P. 2022. Effect of pre- and post-emergence herbicides on weed infestation, crop growth and economics of wheat. *The Pharma Innovation Journal* **11**(3): 152–157.

Sharma KC, Parmar PS, Solanki KS and Singh U. 2018. Weed control efficiency, productivity and energy relationships of wheat (*Triticum aestivum*) production as influenced by herbicidal weed control in vertisols of central India. *Journal of Pharmacognosy and Phytochemistry* **7**(2): 3715–3720.

Sharma R. 2003. Effect of low dose of sulfonyl urea herbicides on weeds and yield of wheat (*Triticum aestivum*). *Annals of Agricultural Research* **24**(1): 217–219.

Sidhu AS, Gill MS, Saini SP, Singh S and Singh P. 2014. Herbicidal control of problematic weeds in wheat. *Indian Journal of Weed Science* **46**(4): 326–329.

Tomar SK and Tomar TS. 2014. Effect of herbicides and their tank mixture on weed dynamics and yield of zero-tilled wheat (*Triticum aestivum*) under rice (*Oryza sativa*)-wheat cropping system of eastern Uttar Pradesh. *Indian Journal of Agronomy* **59**(4): 624–628.

Indian Journal of Weed Science (2024) **56**(3): 263–265
http://dx.doi.org/10.5958/0974-8164.2024.00043.0

RESEARCH ARTICLE

Management of complex weed flora in wheat by herbicide combinations

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Received: 30 January 2023 | Revised: 1 April 2024 | Accepted: 4 April 2024

ABSTRACT

A field experiment was conducted during 2014-15 and 2015-16 to evaluate the efficacy of pre- and post-emergence herbicides and their combination against complex weed flora in wheat. Twelve treatments consisted with ten herbicidal treatments, pre-emergence application of pendimethalin 0.75 kg/ha, metribuzin 0.21 kg/ha, post-emergence application of sulfosulfuron 0.025 kg/ha, clodinafop 0.06 kg/ha, pendimethalin + metribuzin (1 + 0.175 kg/ha), pendimethalin *fb* sulfosulfuron (1 *fb* 0.018 kg/ha), sulfosulfuron + metsulfuron-methyl (0.03 + 0.002 kg/ha), pinoxaden + metsulfuron-methyl (0.06 + 0.004 kg/ha), mesosulfuron + iodosulfuron-methyl (0.012 + 0.0024 kg/ha), clodinafop + metsulfuron-methyl (0.06 + 0.004 kg/ha), two hand weeding at 30 and 60 days after sowing (DAS) and weedy check, were tested in randomized block design with three replications. Two hand weeding at 30 and 60 DAS recorded significantly reduced weed density and weed dry matter at 60 DAS with weed control efficiency of 85.26% and 84.14%, respectively. However, application of sulfosulfuron + metsulfuron resulted in maximum grain yield of 4.58 and 4.54 t/ha, net return of ¹ 51396 and 51136/ha and B:C ratio of 3.26 and 3.24, respectively in both the years compared to other herbicide applications. Thus, it may be concluded that for higher productivity and weed control, application of sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha) was found to be the best practice among the various herbicidal combinations.

Keywords: Economics, Sulfosulfuron + metsulfuron, Weed control efficiency, Wheat, Yield

INTRODUCTION

Wheat (*Triticum aestivum* L.) is widely grown as winter cereal and is the backbone of food security in India. Many factors affect the yield, weed infestation is one of the major causes of reduced yield. Weeds compete with crop species for water, nutrients and light leading to stunted plant growth and reduction in crop yield (Cudney *et al.* 2001). Therefore, suitable weed management practices are vital to produce optimum yields. Among different weed management practices, chemical weed control is preferred (Chaudhari *et al.* 2017) due to less labour availability. Though the chemical method is being discouraged worldwide, farmers in countries like India cannot ignore its immediate effect and economic returns. The application of herbicide is more effective as the weeds even within the rows are killed which escape, because of morphological similarity to wheat. The tank mixture of combination of isoproturon and 2,4-D have been recommended for complex weed flora in wheat but this combination has been effective in the situation where isoproturon was effective against *Phalaris minor* (Alhammad *et al.* 2023). This mixture was not so effective against complex weed flora dominated by other weeds (Patel *et al.* 2017). Under such situations, a proper combination of clodinafop with some broad-spectrum herbicides like sulfosulfuron and metribuzin was needed (Meena *et al.* 2019). Hence, the present experiment was carried out to evaluate the efficacy of pre- and post-emergence herbicides and their combination against diverse weed flora, productivity as well as profitability of wheat.

MATERIALS AND METHODS

A field experiment was conducted in research farm of Dr. Rajendra Prasad Central Agricultural University, Pusa, during winter season of 2014-15 and 2015-16 to find out the effect of herbicides on weed dynamics and productivity of wheat. The treatments consisted of ten herbicidal treatments, pre-emergence application of pendimethalin 0.75 kg/ha, metribuzin 0.21 kg/ha, post-emergence application of sulfosulfuron 0.025 kg/ha, clodinafop 0.06 kg/ha, pendimethalin + metribuzin (1 + 0.175 kg/ha), pendimethalin followed by (*fb*) sulfosulfuron (1 *fb* 0.018 kg/ha), sulfosulfuron + metsulfuron-methyl (0.03 + 0.002 kg/ha), pinoxaden + metsulfuron-methyl (0.06 + 0.004 kg/ha), mesosulfuron + iodosulfuron-methyl (0.012 + 0.0024 kg/ha), clodinafop + metsulfuron-methyl (0.06 + 0.004 kg/ha), two hand weeding at 30 and 60 DAS and weedy check. The experiment was laid out in a randomized block design with three replications. The experimental soil was low in nitrogen (271 kg/ha) and

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medium in phosphorus (17.89 kg/ha) and potassium (142.3 kg/ha). Recommended dose of fertilizer 120:60:40 kg N, P and K/ha, respectively, was applied through urea, di-ammonium phosphate and muriate of potash. Half of the nitrogen, full dose of phosphorus and potassium were applied before sowing. Remaining half of nitrogen was applied in two equal splits at crown root initiation and maximum tillering stages of crop. Crop was sown at spacing of 20 cm on 21st November 2014 and 04th December 2015, and harvested on 22nd April 2015 and 26th April 2016, respectively. The weed density was recorded 60 DAS using a quadrat of 0.25 square meter (0.5 × 0.5 m), and data obtained were expressed as density (number/m^2). The percent composition of weed flora was estimated from weedy check plot. To record weed biomass weeds were cut at ground level, washed with tap water, sun-dried in hot air oven at 70 °C for 48 hrs and then weighed. For the statistical analysis weed density and biomass were converted to 1 m^2 and imposed square root transformation by using formula $(\sqrt{x + 0.5})$ before analysis to normalize their distribution. Economic analysis was carried out by including all the variable costs (rhizome, manure, chemicals, labour, mulch materials) and their respective units used during the experiment. The prevalent market price of the produce was considered to calculate gross and net return and finally benefit–cost ratio was calculated. Statistical analysis was done by adopting appropriate method of Analysis of Variance (Gomez and Gomez 1984) and mean comparisons were performed based on the least significant difference (LSD) at 0.05 probability.

RESULTS AND DISCUSSION

The dominant weed species observed in the experimental field were *Avena fatua, Cynodon dactylon, Phalaris minor, Cyperus rotundus, Anagallis arvensis, Chenopodium album, Cirsium arvense, Convolvulus arvensis, Eclipta alba, Fumaria parviflora, Lathyrus aphaca, Launia pinnatifida, Melilotus alba, Physalis minima, Rumex dentatus* and *Vicia hirsute.*

Weed density, dry matter and weed control efficiency

Two hand weeding at 30 and 60 DAS in wheat crop recorded significantly reduced weed density as well as weed dry matter (**Table 1**) and was at par with post-emergence application of sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha) and clodinafop + metsulfuron (0.06 + 0.004 kg/ha) during 2014-15 and 2015-16. Consequently, two hand weeding recorded maximum weed control efficiency (85.26, 84.14%) followed by post-emergence application of sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha) (75.62, 75.19%) respectively during both of the years. In general, significant reduction in weed dry weight with sulfosulfuron + metsulfuron application of might be due to more effectiveness in controlling broad spectrum weeds than others. Hence, pre-mix formulations of herbicide effectively manage the both group of weeds *i.e.* narrow and broadleaf due to their higher efficacy as compared to sole application of herbicide. This herbicide mixture works by interfering with the acetolactate synthase enzyme in plants, which prevents the development of essential amino acids such as isoleucine, leucine, and valine. It slows cell division and growth which results in drying of weeds and ultimately death of weed (Choudhary *et al.* 2021). Malekian *et al.* (2013) have also reported lower weed dry matter production and increase in weed control efficiency with use of herbicides in wheat.

Yield and economics

The weed control treatments resulted significant increase in grain yield as compared to unweeded

Table 1. Effect of weed control methods on weed dynamics in wheat

Treatment	Weed density/m^2 at 60 DAS		Weed biomass (g/m^2) at 60 DAS		Weed control efficiency (%)		Grain yield (t/ha)	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Pendimethalin 0.75 kg/ha	37	38	18.89	18.76	47.85	47.94	3.86	3.82
Sulfosulfuron 0.025 kg/ha	32	31	16.45	16.15	54.58	50.99	3.96	3.99
Metribuzin 0.21 kg/ha	40	39	19.27	19.12	46.80	46.94	3.82	3.80
Clodinafop 0.06 kg/ha	35	34.5	17.66	17.25	51.24	52.15	3.92	3.94
Pendimethalin + metribuzin (1 + 0.175 kg/ha)	30	29.5	14.82	14.30	59.08	60.32	4.05	4.08
Pendimethalin *fb* sulfosulfuron (1+ 0.018 kg/ha)	22	22.5	10.48	10.59	71.07	70.63	4.42	4.41
Sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha)	19	18.5	8.83	8.94	75.62	75.19	4.58	4.54
Pinoxaden+ metsulfuron (0.06 + 0.004 kg/ha)	22	22.5	10.73	10.92	70.38	69.69	4.37	4.39
Mesosulfuron + iodosulfuron (0.012 + 0.0024 kg/ha)	23	24	11.26	11.49	69.19	68.25	4.29	4.33
Clodinafop + metsulfuron (0.06 + 0.004 kg/ha)	21	21.5	10.25	10.04	71.7	72.14	4.44	4.45
2 hand weeding at 30 and 60 DAS	12	11	5.34	5.72	85.26	84.14	4.77	4.76
Un-weeded control	64	63	36.22	36.04	-	-	3.23	3.20
LSD (p=0.05)	3.89	4.38	2.35	2.64	-	-	0.28	0.30

Table 2. Effect of weed control methods on economics of wheat

Treatment	Gross return (₹/ha)		Net Return (₹/ha)		B:C ratio	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Pendimethalin 0.75 kg/ha	62444	61914	39464	38934	2.72	2.69
Sulfosulfuron 0.025 kg/ha	64273	64801	41090	41618	2.77	2.80
Metribuzin 0.21 kg/ha	61733	61592	38817	38676	2.69	2.69
Clodinafop 0.06 kg/ha	63515	63664	40145	40294	2.72	2.72
Pendimethalin + metribuzin (1 + 0.175 kg/ha)	65567	65868	41937	42238	2.78	2.79
Pendimethalin *fb* sulfosulfuron (1+ 0.018 kg/ha)	71651	71604	47891	47844	3.02	3.01
Sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha)	74191	73931	51396	51136	3.26	3.24
Pinoxaden+ metsulfuron (0.06 + 0.004 kg/ha)	70738	71128	43148	43538	2.56	2.58
Mesosulfuron + iodosulfuron (0.012 + 0.0024 kg/ha)	69690	70184	46750	47244	3.04	3.06
Clodinafop + metsulfuron (0.06 + 0.004 kg/ha)	71827	72103	48932	49208	3.14	3.15
2 hand weeding at 30 and 60 DAS	77754	78247	43384	43877	2.26	2.28
Un-weeded control	52483	52247	30113	29877	2.35	2.34
LSD (p=0.05)	4567	4499	4567	4499	0.20	0.19

control (3.23, 3.20 t/ha). The highest grain yield of wheat (4.77 and 4.76 t/ha) was recorded by the treatment two hand weeding which remained at par with post-emergence application sulfosulfuron + metsulfuron (4.58 and 4.54 t/ha) during both of the years (**Table 1**). This exhibited an increase of grain yield 47.7 and 48.7 % over unweeded control. The higher yield might be due to effective weed control which kept the crop almost weed free during entire crop growth period that markedly reduced the competition for the moisture, space, nutrients, light leading to enhanced crop growth by utilizing greater moisture and nutrients from soil layers (Tiwari *et al.* 2015).

The results revealed that during the year 2014-15, sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha) and clodinafop + metsulfuron (0.06 + 0.004 kg/ha) recorded maximum B:C ratio value of 3.26 and 3.14 respectively. Whereas, during the year 2015-16 sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha), clodinafop + metsulfuron (0.06 + 0.004 kg/ha) and mesosulfuron + iodosulfuron (0.012 + 0.0024 kg/ha) was recorded maximum B:C ratio of 3.24, 3.15 and 3.06 respectively. Moreover, post-emergence application of sulfosulfuron + metsulfuron (0.03 + 0.002 kg/ha) recorded 18.47 and 16.54% higher net returns as compared to two hand weeding at 30 and 60 DAS (**Table 2**). In hand weeded plots the cost of cultivation increased remarkably due to higher labour wages. Different herbicidal treatments are favour on higher economical return because it cut down the application cost as well as labour requirement and it has been supported by Kushwaha and Singh (2000).

From the present study, it was concluded that post-emergence application of sulfosulfuron 0.03 kg/ha + metsulfuron 0.002 kg/ha was as good as two hand weeding at 30 and 60 DAS for higher productivity and profitability of wheat.

REFERENCES

Alhammad BA, Roy DK, Ranjan S, Padhan SR, Sow S, Nath D, Seleiman MF and Gitari H. 2023. Conservation tillage and weed management influencing weed dynamics, crop performance, soil properties, and profitability in a rice–wheat–green gram system in the Eastern Indo-Gangetic Plain. *Agronomy* **13**(7): 1953.

Cudney D, Orloff S, Canevari WM and Orr JP. 2001. Cereals (wheat, *Triticum aestivum*, barley, *Hordeum vulgare*, and oat, *Avena sativa*), In: *Principles of Weed Control*. (Eds. Kurtz E and Colbert F). California Weed Science Society, pp. 302–311.

Chaudhari DD, Patel VJ, Patel HK, Mishra A, Patel BD and Patel RB. 2017. Assessment of pre-mix broad spectrum herbicides for weed management in wheat. *Indian Journal of Weed Science* **49**(1): 33–35.

Choudhary AK, Yadav DS, Sood P, Rahi S, Arya K, Thakur SK, Lal R, Kumar S, Sharma J, Dass A, et al. 2021. Post-emergence herbicides for effective weed management, enhanced wheat productivity, profitability and quality in north-western Himalayas: a 'participatory-mode' technology development and dissemination. *Sustainability* **13**(10): 5425.

Gomez KA and Gomez AA. 1984. *Statistical procedures in agricultural research*. New York: Wiley.

Kushwaha BL and Singh PK. 2000. Comparative efficacy and economics of mechanical and chemical weed control in wheat. *Annals of Plant Production Science* **8**(1): 71–75.

Malekian B, Ghadiri H, Kazemeini SA and Edalat M. 2013. Efficacy evaluation of sulfosulfuron, metsulfuron-methyl plus sulfosulfuron, mesosulfuron-methyl plus iodosulfuron-methyl and iodosulfuron plus mesosulfuron herbicides in winter wheat (*Triticum aestivum* L.). *Journal of Biological and Environmental Science*. **7**(21): 177–182.

Meena V, Kaushik ML, Dotaniya, Meena BP and Das H. 2019. Bio-efficacy of ready-mix herbicides on weeds and productivity in late-sown wheat. *Indian Journal of Weed Science* **51**(4): 344–351.

Patel BD, Chaudhari DD, Patel VJ, Patel HK, Mishra A and Parmar DJ. 2017. Influence of broad-spectrum herbicides on yield and complex weed flora of wheat (*Triticum aestivum* L.). *Research on Crops* **18**(3): 433–437.

Tiwari A, Kumar B, Verma DJ and Kumar, R. 2015. Bio-efficacy of clodinafop-propargyl + metsulfuron-methyl against complex weed flora in wheat. *Indian Journal of Weed Science* **47**(4): 422–424.

Indian Journal of Weed Science (2024) **56**(3): 266–273
http://dx.doi.org/0.5958/0974-8164.2024.00044.7

RESEARCH ARTICLE

Brown manuring in conservation agriculture based maize-wheat-greengram cropping system: Effects on weed flora, crop yield, and profitability of maize

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Received: 30 June 2024 | Revised: 27 September 2024 | Accepted: 29 September 2024

ABSTRACT

An experiment was conducted at the ICAR-Indian Agricultural Research Institute, New Delhi, during 2021 and 2022 to evaluate the efficacy of brown manuring (BM) using *Sesbania* plants in controlling weeds and improving productivity in conservation agriculture-based maize. Treatments included conventional tillage maize (CT-M), conventional tillage maize with green manure from preceding greengram (CT-M+GM), zero tillage maize with residue retention at 3 t/ha (ZT-M+R), and zero tillage maize with *Sesbania* co-culture as brown manuring (ZT-M+BM), combined with five weed control treatments *viz* unweeded check (UWC), pre (atrazine + pendimethalin 750 g/ha, each) + 1 hand weeding (30 DAS), pre (atrazine + pendimethalin 750 g/ha, each) + post (tembotrione) 120 g/ha, pre (atrazine + pendimethalin 750 g/ha, each) + post (pre-mix of mesotrione + atrazine) 120 g/ha, weed free check in sub-plots. Results showed that ZT-M+BM caused 28.4% reduction in total weeds at 60 days after sowing compared to CT-M. Sequential application of atrazine (750 g/ha) and pendimethalin (750 g/ha) *fb* tembotrione (120 g/ha) effectively reduced weed population (78.5%) and dry weight (81.3%) compared to the unweeded control. Maize yield attributes were higher in ZT-M+BM than in CT treatments. The combination of atrazine, pendimethalin, and tembotrione with ZT-M+BM resulted in higher maize productivity (6.88 t/ha) and profitability (₹ 116,570/ha), comparable to the weed-free check. Thus, integrating zero tillage with *Sesbania* brown manure, and pre-emergence application of atrazine + pendimethalin followed by post-emergence tembotrione is recommended for effective weed control and high maize productivity of maize.

Key words: Brown manuring, Integrated weed management (IWM), Resource Conservation Technologies (RCT), Conservation agriculture, HPPD-inhibitor, Cover Crop

INTRODUCTION

Maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.)-mung bean (*Vigna radiata* L.) cropping system under conservation agriculture (CA) has been proposed (Parihar *et al.*, 2017) as an alternative to rice-wheat in the Indo-Gangetic plains. Maize productivity in India (2689 kg/ha) is significantly lower than the global average (5500 kg/ha), largely due to weed interference, particularly in the IGP where post-emergence herbicides are scarce (Swetha *et al.* 2015). Tillage modifications affect weed seed dynamics, often concentrating seeds in the topsoil of no-till systems (Mulugeta and Stoltenberg 1997). Weed competition can reduce maize yields by up to 90% (Dalley *et al.* 2006), with reductions ranging from 40-80% (Reddy and Tyagi 2005). Integrated weed management through Resources Conservation Technologies (RCT), such as brown manuring, offers an eco-friendly alternative.

Brown manuring (BM), a no-till version of green manuring, uses a selective herbicide (2,4-D) to knock down the legume plants before blossoming, thus contributing organic matter to the soil. Maitra and Zaman (2017) describe the BM technique as growing *Sesbania bispinosa* alongside the crop for the first 25-30 days after sowing and then knocking it down with 2,4-D providing up to 35 kg N/ha. The resulting dark brown or yellow *Sesbania* plants are left in the field to decompose naturally, reducing weed interference through allelopathy or smothering effects (Oyeogbe *et al.* 2017). This research investigates *Sesbania* BM's efficacy in controlling weed species in maize and compares the benefits of zero tillage to conventional tillage practices.

MATERIALS AND METHODS

A field experiment was carried out during the rainy (*Kharif*) season of 2021 and 2022 at the ICAR-Indian Agricultural Research Institute (28°08’N latitude,77°12’ E longitude and at an elevation of 228.61 metres (750 feet) above mean sea level) New

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Delhi, India. The treatments were comprised of four tillage methods *viz.* conventional tillage maize (CT-M), conventional tillage maize with green manure from preceding greengram (CT-M+GM), zero tillage maize with residue retention at 3 t/ha (ZT-M+R), zero tillage maize with *Sesbania* co-culture as brown manuring/cover crop (ZT-M+BM) in main plot; and five weed control treatments, *viz.* unweeded check (UWC), pre (atrazine + pendimethalin 750 g/ha, each) + 1 hand weeding (30 DAS), pre (atrazine + pendimethalin 750 g/ha, each) + post (tembotrione) 120 g/ha, pre (atrazine + pendimethalin 750 g/ha, each) + post (pre-mix of mesotrione + atrazine) 120 g/ha, weed free check in sub-plots were evaluated. Atrazine 750 g/ha + pendimethalin 750 g/ha were applied as pre-emergence (day after sowing) with 400 litres of water/ha, followed by the post-emergence application of tembotrione 120 g/ha at 30 DAS using a knapsack sprayer, which was also used to apply a ready-mix herbicide (mesotrione 2.27%W/w + atrazine 22.7%W/w) 120 g/ha with a flat-fan nozzle at 30 DAS. Soil of experimental site was sandy loam, with pH 7.5, low in organic C (0.32%), low in available N (148.4 kg/ha), high in available P (30.8 kg/ha) and medium in available K (256.4 kg/ha). During the winter season (*Rabi*), wheat crop was cultivated with the stipulated treatments, and the leftover crop residues were applied in the subsequent rainy season (*Kharif*) for maize cultivation. Following the wheat harvest, mung bean was cultivated as a green manure crop and then incorporated into the field as per the designated treatment. In the conventional tillage (CT) plots, a tractor-drawn disc plough was used for ploughing, followed by levelling with a planker. For zero tillage (ZT) plots with residues, the residue from the previous wheat crop was kept intact, while ZT plots without residues were left undisturbed. Additionally, a weed-free check was maintained, involving manual weeding carried out at intervals of 30, 60, and 90 days after sowing (DAS). On the same day of maize sowing (18th July 2021 and 20th July 2022), *Sesbania aculeata* L., a leguminous cover crop, was broadcast at a rate of 15 kg/ha. This cover crop served the purpose of suppressing weeds during the early stages of maize growth and also acted as brown manure. On the 30th day after sowing, a blanket spray of 2,4-D herbicide at a rate of 0.25 kg/ha was done over the maize / *Sesbania* plants. Seeds of the '*PJMH-1*' hybrid maize, with a growth duration of 100-110 days, were sown using a 9-tyne zero-till seed drill, maintaining a spacing of 60 cm between lines and a seed-to-seed interval of 20 cm. A calculated amount of nutrients, 120-60-40 kg N, P, K per hectare were applied on the basis of soil-test analysis in maize through urea, single superphosphate and muriate of potash, respectively. Weed species were counted from a 1 × 1m (1 m^2) quadrat, and density was given in number/m^2. The weeds were first dried in the sun, then placed in an electric oven set to 70°C until the weight remained constant. The dry weight was then calculated as g/m^2. The benefit-cost ratios for each treatment were calculated as the ratio of net returns (Using MSP of 2023) to the cost of cultivation. The data were analysed using analysis of variance (ANOVA) for a split plot design to determine the significance of overall treatment differences using the "F" test and conclusion was drawn at 5% probability level. To assess weed control efficacy (WCE), weed control index (WCI), following calculations were made according to Das (2008):

$$WCE\ (\%) = \frac{(Weed\ density\ in\ control\ plot - Weed\ density\ in\ treated\ plot)}{Weed\ density\ in\ control\ plot} \times 100$$

$$WCI\ (\%) = \frac{(Weed\ dry\ matter\ in\ control\ plot - Weed\ dry\ matter\ in\ treated\ plot)}{Weed\ dry\ matter\ in\ control\ plot} \times 100$$

Two years mean data (2021 and 2022) were used for analysis. The standard error of the mean was calculated for each case. When the 'F' value from the ANOVA was significant, the least significant difference (LSD) was computed to test treatment significance. To address data variability, weed density and dry weight were normalized using the square-root $[\sqrt{x+0.5}]$ transformation before ANOVA.

RESULTS AND DISCUSSION

Weed management attributes

In the experimental plot, a diverse array of annual and perennial weeds was observed, encompassing narrow-leaved weeds, *Setaria viridis* L., *Digitaria sanguinalis* L., and *Dactyloctenium aegyptium* L. On the other hand, among the broad-leaved weeds, the dominant species were *Commelina benghalensis* L., *Amaranthus viridis* L., *Trianthema portulacastrum* L., and *Digera arvensis* L. Additionally, among the perennial weeds, *Cyperus rotundas* L. and *Cynodon dactylon* L., were observed.

Tillage and weed control treatments had significant ($p<0.05$) effect on broad-leaf weeds (BLW), narrowleaf weeds (NLW) and sedges distribution. At 30 DAS, the count of BLW was higher (80.7%) in CT-M compared to ZT+BM plots, and also the perennial weed species like sedges *(Cyperus rotundas*) were abundant in ZT than in CT plots. The total weed count was higher in CT-M compared to ZT-M+BM, indicating the weed-suppressing effect of BM (**Table 1**), with dominant weed species including *C. dactylon* and *C. benghalensis* among narrow-leaf weeds, *C. rotundas* in sedge weeds, and *A. viridis* among broad-leaf weeds. The CT-maize had the highest *C. benghalensis* population (6.3/m²), while the ZT-M+BM plot had the lowest (3.7/m²), with similar trend for *A. viridis*. At 60 DAS, weed populations were lower but followed similar trends (**Figure 1**). Unweeded check had the highest weed density, while the weed-free check and pre + post (tembotrione) herbicide-applied plot had the best control. Zero tillage in conservation agriculture (CA) resulted in less effective early weed suppression, leading to variable initial weed growth.

At 30, 60, and 90 days after sowing (DAS), NLW exhibited higher densities compared to broad-leaf weeds (BLW) and sedges. The CT-M recorded the highest weed density at 30 DAS, with 67.6 weeds/m^2, comprising BLW (14.1), NLW (26.4), and sedges (12.1/m^2). Conversely, the ZT-M+BM had the lowest weed density among all crop establishment methods, with a total of 49.2 /m^2 (7.8 BLW, 20.0 NLW, 15.4 sedges/m^2). Among the weed management options, the weed-free check plot consistently had the lowest weed density, followed by pre + post (tembotrione) herbicide.

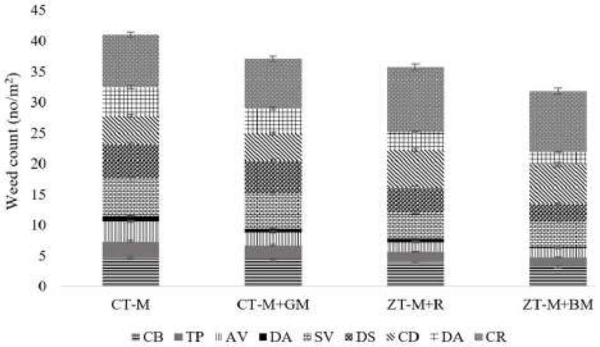


Figure 1. Species wise weed distribution pattern in main plot at 60 DAS

The results demonstrated that *Sesbania* had a smothering effect as a cover crop, leading to a significant reduction in weed population. The sequential application of atrazine 750 g/ha with pendimethalin 750 g/ha (pre) *fb*. tembotrione 120 g/ha (post) outperformed the other weed control techniques by considerably reducing the number of weed species (78.5% reduction over the weedy check) in comparison to pre (atrazine +pendimethalin 750 g/ha) + 1 HW at 25 DAS and pre (atrazine + pendimethaline 750g/ha) + post (premix mesotrione + atrazine 120 g/ha).

At 30 DAS, CT-M exhibited the highest weed dry weight, while ZT-M+BM achieved the most substantial reduction in weed dry weight by 10.4% due the smothering effect of BM. ZT-M+R and CT-M+GM showed reduction of 2.5% and 8.1%, respectively. A similar pattern emerged at 60 DAS in both years, with the lowest weed dry matter accumulation compared to the other two growth stages, indicating the effectiveness of BM (**Table 2**).

Table 1. Effect of crop establishment methods and weed management on species-wise weed distribution (no./m^2) at 30 DAS in maize (two years pooled data)

Treatment	BLW			NLW					Sedge
	Commelina benghalensis	*Trianthema portulacastrum*	*Amaranthus viridis*	*Digera arvensis*	*Setaria viridis*	*Digitaria sanguinalis*	*Cynodon dactylon*	*Dactyloctenium aegyptium*	*Cyperus rotundus*
Crop establishment									
CT-maize	2.4(6.3)	1.4(3.3)	1.9(3.7)	1.1(0.8)	2.6 (7.6)	2.42 (6.9)	2.1(5.5)	2.2 (6.0)	2.8 (10.1)
CT-maize + green manure	2.3(5.5)	1.4(2.7)	1.6(2.5)	1.0(0.7)	2.7 (8.2)	2.43 (6.8)	2.2(6.5)	2.3 (5.6	3.1 (12.0)
ZT-maize + residue*	2.2(5.1)	1.3(2.1)	1.5(2.1)	1.0(0.6)	2.5 (6.8)	1.86 (4.3)	2.9(9.7)	1.8 (4.0)	4.5 (25.1)
ZT-maize + *Sesbania* brown manure	1.9(3.7)	1.1(1.7)	1.6(1.9)	0.9(0.4)	2.3 (5.8)	1.67 (3.2)	2.7(8.3)	1.9 (3.8)	4.3 (21.4)
LSD (p=0.05)	0.3(1.5)	NS	0.3(1.1)	NS	NS	NS	0.3(2.2)	NS	0.9 (9.1)
Weed management									
Un-weeded check	2.9(8.5)	1.6(4.9)	2.1(4.3)	1.1(0.8)	2.9 (8.5)	2.57 (6.9)	3.6(13.0)	2.0 (4.6)	5.3 (30.3)
Pre +1 HW	2.3(4.8)	1.5(2.0)	1.8(3.0)	1.2(1.1)	2.9 (8.4)	2.66 (8.3)	2.5(6.7)	2.8 (7.9)	4.2 (19.3)
Pre + Post (*Tembotrione)*	2.6(6.7)	1.3(2.8)	1.8(2.8)	1.0(0.7)	3.0 (8.7)	2.34 (5.8)	2.7(7.9)	2.0 (4.2)	4.0 (17.7)
Pre+ Post (premix *meso+atra*) §	2.5(5.8)	1.3(2.5)	1.7(2.8)	1.0(0.5)	3.2 (9.9)	2.20 (5.5)	2.9(9.8)	2.6 (7.6)	4.1 (18.4)
Weed free check	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7 (0.0)	0.71 (0.0)	0.7(0.0)	0.7 (0.0)	0.7 (0.0)
LSD (p=0.05)	0.3(1.6)	0.3(1.1)	0.3(1)	0.3(0.6)	0.6 (3.5)	0.85 (4.1)	0.8(4.0)	0.8 (4.3)	1.0 (7.7)

Note: CT: conventional tillage; ZT: zero tillage; * wheat residue 3t/ha; Pre: pre-emergence (atrazine + pendimethaline 750 g/ha); Post: post-emergence; HW: hand weeding at 25 DAS; Tembo: tembotrione 120g/ha; §:pre-mix dose of mesotrione + atrazine 120 g/ha. The data were subjected to square root transformation "x+0.5 before statistical analysis. Figures in parentheses are the original values

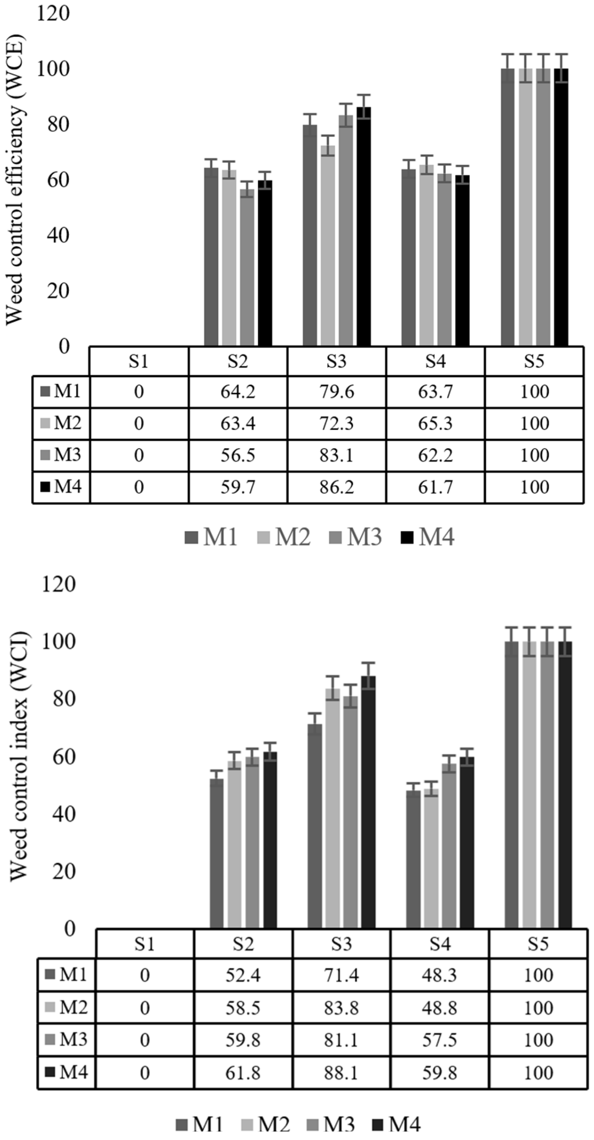
Table 2. Effect of crop establishment methods and weed management on weed dry weight (g/m^2) in maize (mean data of two years)

Treatment	30 DAS	60 DAS	90 DAS
Crop establishment methods			
CT-maize	7.7(71.2)	4.6(26.2)	7.7(72.7)
CT-maize + green manure	7.4(65.4)	4.4(23.9)	7.5(68.2)
ZT-maize + residue*	7.6(69.4)	4.2(21.4)	7.2(64.2)
ZT-maize + *Sesbania* brown manure	7.3(63.8)	3.8(18.4)	6.9(59.3)
LSD (p=0.05)	0.2(4.5)	0.1(2.1)	0.5(8.5)
Weed management options			
Un-weeded check	10.0(99.3)	7.2(52.3)	11.4(129.2)
Pre +1 HW	9.0(79.7)	5.0(24.5)	8.5(71.6)
Pre + post (*tembotrione)*	8.8(76.7)	3.2(9.8)	7.8(61.0)
Pre+ post (premix *meso+atra*) §	9.1(81.6)	5.1(25.8)	8.3(69.0)
Weed free check	0.7(0.0)	0.7(0.0)	0.7(0.0)
LSD (p=0.05)	0.3(6.3)	0.2(2.4)	0.3(5.3)

Note: CT: conventional tillage; ZT: zero tillage; * wheat residue 3 t/ha; Pre: pre-emergence (atrazine + pendimethaline 750 g/ha); Post: post-emergence; HW: hand weeding at 25 DAS; Tembo: tembotrione 120 g/ha; §:pre-mix dose of mesotrione + atrazine 120 g/ha. The data were subjected to square root transformation “x+0.5 before statistical analysis. Figures in parentheses are the original values

Application of atrazine 750 g/ha with pendimethalin 750 g/ha (pre) + post application of tembotrione resulted in the lowest weed dry weight at 60 DAS (9.8 g/m²), followed by atrazine 750 g/ha with pendimethalin 750 g/ha (pre) + 1 hand weeding) and atrazine 750 g/ha with pendimethalin 750 g/ha (pre) + post application of premix meso + atra), relative to the unweeded check. These findings underscore the efficacy of herbicide along with *Sesbania* brown manure in significantly reducing weed dry weight at 60 and 90 DAS, demonstrating their effectiveness in weed control during the later stages of crop growth in 2021 and 2022.

The weed control efficiency (WCE) and weed control index (WCI) at 60 DAS using mean data of two years are shown in **Figure 2**. At 30 DAS, the crop establishment and weed management effects did not have a significant impact. Evidently, the weed-free check plot had the highest weed control index value of 100%. The ZT-M+BM (M4) combined with pre + post tembotrione treatment was the second most effective, with a WCI of 88.1%. At 60 DAS, weed-free check plot showed highest efficiency in controlling the weeds showing a value of 100%. The sequential application of atrazine 750 g/ha with pendimethalin at 750 g/ha (pre), *fb* tembotrione 120 g/ha (post) along with ZT+BM showed the second-best efficiency in terms of weed control efficiency by showing a value of 86.2%, followed by in the application of same herbicide in ZT+R plot which showed a value of 83.1%. This might be due to higher efficacy of herbicides which resulted in lower weed density, weed dry weight along with the smothering effect of cover crop *Sesbania*. Similar reports of higher WCE with tank mix of HPPD inhibiting herbicides with atrazine have been given by Madhavi *et al.* (2014).



	S1	S2	S3	S4	S5
■M1	0	64.2	79.6	63.7	100
■M2	0	63.4	72.3	65.3	100
■M3	0	56.5	83.1	62.2	100
■M4	0	59.7	86.2	61.7	100

	S1	S2	S3	S4	S5
■M1	0	52.4	71.4	48.3	100
■M2	0	58.5	83.8	48.8	100
■M3	0	59.8	81.1	57.5	100
■M4	0	61.8	88.1	59.8	100

Where by, M1: CT-maize; M2: CT-maize + green manure; M3: ZT-maize + residue*; M4: ZT-maize + *Sesbania* brown manure; S1: Un-weeded check ; S2: Pre (atrazine + pendimethalin 750 g/ha) +1 HW at 25 DAS; S3: Pre (atrazine + pendimethalin 750g/ha) + Post (tembotrione 120 g/ha); S4: Pre (atrazine + pendimethalin 750 g/ha) + Post (premix mesotrione + atrazine 120 g/ha) § ; S5: Weed free check

Figure 2. Effect of crop establishment methods and weed management on weed control efficiency (WCE), and weed control index (WCI) at 60 DAS

Crop growth parameters

Growth parameters of maize such as plant height, total dry matter (g/plant), leaf area (cm^2/plant) and leaf area index (LAI) were significantly ($p<0.05$) affected by tillage and weed management treatments

(**Table 3**). Zero tillage with brown manure (ZT+BM) showed substantial increases in plant height over conventional tillage without mulch (CT-M) in both years, with improvements of 27%, 8.1%, 9.5%, and 12.4% at 30, 60, 90 days after sowing (DAS), and harvest, respectively. Although plant dry weight did not differ significantly at 30 DAS, ZT-M+BM produced the highest dry weights at all subsequent stages (60 and 90 DAS), followed by ZT-maize with residue and CT-maize with green manure. ZT-M+BM had the highest LAI at 30 DAS (1.6), surpassing CT-M by 64%, ZT-M+R by 43.2%, and CT-maize with green manure by 20.6%. The weed-free check recorded the highest dry weight at harvest (227.8 g/plant), 14% more than the un-weeded check, with pre + post (tembo) and pre + post (premix meso + atra) also showing significant improvements. LAI was highest in the weed-free check (1.4), followed by pre + post (tembotrione) and pre + post (pre-mix meso. + atra.) treatment.

During the initial growth phase (0-30 DAS), the crop growth rate (CGR) ranged from 3.4 to 2.5 g/m^2/day, averaging 2.9 g/m^2/day, with ZT-M+BM showing the highest CGR, which was significantly more than CT-M and ZT-M+R. From 30-60 DAS, CGR increased significantly, averaging 23.37 g/m^2/day with a range of 20.4 to 26.4 g/m^2/day. The highest CGR occurred during 60-90 DAS (**Figure 3**) in 2021 and 2022, with a mean of 27.55 g/m^2/day, again with ZT-M+BM leading and then decreased at harvest. Similarly, for weed management, the weed-free check plot recorded the highest CGR (3.2 g/m^2/day) during 0-30 DAS, which increased to an average of 23.45 g/m^2/day during 30-60 DAS, and peaked at 11.2 g/m^2/day during 60-90 DAS and then decreased. Effective weed management prevented crop-weed competition, and enhanced growth of maize. The relative growth rate (RGR) was significantly affected during 0-30 DAS, with ZT-maize and *Sesbania* brown manuring exhibiting the highest RGR in both

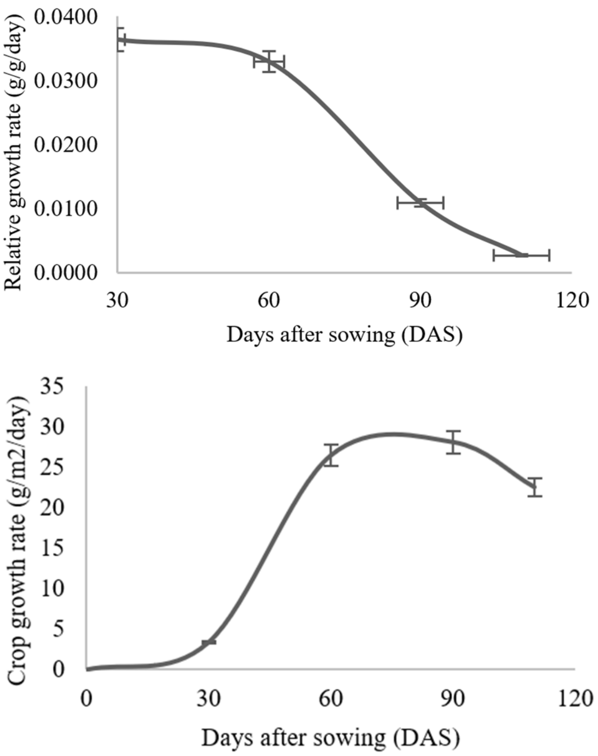


Figure 3. Effect of crop establishment methods and weed management on crop growth rate (CGR) and relative growth rate (RGR) of maize

Table 3. Effect of crop establishment methods and weed management on different crop growth parameter. (mean data of 2 years)

Treatment	Plant Height (cm)		Dry matter accumulation (g/plant)		Leaf area index (LAI)	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Crop establishment methods						
CT-maize	32.9	120.3	9.1	82.4	1.0	3.7
CT-maize + green manure	35.9	126.4	9.3	85.4	1.2	3.8
ZT-maize + residue*	34.6	123.9	10.8	102.5	1.4	4.0
ZT-maize + *Sesbania* brown manure	41.8	130.1	12.4	107.6	1.6	4.3
LSD (p=0.05)	NS	6.2	NS	9.1	0.1	0.28
Weed management options						
Un-weeded check	31.9	119.8	9.5	80.7	1.2	3.4
Pre +1 HW	33.9	123.3	10.0	89.3	1.2	3.8
Pre + post (*tembotrione)*	38.0	127.3	10.6	98.6	1.4	4.0
Pre+ post (premix *meso+atra*) [§]	36.4	124.9	10.3	94.7	1.3	3.9
Weed free check	41.2	130.5	11.5	109.4	1.4	4.6
LSD (p=0.05)	NS	6.7	NS	7.1	0.09	0.23

Note: CT: conventional tillage; ZT: zero tillage; * wheat residue 3 t/ha; Pre: pre-emergence (atrazine + pendimethalin 750 g/ha); Post: post-emergence; HW: hand weeding at 25 DAS; Tembo: tembotrione 120g/ha; [§]: pre-mix dose of mesotrione + atrazine 120 g/ha.

years. While RGR averaged 0.0336 g/g/day at 0-30 DAS, it decreased at later stages (0.0107 g/g/day 60-90 DAS) due to maturation of crop and senescence and at harvest it was the lowest. (**Figure 3**)

Crop growth significantly improved due to co-culture of ZT-maize and *sesbania* brown manure, combined with the application of pre + post (tembotrione) herbicide due to reduced weed competition. Weed management strategies directly reduce crop-weed competition and indirectly lessen competition for resources like light, space, water, and nutrients. Lower weed density and biomass create more space for optimal leaf and branch expansion, enhancing early plant growth and LAI (Gul and Khanday 2015).

Yield attributes

The ZT-M+BM treatment achieved significantly higher kernel yields attributed to superior yield parameters compared to CT-Maize. It demonstrated notably greater cob dimensions (16.14 cm in length, 15.79 cm in girth, and 130.13 g in the weight) and shelling percentage (81.57%) at harvest, surpassing CT-Maize. Additionally, ZT-M+BM exhibited higher values for rows per cob (13.37), kernels per row (29.99), kernel weight per cob (98.50 g), and 100-kernel weight (24.49 g) compared to CT-Maize. Weed management also significantly influenced cob dimensions and shelling percentage, with the weed-free plot showing superior results compared to unweeded plots. The pre + post (tembotrione) treatment similarly contributed positively, with results aligning closely with weed-free conditions (WFC). These findings underscore the efficacy of the ZT-M+BM treatment in enhancing maize productivity through optimized grain production.

Various crop establishment methods and weed management practices had significant impacts ($p<0.05$) on maize yield metrics (**Table 5**). The ZT-M+BM significantly outperformed the CT-Maize

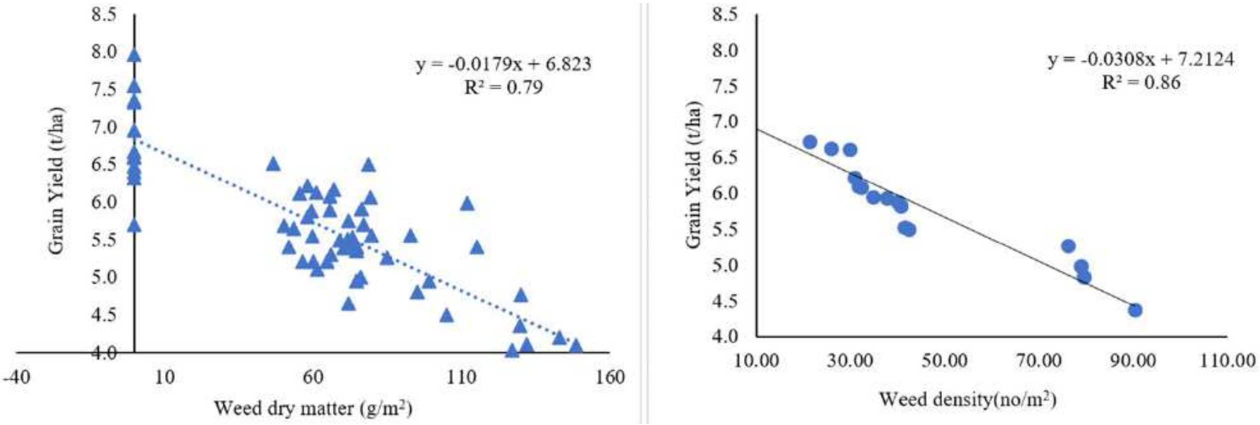


Figure 4. The relationship of grain yield with weed dry matter and weed density at 60 DAS

Table 4. Effect of crop establishment methods and weed management on yield attributes of maize (two years mean data)

Treatment	Cob length (cm)	Cob girth (cm)	Cob weight (g)	No of Kernel/ row	No of Kernel row /cob	Kernel weight/ cob(g)	Seed index (g)	Shelling %	Harvest index (%)
Crop establishment methods									
CT-maize	13.3	12.7	117.7	27.0	11.7	83.8	22.8	72.0	42.21
CT-maize + green manure	13.4	12.9	119.5	27.0	12.3	86.8	23.0	73.6	42.79
ZT-maize + residue*	14.6	13.7	123.9	28.8	12.5	88.0	23.8	76.0	43.42
ZT-maize + *Sesbania* Brown manure	16.1	15.8	130.1	29.9	13.4	98.5	24.5	81.6	43.47
LSD (p=0.05)	1.4	1.2	8.6	2.1	0.5	7.1	1.2	6.5	NS
Weed management options									
Un-weeded check	11.5	12.0	110.3	25.9	10.9	75.8	22.0	69.2	42.00
Pre +1 HW	13.7	13.1	119.2	26.4	11.7	81.8	21.8	71.6	42.83
Pre + Post (*tembotrione)*	15.4	14.6	126.5	29.4	13.2	96.9	24.2	80.6	43.10
Pre+ Post (premix *meso+atra*) §	14.8	13.9	122.5	27.9	12.5	82.3	23.2	70.1	42.92
Weed free check	16.5	15.4	135.6	31.9	14.1	109.5	26.4	87.3	44.01
LSD (p=0.05)	1.1	1.3	10.5	2.2	0.7	6.1	1.5	6.3	NS

Note: CT: conventional tillage; ZT: zero tillage; * wheat residue 3 t/ha; Pre: pre-emergence (atrazine + pendimethalin 750 g/ha); Post: post-emergence; HW: hand weeding at 25 DAS; Tembo: tembotrione 120 g/ha; §: pre-mix dose of mesotrione + atrazine 120 g/ha method, yielding higher grain (6.72 t/ha), stover (8.70 t/ha), yields, and harvest index (43.47%). This represented a 17.7% increase in grain yield over CT maize. Similarly, the pre + post (tembotrione) treatment demonstrated an 18.8% increase in grain yield compared to the unweeded check (UWC). Effective weed management, particularly in the weed-free check plot and with the pre + post (tembotrione) treatment, resulted in superior grain (6.32 t/ha), stover (8.72 t/ha) and harvest index (43.10%), emphasizing their crucial role in enhancing maize productivity and overall crop performance. The grain and straw yield showed significant improvement in ZT-maize with *Sesbania* brown manuring, indicating synergistic interactions of BM between vegetative and reproductive growth components. These qualities are positively correlated with maize grain yield, leading to increased productivity in ZT-maize treatments. Effective crop residue management can enhance nutrient cycling and overall crop yields (Sarkar *et al.* 2020). Turmel *et al.* (2015) suggested that excessive soil disturbance from tillage operations is unnecessary for optimal crop yields.

In terms of net returns (calculated based on the minimum support price (MSP) of 2023 on pooled data of grain yield), ZT-Maize + BM performed the best, with a value of ₹ 116,570/ha, followed by CT-Maize with ₹ 94,320/ha. Among the crop establishment methods, ZT-M+BM achieved the highest net benefit-cost (B:C) ratio of 3.71, surpassing other methods. Among the weed management methods, (weed-free check) achieved the highest net returns at ₹ 112,320/ha, followed by S3 (pre + post tembotrione) at ₹ 109,230/ha, and (pre + 1 HW at 30 DAS) at ₹ 97,730/ ha. In contrast, W1 (un-weeded check) yielded net returns of ₹ 77,530/ ha. Although the weedy check had the lowest cultivation costs, it resulted in the lowest returns due to reduced yields. For weed management, the pre + post (tembotrione) option had the highest net B:C ratio of 3.01, outperforming other options. The superior B:C ratios for ZT-maize with *Sesbania* brown manuring and pre + post (tembotrione) was due to their higher yields and lower cultivation costs.

A negative linear correlation between weed density and dry weight accumulation with maize yield indicated that as weed density or biomass increased, maize yield decreased linearly (calculation based on the pooled data of weed parameters). This correlation suggests that weeds adversely affected maize growth by competing for resources like water, nutrients, and sunlight. At 60 DAS, grain yield showed strong correlation with weed biomass ($R^2 = 0.79$) and weed density ($R^2 = 0.86$), indicating that weed biomass and density accounted for 79% and 86% of the variation in maize yield, respectively. The outcome is backed by the research conducted by Mitra *et al.* (2018).

In summary, findings from a 2-year field study suggested that brown manuring in zero tillage combining 15 kg/ha of *Sesbania* seed with 0.25 kg/ha of 2,4-D applied at 30 days after sowing for knocking it down, effectively managed weeds in maize cultivation. This integrated approach, particularly effective when paired with pre-emergence application of atrazine 750 g/ha and pendimethalin 750 g/ha, followed by post-emergence treatment with 120 g/ha of tembotrione, demonstrated superior weed suppression mainly the perennial weed compared to

Table 5. Effect of crop establishment methods and weed management on grain yield, straw yield, total biomass yield, gross return, net return and net benefit cost ratio(B:C)

Treatment	Grain yield (t/ha)			Straw yield (t/ha)			Gross returns ($x10^3$ ₹/ha)	Net returns ($x10^3$ ₹/ha)	Net B:C
	2021	2022	Mean	2021	2022	Mean			
Crop establishment									
CT -maize	5.34	5.72	5.53	7.63	7.57	7.60	129.26	94.32	2.70
CT-maize + green manure	5.96	5.85	5.91	7.96	7.80	7.88	130.22	90.27	2.26
ZT-maize + Residue*	5.97	6.06	6.01	8.14	8.0	8.07	133.34	93.90	2.38
ZT-maize + *Sesbania* brown manure	6.63	6.81	6.72	8.74	8.66	8.70	148.00	116.57	3.71
LSD (p=0.05)	0.69	0.72	0.70	0.64	0.63	0.64	10.8	10.8	
Weed management									
Un-weeded check	5.26	5.0	5.13	7.06	7.00	7.03	109.38	77.53	2.43
Pre +1 HW	5.69	5.75	5.72	7.98	7.70	7.84	133.88	97.73	2.70
Pre + post (*tembotrione)*	6.43	6.21	6.32	8.74	8.70	8.72	145.48	109.23	3.01
Pre+ post (premix *meso+atra*) §	6.32	6.02	6.17	7.88	7.90	7.89	132.61	97.02	2.73
Weed free check	7.05	6.71	6.88	9.16	8.60	8.83	154.67	112.32	2.65
LSD (p=0.05)	0.64	0.62	0.63	0.98	0.96	0.97	17.7	17.7	

Note: CT: conventional tillage; ZT: zero tillage; * wheat residue 3 t/ha; Pre: pre-emergence (atrazine + pendimethalin 750 g/ha); Post: post-emergence; HW: hand weeding at 25 DAS; Tembo: tembotrione 120g/ha; §: pre-mix dose of mesotrione + atrazine 120 g/ha other methods. This strategy significantly reduced weed dry matter accumulation and density, leading to higher grain and stover yields in maize, thereby enhancing overall productivity and net returns in the North-Western Indo-Gangetic plains of India.

REFERENCE

Dalley CD, Bernards ML and Kells JJ. 2006. Effect of weed removal timing and row spacing on soil moisture in corn (*Zea mays* L.). *Weed Technology* **20**: 399–409.

Das TK. 2008. *Weed science: Basics and applications*. Jain brothers.

Gul S and Khanday BA. 2015. Influence of fertility levels and weed management practices on yield and yield attributes of rainfed maize. *Scientific Research and Essays* **10**: 659–663

Madhavi M, Ramprakash T, Srinivas A and Yakadri M. 2014, February. Topramezone (33.6% SC) + Atrazine (50%) WP tank mix efficacy on maize. p. 23. In: Biennial Conference of Indian Society of Weed Science on "*Emerging Challenges in Weed Management*.

Maitra S and Zaman A. 2017. Brown manuring, an effective technique for yield sustainability and weed management of cereal crops: a review. *International Journal of Bioresource Science* **4**: 1–5.

Mitra B, Bhattacharya PM, Ghosh A, Patra K, Chowdhury AK and Gathala MK. 2018. Herbicide options for effective weed management in zero-till maize. *Indian Journal of Weed Science* **50**(2): 137–141,

Mulugeta D and Stoltenberg DE. 1997. Weed and seedbank management with integrated methods as influenced by tillage. *Weed Science* **45**: 706–15.

Oyeogbe AI, Das TK, Bhatia A and Singh SB. 2017. Adaptive nitrogen and integrated weed management in conservation agriculture: impacts on agronomic productivity, greenhouse gas emissions, and herbicide residues. *Environmental Monitoring and Assessment* **189**: 1–11.

Parihar CM, Jat SL, Singh AK, Majumdar K, Jat ML, Saharawat YS and Kuri BR. 2017. Bio-energy, water-use efficiency and economics of maize-wheat-mungbean system under precision-conservation agriculture in semi-arid agro-ecosystem. *Energy* **119**: 245–256.

Reddy DA and Tyagi SK. 2005. Integrated weed management in maize groundnut cropping system, *Agricultural Reviews* **26**: 235–248.

Sarkar S, Skalicky M, Hossain A, Brestic M, Saha S, Garai S and Brahmachari K. 2020. Management of crop residues for improving input use efficiency and agricultural sustainability. *Sustainability* **12**(23): 9808.

Swetha K, Madhavi M, Pratibha G and Ramprakash T. 2015. Weed management with new generation herbicides in maize. *Indian Journal of Weed Science* **47**(4): 432–433.

Turmel MS, Speratti A, Baudron F, Verhulst N and Govaerts B. 2015. Crop residue management and soil health: A systems analysis. *Agricultural Systems* **134**: 6–16.

Indian Journal of Weed Science (2024) **56**(3): 274–278
http://dx.doi.org/10.5958/0974-8164.2024.00045.3

RESEARCH ARTICLE

Studying effectiveness of post-emergence herbicides in chickpea

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Received: 16 April 2024 | Revised: 18 September 2024 | Accepted: 21 September 2024

ABSTRACT

Broad spectrum post-emergence herbicides are being popular among the chickpea growers. However, systematic study is required to assess the effectiveness of these in comparison with popular pre-emergence herbicides and hence a field study was conducted at Indira Gandhi Krishi Vishwavidyalaya, Raipur in Alfisols during winter (*Rabi*) season of 2020-21 and 2021-22 to study the effect of pre-emergence and combination of pre- and post-emergence herbicides in chickpea (*Cicer arietinum* L.) with mechanical/hand weeding. The experiment was designed in randomized block design with three replications. Major weeds were *Chenopodium album* and *Cichorium intybus*. *Echinochloa colona, Cynadon dactylon* with almost 50% dominance of *Medicago denticulata*. Among the chemical weed management treatments, the lowest count of the aforesaid individual and total weeds was registered under the treatment topramezone 25.28 g/ha as POST at 90 DAS. Topramezone 25.28 g/ha as PoE (18 DAS) reduced total weed density by 50% at 90 DAS when compared with weedy check and eventually had higher weed control efficiency in both the years (81.1 in 2020-21 and 83.8% in 2021-22) than the other treatments. Comparable lower weed count was also observed under the hand weeding at 30 DAS/Farmers practice. Although, slight phytotoxicity (3 to 5 out of 10 scale) in terms of yellowing, stunting and scorching was observed upto 14 days in topramezone 25.28 g/ha as PoE, propaquizafop+ imazethapyr 125 g/ha as POST and flauzifop-p-butyl + fomesafen 250 g/ha PoE, but these symptoms were entirely disappeared and chickpea has recovered and regained its growth later. Application of topramezone produced average 275% more seed yield over weedy check and 133% over pendimethalin 678 g/ha PE. It also generated the highest net return (Rs. 53290 and 54630/ha) and B:C ratio (3.35 and 3.33).

Keywords: Chemical control, Chickpea, Comparison of pre- and post-emergence, Herbicide, Phytotoxicity, topramezone, WCE, Weed biomass

INTRODUCTION

In Chhattisgarh, chickpea is one of the most important *Rabi* crops in soybean and rice-based cropping system occupies an area of 0.32 m ha predominantly in Chhattisgarh plains in medium to heavy soils using residual moisture mainly by broadcast method, which resulted in low plant population and difficult to apply mechanical means of weed control. The productivity of chickpea is quite low (1026 kg/ha) due to various constrains, among them weed infestation is one of the most important constraints. Chickpea is poor competitor to weeds due to slow growth rate and limited leaf development at early stage of crop growth and establishment. The initial 30- 60 days of the crop growth period are very important for crop weed competition in chickpea (Kumar and Singh, 2010) and hence, chickpea is highly susceptible to weed competition and weeds causes up to 75% yield loss (Chaudhary *et al.* 2005). The farmers adopt hand weeding, which is totally labour dependent and costly in the present scenario. The availability of labour at critical crop weed competition becomes problematic due to labour scarcity. Chickpea crop mainly infested with broadleaf weeds especially *Medicago denticulata*, *Chinopodium album*, *Cichorium intybus*, *Convolvulus arvensis*, *Parthenium hysterophorus* and *Melilotus alba* etc. which are difficult to control with available pre-emergence herbicides. Application of pre-emergence (PE) herbicides does not control the second flushes of many weeds. There is no alternative recommendation except using pendimethalin as pre-emergence in chickpea for the farmers which is not effective after 30 days (Kumar *et al.* 2015) and eventually, weed management is often the costliest agronomic input in chickpea. Although, they are using some early post-emergence herbicides like quizalofop-p-ethyl at 100 g/ha available in market inadvertently for narrow-leaf weeds, but dominated broad-leaf weed flora consist of *Medicago denticulata*, *Chinopodium album* caused huge crop yield loss if not controlled (Nath *et al.* 2018). Topramezone as post-emergence herbicide, specially recommended for weed management in maize could be effective in chickpea under the rice-based cropping system for higher WCE and achieving good

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crop yield (Nath *et al*. 2021). There is an urgent need to identify an effective early post-emergence and post-emergence herbicides for comprehensive control of weeds in chickpea and replace costly affair of HW. Hence, an experiment has been framed with the objectives to study the effect of pre- and post-emergence herbicidal weed management on weed flora in chickpea and their effectiveness in chickpea crop.

MATERIALS AND METHODS

Experiment was conducted during *Rabi* 2020-21 and 2021-22 on Alfisols under AICRP on Weed Management, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh in mid land ecosystem. Twelve treatments comprised of single as well as combination of pre and post-emergence herbicides i.e. pendimethalin 678 g/ha PE, pendimethalin + imazethapyr 1000 g/ha as PE, oxyfluorfen 140 g/ha as PE, topramezone 25.28 g/ha as PoE (18 DAS), pendimethalin 678 g/ha PE *fb* quizalofop 50 g/ha PoE, pendimethalin 678 g/ha PE *fb* propaquizofop 50 g/ha PoE, flauzifop-p-butyl + fomesafen 125 g/ha PoE, flauzifop-p-butyl + fomesafen 250 g/ha PoE, propaquizafop + imazethapyr 125 g/ha PoE on active ingredient basis, mechanical weeding at 20 *fb* 40 DAS, hand weeding at 30 DAS/farmers' practice and one weedy check were studied in randomized block design with three replications. All the post-emergence herbicides were applied at 20 days after sowing. The soil was clay loam with low organic carbon and available nitrogen (196 kg/ha) but medium (16.5 kg/ha) in phosphorus and high (328 kg/ha) in potassium with neutral soil reaction. Chickpea cultivar '*Indira Chana 1*' was taken as test crop. Sowing of chickpea crop was done on 13/11/2020 and 15/11/2021 using seed rate of 75 kg/ha and row spacing of 30 cm with the help of seed cum fertilizer drill. The recommended fertilizer dose of 20:50:30 kg/ha N:P:K was applied to chickpea as basal through urea, SSP and murate of potash, respectively. The crop did not suffer from any kind of incidence like drought, insect, disease etc. during its entire growth period. The observations, *viz*. weed flora, weed density, weed biomass and their effect on yield of chickpea and economic viability of different treatments were taken and analyzed as per the standard procedure. Visual scoring for phytotoxicity (like- yellowing, chlorosis, stunting, scorching and death) was recorded for applied post-emergence herbicides at 1, 3, 7, 14 and at 28 days after application on a 0-10 scale for crop. For chickpea, 0 meant no phytotoxicity and 10 meant complete death of the plant and scoring of <3 was considered acceptable. The crop was harvested on 08/03/2021 and 11/03/2022. All other agronomic practices were kept normal and uniform for all the treatments of the experiment. A quadrate of 0.5 x 0.5 m (0.25 m^2) was used for taking species wise data. Weed samples were sun dried for two days and then oven dried at 70°C for 72 hrs. Number and biomass of weeds were transformed through square root ($\sqrt{x+0.5}$) for statistical analysis. The herbicides were applied by using knapsack sprayer with 375 liters of spray volume per hectare.

RESULTS AND DISCUSSION

Weed density and weed biomass

The experimental field was dominated by the *Medicago denticulata* which accounts for 50% of the total weed population during entire crop growth. Other major weeds were *Chenopodium album* and *Cichorium intybus*. *Echinochloa colona* and *Cynadon dactylon*. All the weed management practices reduced the total weed density and weed biomass over the weedy check. Topramezone 25.28 g/ha as PoE (18 DAS) has performed best to reduce the total weed density and significantly the lowest total weed bio mass (4.38, 4.22 and 6.54 and 5.71 g/m^2) over rest of the chemical weed management treatments and registered 41.8 and 41.1% and 43.7 and 40.5% less weed biomass recorded as compared to the weedy check at 60 and 90 DAS during 2020-21 and 2021-22, respectively. Lowest weeds density and total weed dry weight were also registered with topramezone 25.7 g/ha PoE at 21 DAS by Gajanand *et al*. (2023) and topramezone 25.2 g/ha (PoE) *fb* mechanical weeding at 40 DAS by Sanketh *et al.* (2021). Single application of pendimethalin 678 g/ha as PE did not control weed density as compared to the pre-emergence *fb* post-emergence application of herbicides *e.g.* pendimethalin 678 g/ha PE *fb* quizalofop 50 g/ha PoE or pendimethalin 678 g/ha PE *fb* propaquizofop 50 g/ha PoE. Even combination of herbicides either as PE or PoE controlled weeds effectively to that of pendimethalin as PRE. Flauzifop-p-butyl + fomesafen 125 g/ha PoE or flauzifop-p-butyl + fomesafen 250 g/ha PoE both performed well to reduce the weed density at 60 and 90 DAS. Similar observations were made by Kashyap *et al.* (2022) at 30 DAS. While, propaquizafop + imazethapyr 125 g/ha PoE could not diminish the much density and weed biomass as compared to the others. On the otherhand, prolonged effect of hand weeding at 30 DAS was found to control total weeds (5.34 and 5.87/m^2) upto maturity stage over the others during both the years (**Table 3**).

Highest weed control efficiency, WCE (81.1 and 83.8%) was derived under weed management treatments of topramezone 25.28 g/ha as PoE (18 DAS) during 2020-21 and 2021-22 respectively at 90 DAS. It is a highly selective phenyl pyrazolyl ketone herbicide for controlling broad spectrum weeds that controls weeds by inhibiting carotenoid biosynthesis (HPPD inhibitor). Flauzifop-p-butyl + fomesafen 250 g/ha PoE also performed well next to the topramezone 25.28 g/ha over other chemicals tested for lowering the weed biomass and increasing WCE. Hand weeding at 30 DAS has also performed appreciably and achieved WCE of 78.2 and 81.7% at harvest during both the years, respectively. Sanketh *et al.* (2021) also reported noticeable WCE using topramezone 25.2 g/ha (PoE) *fb* mechanical weeding at 40 DAS. The lowest weed control efficiency was recorded in post-emergence application of propaquizafop + imazethapyr 125 g/ha (**Table 4**).

Phytotoxicity

Phytotoxicity observations were recorded at 1, 3, 7, 14 and 28 days after post-emergence herbicide application (DAHA). Chlorosis and necrosis-like symptoms were not observed on crop plants in herbicide application. All the four post-emergence herbicides applied had yellowing, stunting and scorching symptoms after 3 and 7 DAHA.

Table 1. Phyto-toxicity of different herbicide on chickpea plants during 2020-21and 2021-22

	Herbicidal phyto-toxicity effect on Chickpea (DAHA)																	
	Yellowing						Stunting						Scorching					
	0	1	3	7	14	28	0	1	3	7	14	28	0	1	3	7	14	28
Topramezone 25.28 g/ha as PoE (18 DAS)	0	0	5	2	0	0	0	0	5	2	0	0	0	0	5	2	0	0
Flauzifop-p-butyl + fomesafen 125 g/ha PoE	0	0	4	2	0	0	0	0	4	2	0	0	0	0	4	2	0	0
Flauzifop-p-butyl + fomesafen 250 g/ha PoE	0	0	5	4	1	0	0	0	5	4	1	0	0	0	5	4	1	0
ropaquizafop+ imazethapyr 125 g/ha PoE	0	0	3	2	1	0	0	0	3	2	1	0	0	0	3	2	1	0
Weedy check	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

DAHA= Days after herbicide application

Table 2. Weed density in chickpea as influenced by different pre- and post-emergence herbicides

Treatment	Weed density (no./m^2) at 60 DAS							
	Medicago denticulata		*Chinopodium Album*		*Cichorium intybus*		Other weeds	
	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
Pendimethalin 678 g/ha PE	3.67 (13.00)	3.39 (11.00)	2.55 (6.00)	2.35 (5.00)	3.08 (9.00)	2.92 (8.00)	3.54 (12.00)	3.39 (11.00)
Pendimethalin + imazethapyr 1000 g/ha as PE	3.39 (11.00)	3.24 (10.00)	2.92 (8.00)	2.55 (6.00)	2.55 (6.00)	2.35 (5.00)	3.67 (13.00)	3.24 (10.00)
Oxyfluorfen 140 g/ha as PE	3.08 (9.00)	2.92 (8.00)	2.35 (5.00)	2.12 (4.00)	2.74 (7.00)	2.35 (5.00)	3.08 (9.00)	2.92 (8.00)
Topramezone 25.28 g/ha as PoE (18-20 DAS)	2.12 (4.00)	2.12 (4.00)	2.12 (4.00)	1.87 (3.00)	2.74 (7.00)	2.55 (6.00)	2.12 (4.00)	1.87 (3.00)
Pendimethalin 678 g/ha PE *fb* quizalofop 50 g/ha PoE	3.24 (10.00)	3.24 (10.00)	3.08 (9.00)	2.74 (7.00)	3.08 (9.00)	3.08 (9.00)	2.12 (4.00)	1.58 (2.00)
Pendimethalin 678 g/ha PE *fb* propaquizofop 50 g/ha PoE	3.54 (12.00)	3.24 (10.00)	3.39 (11.00)	3.24 (10.00)	2.92 (8.00)	2.74 (7.00)	2.55 (6.00)	2.35 (5.00)
Flauzifop-p-butyl + fomesafen 125 g/ha PoE	3.08 (9.00)	2.74 (7.00)	2.92 (8.00)	2.74 (7.00)	2.74 (7.00)	2.55 (6.00)	2.35 (5.00)	2.35 (5.00)
Flauzifop-p-butyl + fomesafen 250 g/ha PoE	2.55 (6.00)	2.35 (5.00)	2.74 (7.00)	2.55 (6.00)	2.92 (8.00)	2.92 (8.00)	2.35 (5.00)	2.12 (4.00)
Propaquizafop + imazethapyr 125 g/ha PoE	4.85 (23.00)	4.53 (20.00)	3.24 (10.00)	3.08 (9.00)	2.35 (5.00)	2.12 (4.00)	3.54 (12.00)	3.24 (10.00)
Mechanical weeding at 20 *fb* 40 DAS	2.74 (7.00)	2.35 (5.00)	2.92 (8.00)	2.74 (7.00)	2.92 (8.00)	2.55 (6.00)	2.55 (6.00)	2.35 (5.00)
Hand weeding at 30 DAS/Farmers practice	1.87 (3.00)	2.35 (5.00)	1.58 (2.00)	1.87 (3.00)	1.87 (3.00)	1.87 (3.00)	2.12 (4.00)	2.35 (5.00)
Weedy check	6.44 (41.00)	6.20 (38.00)	3.81 (14.00)	3.67 (13.00)	3.54 (12.00)	3.24 (10.00)	3.39 (11.00)	3.08 (9.00)
LSD (p=0.05)	-	-	-	-	-	-	-	-

Original values are given in the parentheses

Topramezone acts as inhibiting 4- hydroxy-phenyl-pyruvate dioxygenase (HPPD) enzyme and preventing carotenoid biosynthesis, which lead to photo-oxidation of chlorophyll molecules (Wang *et al*. 2018). Spray of topramezone 25.28 g/ha at 18 DAS controlled weeds properly with some phytotoxic effects on the crop (rating 3-4), as well as weeds also emerged at later stage, due to slow early growth of crop. Topramezone application was safe for crop and also controlled all narrow and broad-leaf weeds and hence score of yellowing, stunting and scorching symptoms was higher at 3 days as compared to 7 DAHA. These symptoms were entirely disappeared and crop has recovered and regained its growth very well in topramezone 25.28 g/ha after 14 days of application. Study conducted at ICAR-DWR, Jabalpur showed that topramezone 20.6 g/ha at 25 DAS resulted in higher phytotoxicity on weeds (toxicity scale of 7-10) without any phytotoxicity on chickpea (Annual Report (Bilingual), 2018-19). Flauzifop-p-butyl + fomesafen 125 g/ha also showed regrowth of the crop at 14 DAHA. Slight effect of phytotoxicity was observed upto 14 DAHA in propaquizafop + imazethapyr 125 g/ha PoE and flauzifop-p-butyl + fomesafen 250 g/ha PoE due to higher dose (**Table 1**).

Yield attributing characters, seed yield and economics

Significantly the highest number of branches/ plant (21.3 and 21.6), pods/plant (37.6 and 37.8) and 100 seed weight (25.46 and 25.79 g) were observed under application of topramezone 25.28 g/ha as PoE (18-20 DAS) which was closely followed by hand weeding at 30 DAS, oxyfluorfen 140 g/ha as PE and mechanical weeding at 20 *fb* 40 DAS among all weed management options. Effectively managed weed density under these treatments brought more space to

Table 3. Weed density and weed biomass in chickpea as influenced by different pre- and post-emergence herbicides

Treatment	Total weed density		Total weed biomass at 60 DAS (g/m^2)		Total weed biomass (g/m^2) at 90 DAS	
	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
Pendimethalin 678 g/ha PE	6.36(40.0)	5.96(35.0)	7.46	7.33(53.24)	11.22(125.32)	9.96(98.78)
Pendimethalin + imazethapyr 1000 g/ha as PE	6.20(38.0)	5.61(31.0)	7.14(50.43)	6.99(48.38)	10.94(119.12)	9.61(91.85)
Oxyfluorfen 140 g/ha as PE	5.52(30.0)	5.05(25.0)	6.19(37.81)	6.04(35.96)	9.96(98.72)	8.48(71.34)
Topramezone 25.28 g/ha as PoE (18-20 DAS)	4.42(19.0)	4.06(16.0)	4.38(18.67)	4.22(17.32)	6.54(42.27)	5.71(32.05)
Pendimethalin 678 g/ha PE *fb* quizalofop 50 g/ha PoE	5.70(32.0)	5.34(28.0)	6.73(44.82)	6.57(42.64)	10.20(103.46)	8.99(80.36)
Pendimethalin 678 g/ha PE *fb* propaquizofop 50 g/ha PoE	6.12(37.0)	5.70(32.0)	6.92(47.36)	6.81(45.83)	10.55(110.84)	9.37(87.36)
Flauzifop-p-butyl + fomesafen 125 g/ha PoE	5.43(29.0)	5.05(25.0)	5.55(30.26)	5.41(28.76)	8.43(70.54)	7.66(58.25)
Flauzifop-p-butyl + fomesafen 250 g/ha PoE	5.15(26.0)	4.85(23.0)	5.14(25.91)	5.01(24.64)	7.83(60.86)	7.03(48.96)
Mechanical weeding at 20 *fb* 40 DAS	5.43(29.0)	4.85(23.0)	4.55(20.16)	4.36(18.53)	8.03(63.96)	7.17(50.84)
Hand weeding at 30 DAS/Farmers practice	3.54(12.0)	4.06(16.0)	3.56(12.18)	3.47(11.57)	7.01(48.68)	6.05(36.15)
Weedy check	8.86(78.0)	8.40(70.0)	10.48(109.3)	10.27(105.1)	14.96(223.4)	14.08(197.6)
LSD (p=0.05)	-	-	0.10	0.08	0.04	0.05

Original values are given in the parentheses

Table 4. No. of branches/plant, pods/plant, 100 seeds weight, WCE, seed yield and economics of chickpea as influenced by weed management practices

Treatment	No. of branches/plant (at harvest)		No. of pods/ Plant		100 seeds weight (g)		Seed yield (t/ha)		Net returns (Rs/ha)		B:C		WCE at 90 DAS	
	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
Pendimethalin 678 g/ha PE	18.4	18.5	33.0	33.2	22.46	22.52	1.12	1.15	36165	37250	2.75	2.74	43.9	50.0
Pendimethalin + imazethapyr 1000 g/ha as PE	18.5	18.6	33.2	33.5	23.18	23.36	1.13	1.23	36930	41330	2.78	2.93	46.7	53.5
Oxyfluorfen 140 g/ha as PE	20.2	20.4	36.2	36.3	24.96	25.28	1.29	1.34	45090	46940	3.18	3.19	55.8	63.9
Topramezone 25.28 g/ha as PoE (18-20 DAS)	21.3	21.6	37.6	37.8	25.46	25.79	1.49	1.53	53290	54630	3.35	3.33	81.1	83.8
Pendimethalin 678 g/ha PE *fb* quizalofop 50 g/ha PoE	18.9	19.1	34.7	34.9	23.83	23.99	1.18	1.22	37725	39320	2.70	2.72	53.7	59.3
Pendimethalin 678 g/ha PE *fb* propaquizofop 50 g/ha PoE	18.7	18.8	34.7	34.1	23.64	23.78	1.17	1.19	38055	38290	2.75	2.71	50.4	55.8
Flauzifop-p-butyl + fomesafen 125 g/ha PoE	19.4	19.7	35.1	35.2	24.54	24.83	1.24	1.28	42285	43880	2.04	3.05	68.4	70.5
Flauzifop-p-butyl + fomesafen 250 g/ha PoE	19.7	20	35.7	35.9	24.72	24.91	1.28	1.32	44050	45220	3.06	3.05	72.8	75.2
Propaquizafop + imazethapyr 125 g/ha PoE	18.1	18.3	32.8	33.1	22.28	22.46	1.11	1.13	35995	36230	2.74	2.69	38.1	43.7
Mechanical weeding at 20 *fb* 40 DAS	20.6	20.8	36.8	36.9	25.14	25.39	1.31	1.40	45610	49500	3.15	3.26	71.4	74.3
Hand weeding at 30 DAS/Farmers practice	21.0	21.3	37.5	37.7	25.28	25.57	1.39	1.43	44860	46030	2.71	2.71	78.2	81.7
Weedy check	14.5	14.6	20.5	20.8	21.65	21.86	0.53	0.56	8830	9660	1.49	1.51	-	-
LSD (p=0.05)	1.2	0.6	1.4	0.19	0.63	0.7	0.30	0.11	-	-	-	-		

the crop and reduced the competition for solar energy, moisture and nutrients eventually increased the number of branches and pods/plants which converted into higher seed yield.

Considerably higher seed yield (1.49 and 1.53 t/ha) was recorded in the topramezone 25.28 g/ha as PoE (18 DAS) produced average 275% more seed yield than the weedy check and 133% over pendimethalin 678 g/ha PE on mean basis and was found to be significantly superior over all the other chemical weed control treatments during 2021-22 and except oxyfluorfen 140 g/ha as PE (1.29 and 1.34 t/ha), flauzifop-p-butyl + fomesafen 250 g/ha PoE (1.28 and 1.32 t/ha) and flauzifop-p-butyl + fomesafen 125 g/ha PoE (1.28 t/ha) during 2020-21. Gajanand *et al.* (2023) also reported topramezone 25.7 g/ha (21 DAS) yielded the 82% higher seed yield of chickpea over weedy check. Mechanical weeding at 20 *fb* 40 DAS (1.31 and 1.40 t/ha) and hand weeding at 30 DAS/Farmers practice (1.39 and 1.43 t/ha) also produced comparable seed yield (**Table 4**). Higher seed yield under weed management treatments might be due to lesser infestation of weeds due to effective control of weeds during critical crop weed competition period that encourage adequate nutrient supply to the crop and proper translocation of photosynthesis from source to sink. Maximum reduction in seed yield was recorded in PE application of pendimethalin 678 g/ha and propaquizafop + imazethapyr 125 g/ha PoE. These results are in agreement with Dubey *et al.* (2018).

Topramezone 25.28 g/ha as PoE (18 DAS) also generated the highest net return (₹ 53,290 and 54630/ha) and B:C ratio (3.35 and 3.33). Pre-emergence application of oxyfluorfen 140 g/ha and mechanical weeding at 20 *fb* 40 DAS were the other two weed management option which were found comparable and performed well (**Table 4**). Grain yield under weedy check was reduced by 256 and 245% as compared to the hand weeding and mechanical weeding, respectively. Topramezone 25.28 g/ha as PoE (18-20 DAS) also generated the highest net return (₹ 53,290 and 54630/ha) and B:C ratio (3.35 and 3.33). Pre-emergence of oxyfluorfen 140 g/ha and mechanical weeding at 20 *fb* 40 DAS were the other two weed management option which found comparable and performed well to generate returns.

Post-emergence herbicides particularly topramezone (25.28 g/ha) and flauzifop-p-butyl + fomesafen (either 125 or 250 g/ha) could be better option for controlling weeds than hand weeding to achieve higher yield and net returns without any perceptible phytotoxic effects. Using oxyfluorfen 140 g/ha as pre-emergence also found to be better choice than pendimethalin 678 g/ha as PE or pendimethalin + imazethapyr 1000 g/ha as PE to harvest more seed yield.

REFERENCES

Annual Report (Bilingual). 2018-19. ICAR-Directorate of Weed Research, Jabalpur, 178 p.

Chaudhary BM, Patel JJ and Delvadia DR. 2005. Effect of weed management practices and seed rates on weeds and yield of chickpea. *Indian Journal of Weed Sciences* **37**(3&4): 271–272.

Dubey SK, Sharma JD, Choudhary SK, Vinod Kumar, and Suman S. 2018 Weed management in chickpea under irrigated conditions. *Indian Journal of Weed Science* **50** (1): 85–87.

Gajanand, Kumar, S, Kumar M, Birla D, Choudhary S and Singh D 2023. Evaluation of dose and application time of topramezone for weed management in chickpea. *Indian Journal of Weed Science* **55**(3): 324–327.

Kumar N and Singh KK. 2010. Weed management in pulses. *Indian Farming* **60**(4): 9–12.

Kumar N, Hazra KK, Yadav SL and Singh SS. 2015. Weed dynamics and productivity of chickpea (*Cicer arietinum*) under pre- and post-emergence application of herbicides. *Indian Journal of Agronomy* **60**(4): 570–575.

Kashyap AK, Kushwaha HS and Mishra, H 2022. Effect of herbicides on weeds, yield and economics of chickpea. *Indian Journal of Weed Science* **54** (2): 182–186.

Nath CP, Dubey RP, Sharma AR, Hazra KK, Kumar N and Singh SS. 2018. Evaluation of new generation postemergence herbicides in chickpea (*Cicer arietinum* L.). *National Academy Science Letters* **41**(1): 1–5.

Nath CP, Kumar N, Hazra KK, Praharaj CS, Singh SS, Dubey RP, Sharma AR. 2021. Topramezone: A selective post–emergence herbicide in chickpea for higher weed control efficiency and crop productivity. *Crop Protection* **150**: 105814.

Sanketh GD, Bhanu Rekha K, Ram Prakash T. and Sudhakar KS. 2021. Bio-efficacy of ready and tank mixed herbicides in chickpea. *Indian Journal of Weed Science* **53** (3): 307–309.

Sethi IB, Singh H, Kumar S, Jajoria M, Jat LK, Braod MK, Muralia S and Mali HR. 2021. Effect of post-emergence herbicides in chickpea. *Indian Journal of Weed Science* **53** (1): 49-53.

Wang H, Lui W, Zhao K, Yu H, Zhang J and Wang J. 2018. Evaluation of weed control efficacy and crop safety of the new HPPD - inhibiting herbicide. *Scientific Reports* **8**: 7910.

Indian Journal of Weed Science (2024) **56**(3): 279–282
http://dx.doi.org/10.5958/0974-8164.2024.00046.X

RESEARCH ARTICLE

Response of crop establishment and weed management practices on weed dynamics and yields of lentil under Indo-Gangetic Plains of Bihar

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Received: 25 May 2024 | Revised: 5 September 2024 | Accepted: 8 September 2024

ABSTRACT

A field experiment was conducted during two consecutive winter (*Rabi*) seasons of 2020 and 2021 at Chutiya village, Banka, Bihar (24^{0}30’N latitude and 86^{0}30’E latitude), India to evaluate the effect of crop establishment and weed management practices [(pendimethalin 1000 g/ha pre-emergence, pendimethalin 1000 g/ha pre-emergence *fb* 1 hand weeding at 30 days after sowing (DAS), two hands weeding at 30 and 60 DAS and weedy check)] on weed dynamics and crop productivity of lentil. Our results revealed that altogether 11 dominant weed species, *viz. Cynodon dactylon, Digitaria sanguinalis, Panicum repens, Dactyloctenium aegyptium, Cyperus rotundus, Medicago denticulata, Gnaphalium purpureum, Rumex dentatus, Lethyrus aphaca, Solanum nigrum* and *Xanthium strumarium* infested lentil. The minimum weed density and biomass were noted under the treatment of two hands weeding 20 and 40 DAS, which was significantly higher compared to rest of weed management treatments. The crop yield attributes (pods/plant and dry matter/plant) were recorded with crop planted with Happy seeder and significantly superior over ZT production system. Thus, was conclude that application of pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 30 DAS resulted in significantly higher pods/ plant, dry matter/plant and seed yield and considered as the best treatment to manage all weeds effectively leading to higher weed control efficiency as well herbicidal efficiency index.

Keywords: Crop establishment, Happy seeder, Pendimethalin, Weed management, Lentil

INTRODUCTION

Legume crops are essential as they fix nitrogen in the soil biologically, which not only produces food and feed but also preserves the soil environment. Lentil (*Lens culinaris Medic*. L.) is one of the most ancient and valuable crops used for human nourishment. It is mostly eaten as a split, decorticated dry grain. India accounts 41 and 50% of global production and acreage, respectively. With a yield of 660 kg/ha, India produces ~1.0 MT of lentil from 1.4 million hectares of land with productivity of 660 kg/ ha. Weeds in lentil have been reported to offer a serious competition and cause yield reduction to the extent of 70% (Kumar *et al*. 2022). Zero tillage has been found effective in reducing cost of cultivation (Bohra and Kumar 2015, Samal *et al.* 2017) without sacrificing crop yield as compared to conventional tillage in some of crops (Malik *et al.* 2000) and happy seeder machine helps in sowing of lentil into paddy stubbles while retaining crop residue as surface mulch (Mishra *et al*. 2022). It has many benefits such as 60-70% less weed growth, water saving (particularly pre-sowing irrigation), improved the soil health (through improvements in nutrient supply capacity and soil structure) and environment quality improvement (Mishra *et al.* 2019). This ultimately causes crop’s yield to rise. Crop plants compete with weeds for nutrients, moisture, light, and space. Impact of weeds on lentil varied as a function of climate, weed density and length of competition period (Dixit and Varshney 2009). Weed emergence in lentil begins almost with crop emergence leading to crop-weed competition from initial stages (Kumar *et al*. 2020 a,b). Lentil is affected by weeds severely because of its slow-growing nature. The labours for hand weeding can be available during busy sowing season. As a result, use of herbicide to reduce the weed growth, especially in early stages can be investigated for evaluation of crop establishment and weed management practices on weed dynamics and yields of lentil. This was taken into consideration when planning the current investigation.

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MATERIALS AND METHODS

A field experiment was carried out during winter (*Rabi*) seasons of 2020 and 2021 at farmer's field in Banka District of Bihar ($24^0$30'N latitude and $86^0$30'E latitude, at an altitude of 79 m from mean sea level) as a cluster frontline demonstration of pulses to assess the impact of various establishment methods and weed management treatments on weed density, their biomass, and lentil production. Experimental site having sandy-clay loam soil at farmer's field had a neutral pH of 7.21, medium in terms of available P (19.1 kg/ha) and K (216.6 kg/ha), low in organic C (0.46%) and available N (191.1 kg/ha). There were four establishing methods, (Happy seeder machine, zero tillage technology, seed-cum-ferti-drill, broadcasting methods) in main plot of field experiment, and four weed management treatments, (pendimethalin 1000 g/ha pre-emergence, pendimethalin 1000 g/ha pre-emergence *fb* 1 hand weeding at 30 DAS, two hands weeding at 20 and 40 DAS and weedy check) in sub-plot. Lentil crop (*HUL-57*) was sown by happy seeder machine in the presence of rice residue, which was harvested by combine harvester. Zero tillage sowing of lentil was done without land preparation. In seed-cum-ferti-drill (tractor-drawn cultivator) two ploughings were used to open the soil for sowing and then planking and in broadcasting techniques, sowing was done by broadcasting. Lentil crop was seeded 30 x 10 cm apart. A uniform fertilizer dose of 20 and 40 kg N and P/ha, respectively in the form of di-ammonium phosphate was applied to each experimental unit. At the time of seeding, full doses of nitrogen and phosphorus were administered. Using a knap-sack sprayer equipped with a flat-fan nozzle and 300 L/ha of water, pre-emergence herbicide was administered treatment-wise two days after sowing (DAS). Samples of weeds and crops were taken from every plot so that different weed and crop characteristics could be investigated. In each plot, a quadrat (0.5 x 0.5 m) was positioned at random in two locations to gather weed samples. Prior to the statistical analysis, density and biomass of all weeds were transformed using square root $(\sqrt{x+1})$ to ensure homogeneity of variances. At 30, 60, and 90 DAS, measurements of density and biomass of all weeds were made. seed yield (t/ha) was noted at harvest. Weed control efficiency (WCE), weed index (WI) and herbicide efficiency index (HEI) were calculated using the following equations:

$$\text{WCE}= \frac{\text{Dry wt. of weeds in control plot–Dry wt. of weeds in treatment plot}}{\text{Dry wt. of weeds in control plot}} \times 100$$

$$\text{WI}= \frac{\text{Yield from two hands weeding plot–Yield from treatment plot}}{\text{Yield from weed free plot}} \times 100$$

$$\text{HEI}= \frac{\dfrac{\text{Yield from treatment plot–Yield from control plot} \times 100}{\text{Yield from control plot}}}{\dfrac{\text{Dry matter of weeds in treatment} \times 100}{\text{Dry matter of weeds in control}}}$$

RESULTS AND DISCUSSION

Effect on weeds

Dominant weed flora in experimental site was in the order of broad-leaved weeds>grasses>sedges at all stages of observation. The lowest density and biomass of different categories of weed was recorded in two hands weeding at 20 and 40 DAS whereas the highest in weedy check irrespective of time of observation **(Table 1)**. Predominant weeds were *Cynodon dactylon* (6.21/m^2), *Dactyloctenium aegyptium* (5.61/m^2), *Digitaria sanguinalis* (5.13/m^2) and *Panicum repens* (4.24/m^2) among the grasses. *Cyperus rotundus* (6.19/m^2) was the dominant sedge. *Medicago denticulata* (13.55/m^2), *Gnaphalium purpureum* (11.13/m^2), *Lethyrus aphaca* (9.26/m^2), *Rumex dentatus* (7.56/m^2), *Solanum nigrum* (6.67/m^2) and *Xanthium strumarium* (5.67/m^2) were the major broad-leaved weeds.

The minimum weed density (/m^2) were recorded with happy seeder sowing and which was recorded significantly superior over ZT, seed-cum-ferti-drill and broad casting methods at 30, 60, 90 DAS during both years of experimentation. Weed biomass (g/m^2) were recorded minimum with happy seeder sowing and which was recorded statistically at par with zero tillage technology significantly superior over seed-cum-ferti drill and broad casting methods at 30, 60, 90 DAS. Among all the weed management techniques, the highest weed density and biomass have been observed under weedy check. Among the chemical treatments, pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 30 DAS was found to be the most effective with significantly lower weed density and biomass at 30, 60 and 90 DAS than pendimethalin (1000 g/ha) 2 DAS and weedy check (**Table 1**). The fact that chemical and physical approaches work together better to reduce dry matter and weed populations may be the reason for this combination superior effectiveness (Sahu *et al.* 2019). Raman and Krishnamurthy (2005) have also reported that pre-emergence application of pendimethalin at 0.75 kg/ha + 1 HW at 30 DAS as most efficient method of controlling weeds.

Weed control efficiency

The weed control efficiency was recorded more with happy seeder sowing followed by ZT, seed-cum-ferti-drill and broad casting methods at 30, 60, 90 DAS during both years of experimentation.

Application of pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 30 DAS was recorded more weed control efficiency at 20 and 40 DAS (**Table 1**). During both years, pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 30 DAS and two hands weeding at 20 and 40 DAS produced the ultimate weed control efficiency. Combination of chemical and mechanical weed control methods, led to broad-spectrum weed control as reported by Sahu *et al.* (2015).

Effect on crop

The yield parameters like plant height, dry matter/plant, pods/plant and seed yield were significantly higher in two hands weeding 20 and 40 DAS, whereas the lowest values were observed in weedy check **(Table 2)**. However, differences in 1000-grain weight was non-significant in rice-establishment treatment-while in weed control methods hand weeding recorded more 1000–grain weight and at par with pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 30 DAS and pendimethalin (1000 g/ha) 2 DAS. The maximum plant height, pods/plant and dry matter/plant were recorded with happy seeder sowing and which was recorded significantly superior over ZT, seed-cum-ferti-drill and broad casting methods. It owed that the better development of root leading to photosynthesis with the presence of continuous supply of soil moisture which was conserved by rice stubble present in field to lentil plant and ultimately produced maximum number of productive branches. Pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 30 DAS was recorded higher, pods/plant, dry matter/plant, seed and stover yield and statistically at par with pendimethalin (1000 g/ha) 2 DAS excluding two hand weeding at 20 and 40 DAS during both years of experimentation. This finding was similar with Chhodavadia *et al.* (2013).

Effect on efficiency indices

However, differences in harvest index were non-significant due to establishment treatment and weed management practices **(Table 2)**. Weed control efficiency (WCE) based on weed biomass was observed more with happy seeder compared to zero tillage, seed-cum-ferti-drill and broadcasting methods in case of crop establishment methods. The WCE was recorded higher in pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 30 DAS during both years of experimentation **(Table 1)**. In happy seeder, application of crop establishment methods, herbicidal efficiency index (HEI), which is the ratio of percent increase in grain yield to percent weight of dry matter

Table 1. Effect of crop establishment and weed management practices on weed density and weed biomass of lentil (mean data of 2 years)

Treatment	Weed density (no./m^2)			Weed biomass (g/m^2)			Weed control efficiency (%)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Crop establishment method									
Happy Seeder	1.71 (3.92)	2.43 (6.90)	1.20 (2.44)	3.20 (11.24)	6.63 (44.95)	8.84 (79.14)	80.41	83.06	83.47
Zero tillage	2.41 (5.80)	3.79 (15.36)	1.38 (2.90)	3.62 (14.10)	7.44 (56.35)	10.05 (102.00)	75.43	78.76	78.69
Seed-cum-ferti drill	2.67 (8.12)	4.22 (18.80)	1.51 (3.28)	4.02 (17.16)	8.45 (72.40)	11.23 (127.11)	70.10	72.71	73.45
Broadcasting method	2.96 (9.76)	4.71 (23.18)	1.67 (3.78)	4.49 (21.16)	9.41 (89.54)	12.58 (159.25)	63.13	66.25	66.74
LSD (p=0.05)	0.25	0.49	0.09	0.47	1.00	1.35	-	-	-
Weed management practice									
Pendimethalin PE	2.40 (6.76)	3.81 (15.51)	1.29 (2.66)	3.86 (15.89)	8.26 (69.22)	11.22 (126.80)	72.31	73.91	73.51
Pendimethalin PE *fb* 1 HW at 30 DAS	1.79 (4.20)	2.92 (9.52)	0.99 (1.98)	2.96 (9.76)	6.41 (42.08)	8.62 (69.22)	82.99	84.14	85.54
Two HW at 20 and 40 DAS	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	100	100	100
Weedy check	4.56 (21.79)	7.42 (56.05)	2.47 (7.10)	7.51 (57.40)	16.26 (265.38)	21.86 (478.85)	0	0	0
LSD (p=0.05)	0.21	0.32	0.08	0.32	0.69	0.94	-	-	-

*Data subjected to square root ($\sqrt{x+1}$) transformation and figures in parentheses are original value, PE = pre-emergence application, HW = hand weeding, *fb* = followed by PE: pre-emergence; HW: Hand weeding, LSD, least significant difference at the 5% level of significance

Table 2. Effect of crop establishment and weed management practices on yield attributes, yields, harvest index, weed index, weed control efficiency and herbicidal efficiency index of lentil (mean data of 2 years)

Treatment	Yield attributes			Yield						Harvest index (%)	Weed index	Herbicidal efficiency index
	Pods/ plant	Dry matter/ plant (g)	1000-grain weight	Seed (t/ha) 2020	Seed (t/ha) 2021	Seed (t/ha) pooled	Straw (t/ha) 2020	Straw (t/ha) 2021	Straw (t/ha) pooled			
Crop establishment methods												
Happy Seeder	61.04	9.62	29.81	1.14	1.18	1.16	2.68	2.80	2.74	29.79	40.06	4.12
Zero tillage	56.14	9.31	29.90	1.02	1.04	1.03	2.41	2.58	2.50	28.40	32.85	2.31
Seed-cum-ferti drill	54.29	8.85	30.77	0.97	0.99	0.98	2.27	2.37	2.32	28.85	29.38	1.58
Broadcasting method	50.83	8.47	30.38	0.89	0.89	0.89	2.10	2.12	2.11	28.12	22.46	0.87
LSD (p=0.05)	4.21	0.68	NS	0.07	0.07	0.07	0.234	0.236	0.235	NS	-	-
Weed management practices												
Pendimethalin PE	53.85	8.86	29.76	0.98	1.02	1.00	2.31	2.45	2.38	29.06	30.50	1.70
Pendimethalin PE *fb* 1HW at 30 DAS	56.29	9.20	30.80	1.10	1.16	1.13	2.60	2.72	2.66	29.15	38.31	4.41
Two HW at 20 and 40 DAS	61.03	10.17	31.64	1.23	1.27	1.25	2.95	3.01	2.98	29.71	44.50	infinite
Weedy check	51.14	8.03	28.66	0.69	0.69	0.69	1.65	1.67	1.66	28.07	0.00	0.00
LSD (p=0.05)	3.42	0.63	2.17	0.07	0.07	0.07	0.16	0.16	0.16	NS	-	-

PE = pre-emergence application, HW = hand weeding, *fb* = followed by PE: pre emergence; HW: Hand weeding, LSD, least significant difference at the 5% level of significance

in the treatment, was recorded at its highest level. Pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 30 DAS was the best treatment to control all weeds effectively leading to higher grain yield, which due to increased WCE and HEI.

From the above findings, it may be concluded that planting of lentil by happy seeder produced noticeably greater crop yields with net returns and B: C ratio along with application of pendimethalin (1000 g/ha) 2 DAS *fb* 1 hand weeding at 30 DAS.

REFERENCES

Bohra JS and Kumar R. 2015. Effect of crop establishment methods on productivity, profitability, and energetics of rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) system. *Indian Journal of Agricultural Sciences* **85**(2): 217–223.

Chhodavadia SK, Mathukiya RK and Dobariya VK. 2013. Pre- and post-emergence herbicides for integrated weed management in summer green gram. *Indian Journal of Weed Science* **45**(2): 137–139.

Dixit A and Varshney JG. 2009. *Herbicide Use in Field Crops.* Directorate of Weed Science Research, Jabalpur.

Kumar R, Kumawat N, Mishra JS, Ghosh D, Ghosh S, Choudhary AK and Kumar U. 2022. Weed dynamics and crops productivity as influenced by diverse cropping systems in eastern India. *Indian Journal of Weed Science* **54**(1): 18–24.

Kumar R, Mishra JS, Kumar S, Choudhary AK, Singh AK, Hans H, Srivastava AK and Singh S. 2023. Weed competitive ability and productivity of transplanted rice cultivars as influenced by weed management practices. *Indian Journal of Weed Science* **55**(1): 13–17.

Kumar R, Mishra JS, Kumar S, Rao KK, Hans H, Bhatt BP, Srivastava AK and Singh S. 2020a. Evaluation of weed competitiveness of direct-seeded rice (*Oryza sativa*) genotypes under different weed management practices. *Indian Journal of Agricultural Sciences* **90**(5): 914–918.

Kumar R, Mishra JS, Rao KK, Mondal S, Hazra KK, Choudhary JS, Hans H and Bhatt BP. 2020b. Crop rotation and tillage management options for sustainable intensification of rice-fallow agro-ecosystem in eastern India. *Scientific Reports*10:11146. https://doi.org/10.1038/s41598-020-67973-9

Malik RS, Yadav A and Malik RK. 2000. Efficacy of trifluralin, linuron and acetachlor against weeds in mungbean (*Vignaradiata*L.). *Indian Journal of Weed Science* **32**:181–185.

Mishra JS, Kumar R, Kumar R, Rao KK and Bhatt BP. 2019. Weed density and species composition in rice-based cropping systems as affected by tillage and crop rotation. *Indian Journal of Weed Science* **51**(2): 116–122.

Mishra JS, Kumar R, Mondal S, Poonia SP, Rao KK, Dubey R, Raman RK, Dwivedi SK, Kumar R, Saurabh K, Monobrullah M, Kumar S, Bhatt BP, Malik RK, Kumar V, McDonald A and Bhaskar S. 2022. Tillage and crop establishment effects on weeds and productivity of a rice-wheat-mungbean rotation. *Field Crops Research* **284**: 108577.https://doi.org/10. 1016/j.fcr.2022.108577

Raman R and Krishnamoorthy R. 2005. Nodulation and yield of mung bean (*Vigna radiata* L.) influenced by integrated weed management practices. *Legume Research* **28(**2): 28–30.

Sahu R, Sharda K and Mandal SK. 2019. Sowing date and weed management effects on weeds, nutrient uptake and productivity of summer green gram. *Indian Journal of Weed Science* **51**(3): 302–305.

Sahu R, Singh MK and Singh M. 2015. Weed management in rice as influenced by nitrogen application and herbicide use. *Indian Journal of Weed Science* **47**(1): 1–5.

Samal SK, Rao KK, Poonia SP, Kumar R, Mishra JS, Prakash V, Mondal S, Dwivedi SK, Bhatt BP, Naik SK, Choubey AK, Kumar V, Malik RK and McDonald A. 2017. Evaluation of long-term conservation agriculture and crop intensification in rice–wheat rotation of Indo–Gangetic Plains of South Asia: Carbon dynamics and productivity. *European Journal of Agronomy* **90**: 198–208. https://doi.org/10.1016/j.eja.2017.08.006.

Indian Journal of Weed Science (2024) **56**(3): 283–289
http://dx.doi.org/10.5958/0974-8164.2024.00047.6

RESEARCH ARTICLE

Chemical weed management in soybean with early post-emergence herbicides

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Received: 28 February 2024 | Revised: 27 July 2024 | Accepted: 7 August 2024

ABSTRACT

In soybean, weed control has proven to be particularly difficult during rainy (*Kharif*) season because of erratic precipitation, unusable soil on rainy days, and a shortage of labour. Under such conditions, using superior broad-spectrum herbicides is the only other viable way to suppress weeds. Thus, field experiments were conducted to study the effects of ready-mix early post emergence herbicides on soybean crop at research farm of Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal during the *Kharif* season of 2020 and 2021. Seven treatments consisted of three doses of early post-emergence ready-mix herbicide fluazifop-p-butyl 11.1% + fomesafen 11.1% SL at 250, 312.5 and 500 g/ha, other post emergence herbicide such as quizalofop-ethyl 5% EC (50 g/ha) and imazethapyr 10% SL (100 g/ha), and hand weeding at 20 and 40 DAS and weedy check control were laid out in randomized complete block design with three replications. Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL (312.5 g/ha) found effectively to control all types of weed and dry weight and increased seed (2.41 t/ha) and stover (2.73 t/ha) yield significantly by improving growth and yield attributing characters which were at par with the twice hand weeding. The highest dose of fluazifop-p-butyl 11.1% + fomesafen 11.1% SL (500 g/ha) were found to be superior against weed flora but caused phytotoxicity on crop and reduced seed (1.58 t/ha) and stover yield (2.15 t/ha).

Keywords: Early post-emergence herbicides, Fluazifop-p-butyl + fomesafen, Hand weeding, Seed yield, Soybean

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is the important source of cheapest and richest vegetable protein and oil. About 18–20% oil and 40% protein are found in it (Ghosh and Pramanik 2020). Thus, compared to other oilseed and pulse crops grown during the *Kharif* season, soybean has emerged as a viable protein as well as oilseed crop across the world with greater adaptability and high production potential (Dhakad *et al.* 2022). During 2022-23, India recorded 13.98 mt soybean production from an area of 12.07 m ha with a productivity of 1158 kg/ha (IISR 2024) despite of its potential yield of 2500 kg/ha, as a result of severe weed competition (Sangeetha *et al.* 2013). As a rainy season crop, soybean is severely infested with grasses, *viz. Echinochloa colona*, *Echinochloa crusgalii*, *Cyperus* spp., *Cynodon dactylon* and broad leaf weeds like *Phyllanthus niruri*, *Euphorbia* spp., *Commelina benghalensis*, *Eclipta alba*, *Corchorus acutangulus etc.* (Sharma and Shrivastava 2002, Patidar *et al.* 2019). Further, due to the wide spacing which is necessary for the development of branches and the complete expansion of the canopy during the late growth stage, soybeans are susceptible to interference by weeds (Wax and Pendleton 1968, Yelverton and Coble 1991, Hock *et al.* 2006). Compared to other crops, soybeans have a late canopy closure that makes it easier for weeds to grow (Carey and Defelice 1991, Nelson and Renner 1998, Harder *et al.* 2007) which directly impact production during the *Kharif* season (Ghosh and Pramanik 2020).

Despite being very efficient, the conventional hand weeding approach is time-consuming, expensive, labour-intensive, and often impossible owing to a lack of manpower (Ghosh and Pramanik 2020, Dhakad *et al.* 2022, Patidar *et al.* 2023). Because of erratic rainfall, unusable soil on rainy seasons, and a shortage of labour in a timely manner, weed control in soybean has proven to be particularly difficult, especially during the *Kharif* season (Dhakad *et al.* 2022). Under such conditions, using superior broad-spectrum herbicides is the only alternate and viable way to suppress weeds. Although, farmers mainly use pendimethalin as a pre-emergence herbicide in soybean fields (Virk *et al.* 2018), but there is a limited window for using pre-emergence herbicides. Hence, in order to effectively manage weeds on soybean field, it is essential to use of post-emergence herbicides be investigated.

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With its distinct selectivity and herbicidal action over broad-leaved weeds in soybeans, fomesafen is found to be a novel herbicide belonging to the diphenyl ether group that is used as an early post-emergence herbicide (Patidar *et al.* 2023) and also in beans (Soltani *et al.* 2017). A study conducted on soybeans by Singh *et al.* (2014) found that a pre-mix of fomesafen + fluazifop-p-butyl at 250+250 g/ha efficiently reduced both grasses and non-grassy weeds, resulting in less weeds compared to the untreated check. However, there is a dearth of research on their effectiveness in the soil of West Bengal's New Alluvial Zone under soybean cultivation. In order to better understand the effectiveness of ready-mix herbicides fluazifop-p-butyl 11.1% + fomesafen 11.1% SL in controlling weeds and enhancing soybean production, an experiment was conducted in West Bengal conditions.

MATERIALS AND METHODS

Field experiments were carried out to investigate the impact of ready-mix early post-emergence herbicides on soybean crop at Kalyani C-Unit Farm, Kalyani, Nadia under Bidhan Chandra Krishi Viswavidyalaya (BCKV), Mohanpur, Nadia, West Bengal during the *Kharif* season of 2020 and 2021. The farm is located 9.75 meters above mean sea level (MSL) in West Bengal's New Alluvial Zone (NAZ), which is located at latitude 22°98'N and longitude 88°42'E. The soil in this area was created by the recently formed Ganges River alluvium and is mostly rich, deep, and nearly neutral in response (7.34 pH) having 0.57% OC, medium N and P content with low K.

The present investigation was conducted in randomised block design with three replications. Seven treatments consist of different three levels of ready-mix fluazifop-p-butyl 11.1% + fomesafen 11.1% SL herbicide application at 250, 312.5 and 500 g/ha doses, quizalofop-ethyl 5% EC at 50 g/ha, imazethapyr 10% SL at 100 g/ha, two hand weeding at 20 and 40 DAS and weedy check control. Using a knapsack sprayer with a flat fan nozzle and a 500 L/ha spray volume, the formulated herbicide solution was uniformly sprayed on weeds at the 2-4 leaf stage (20 days after crop sowing). A simultaneous application of water was made to the weedy check and hand-weeded plots. In the hand weeding plots, weeds were physically pulled from each plot twice, at 20 and 40 DAS. Soybean seeds (var. *'Prabhakar'*) were planted with a spacing of 30cm ×10cm during second fortnight of June during both the years. The experimental plots were adhered to the recommended package of operations in all cases with the exception of weed control methods. 20 kg N, 60 kg P and 60 kg K/ha were applied basal at the time of sowing.

After applying herbicide, the population of dominating weeds species per square meter was observed individually at 45, 60 and 75 days after crop planting. The dry weight of the weeds (dried in an oven at 70°C) were computed. A 50 cm × 50 cm quadrate was positioned at four random locations per plot to record the population size as well as the dry weight of the weed flora. The results were presented on per square meter basis to assess the relative effectiveness of the test products. Statistical analysis was performed on the data related to weed count and dry weight where appropriate. Additionally, weed control efficiency was computed using the dry weight of the weeds. The following formula was used to calculate the weed index (WI) and weed control efficiency (WCE) (Lal *et al.* 2017, Singh *et al.* 2017):

$$WCE = \frac{DWC - DWT}{DWC} \times 100$$

Where, WCE: Weed control efficiency, DWC: Dry weight (g) of weeds in weedy check plots and DWT: Dry weight (g) of weeds in the treated plots.

$$WI = \frac{X - Y}{X} \times 100$$

Where, WI: Weed index, X: Seed yield of hand weeded plot and Y: Seed yield of the treated plot for which weed index is to be worked out.

From each replication of the treatment, five plants were chosen randomly and tagged. Replication-wise plant height (cm) at 75 DAS, number of branches/plant, number of pods/plant, number of seeds/pod, 100 seed weight (g) and also the seed and haulm yields (t/ha) were recorded for each treatment at harvest.

Also, the soil samples from the individual experimental plots were collected from rhizosphere at a depth of 0-15 cm at different intervals, *viz.* pre-treatment, 15, 30 and 45 DAA and then requisite samples of each treatment were taken for soil microbial count such as total bacteria, total fungi and total actinomycetes. Specific media for plating, *viz.* Tronton's agar medium, Martin Rose Bengal Streptomycin in agar medium and Jensen's agar medium was also prepared for total bacteria, total fungi and total actinomycetes count, respectively. Then the plates were incubated at 28 ± 1 °C in BOD incubator and observations in terms of counting the total number of colonies per plate were taken at 2 days interval up to 7 days.

The data on density and dry weight of weeds were subjected to square root transformation $(\sqrt{x+1})$ to improve the homogeneity of the variance (ANOVA) separately for each year (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Associated weed flora

Density of grassy weeds *Digitaria sanguinalis*, *Echinochloa colona, Dactyloctenium aegyptium* and *Brachiaria* spp. were higher as compared to broad leaf weeds (BLW) *Cleome gynandra*, *Parthenium hysterophorus, Amaranthus spinosus*, *Senna tora*, *Phyllanthus niruri*, *Acalypha indica* and *Trianthema* sp. in weedy check plot at 60 DAS. Weedy check plot recorded 45.45% grassy weeds whereas, 35.27% BLW was observed at 60 DAS (**Table 1**). *Cyperus rotundus* (19.28%) was the only sedge weed found in the experimental field during the all three observations. Similar trend about the weed flora presence in soybean field was also reported by Lodha (2018) and Patidar *et al.* (2023).

Weed density and dry weight of weeds

All types of weeds (*i.e.*, grasses, BLW and sedges) were controlled efficiently by different weed control treatments (**Table 1**). Weedy check plots recorded the highest weed density and dry weight of weeds (**Table 2**) at 60 DAS because of continuous development throughout the crucial crop-weed competition phase (Patidar *et al.* 2023). 2 hand weedings at 20 and 40 DAS reduced the density and biomass of weeds to the maximum extent, when compared to herbicide-based treatments, as a result of all weed types being removed during manual weeding, as previously noted by Singh and Jolly (2004), Sharma *et al.* (2017) and Gidesa and Kebede (2018). Among the herbicide treatments, lowest number of weeds and their dry weight was recorded under the application of fluazifop-p-butyl 11.1% + fomesafen 11.1% SL at 500 g/ha followed by 312.5 g/ha during both the experimental seasons as a resultant of the two herbicides working together for successfully elimination of both grassy and non-grassy weeds in a broad-spectrum manner and significantly reduce the accumulation of dry weight of weeds over the weedy check (Deshmukh *et al.* 2023). According to Patidar *et al.* (2019), both lower as well as higher doses of the pre-mixture fomesafen + fluazifop-p-butyl (90+90 g/ha) applied early post-emergence resulted in a significant decrease in the dry weight of both dicot and monocot.

Weed control efficiency (WCE) and weed index

Highest weed control efficiency (WCE) was recorded under the hand weeding at 20 and 40 DAS at all the stages. Among the herbicidal treatments, application of fluazifop-p-butyl 11.1% + fomesafen 11.1% SL (500 g/ha) exhibited the highest WCE on all types of weed *i.e.*, grasses, BLW and sedges at all the observations, followed by fluazifop-p-butyl 11.1% + fomesafen 11.1% SL (312.5 g/ha). At 60 DAS, highest WCE on grasses (61.02%) and sedges (43.35%) was recorded under the application of fluazifop-p-butyl 11.1% + fomesafen 11.1% SL (500

Table 1. Population of dominant weeds/m^2 in soybean at 60 days after crop sowing (pooled data of 2 years)

Treatment	Doses (g/ha)	Grasses				Broad-leaf weeds							Sedges
		Digitaria spp.	*E. colona*	*Dactyloctenium* spp.	*Brachiaria* spp.	*Cleome gynandra*	*Parthenium* sp.	*Amaranthus* spp.	*Cassia* sp.	*Phyllanthus* sp.	*Acalypha indica*	*Trianthema* sp.	*Cyperus rotundus*
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	250	2.12 (3.50)	3.26 (9.60)	1.82 (2.30)	2.05 (3.20)	2.43 (4.90)	2.39 (4.70)	1.52 (1.30)	1.73 (2.00)	1.87 (2.50)	1.70 (1.90)	1.87 (2.50)	3.49 (11.20)
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	312.5	1.84 (2.40)	2.61 (5.80)	1.61 (1.60)	1.82 (2.30)	2.05 (3.20)	2.00 (3.00)	1.41 (1.00)	1.58 (1.50)	1.73 (2.00)	1.48 (1.20)	1.67 (1.80)	3.00 (8.00)
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	500	1.76 (2.10)	2.39 (4.70)	1.52 (1.30)	1.73 (2.00)	2.00 (3.00)	1.90 (2.60)	1.41 (1.00)	1.52 (1.30)	1.64 (1.70)	1.45 (1.10)	1.58 (1.50)	2.86 (7.20)
Quizalofop-ethyl 5% EC	50	1.90 (2.60)	2.86 (7.20)	1.73 (2.00)	2.00 (3.00)	2.26 (4.10)	2.32 (4.40)	1.55 (1.40)	1.73 (2.00)	2.02 (3.10)	1.64 (1.70)	2.02 (3.10)	3.81 (13.50)
Imazethapyr 10% SL	100	2.02 (3.10)	3.00 (8.00)	1.67 (1.80)	2.07 (3.30)	2.12 (3.50)	2.24 (4.00)	1.41 (1.00)	1.61 (1.60)	1.90 (2.60)	1.48 (1.20)	1.84 (2.40)	3.29 (9.80)
Hand weeding at 20 & 40 DAS	-	1.45 (1.10)	1.76 (2.10)	1.41 (1.00)	1.00 (0.00)	1.41 (1.00)	1.58 (1.50)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.76 (2.10)
Weedy check control	-	2.97 (7.80)	6.15 (36.80)	2.19 (3.80)	2.83 (7.00)	3.51 (11.30)	3.29 (9.80)	1.95 (2.80)	2.26 (4.10)	2.41 (4.80)	2.30 (4.30)	2.63 (5.90)	4.95 (23.50)
LSD (p=0.05)		0.05	0.12	0.06	0.15	0.08	0.20	0.10	0.12	0.16	0.11	0.14	0.27

Data are subjected to square root transformation $(\sqrt{x+1})$ and original data presented in parentheses g/ha) next to the hand weeded plots. It might have been caused by using a ready-mix combination of two herbicides, which successfully inhibited or controlled weed development in a wide manner and decreased the dry mass of weeds relative to the control, increasing the efficacy of weed control (Deshmukh *et al.* 2023). Better plant leaf development at a later stage of the crop inhibits weed growth in addition to having an efficient herbicidal impact. Findings are in agreement with Singh *et al.* (2014), Yadav *et al.* (2022) and Patidar *et al.* (2023).

Highest weed index (%) was recorded in weedy check plots during both the years due to maximum yield reduction as well as heavy infestation of weeds and higher competition between weeds and crop plants (**Table 3**). Lowest weed index was observed with the application of fluazifop-p-butyl 11.1% + fomesafen 11.1% SL at 312.5 g/ha (3.22%) followed by quizalofop ethyl 5% EC at 50 g/ha (8.45%) and imazethapyr 10% SL at 100 g/ha (11.67%). In comparison to all other ready-mix herbicide treatments, the said treatment having greater WCE, resulted in higher yields. Singh *et al.* (2014) and Patidar *et al.* (2023) also recorded the lowest weed index with the application of fluazifop-p-butyl + fomesafen.

Growth parameters

All the early post emergence herbicidal treatments produced significantly superior growth parameters of soybean crop as compared to weedy check (**Table 4**) since they controlled the weed population and growth. Pooled data clearly depicted that the highest plant height (71.9 cm) and number of branches per plant (6.33) was recorded under the hand weeding twice which was at par with the herbicide fluazifop-p-butyl 11.1% + fomesafen 11.1% SL (312.5 g/ha) application. Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL application recorded significantly higher plant height and number of branches per plant than other herbicidal treatments. This could be the result of wide spectrum post-emergence herbicidal combination of fluazifop-p-butyl 11.1% + fomesafen 11.1% SL controlling weeds more effectively than other herbicides and reducing the competition of weeds with crop for resources, such as light, nutrients, and moisture. Similar findings were also reported by Dhakad *et al.* (2022).

Yield attributes and yield

Weed control treatments significantly improved the number of pods/plant, number of seeds/pod, 100 seed weight (g), seed and stover yield in comparison to weedy check. Among the yield attributes, pods/plant (116) and seeds/pod (3.0) were significantly higher under the 2-hand weeding at 20 and 40 DAS (**Table 4**). The lowest yield attributes were observed under weedy check during both the years which were significantly lower than all other treatments applied

Table 2. Effects of weed control measures on weed dry weight (g/m^2) in soybean at 60 days after crop sowing (pooled data of 2 years)

Treatment	Doses (g/ha)	Grasses	Broad-leaf weeds	Sedges
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	250	3.53(11.43)	2.20(3.85)	2.61(5.82)
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	312.5	2.90(7.4)	1.93(2.72)	2.44(4.94)
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	500	2.73 (6.48)	1.84(2.39)	2.18(3.75)
Quizalofop-ethyl 5% EC	50	3.19(9.15)	2.25(4.06)	2.71(6.35)
Imazethapyr 10% SL	100	3.31(9.97)	2.07(3.29)	2.49 (5.2)
Hand weeding at 20 and 40 DAS	-	1.91(2.64)	1.20(0.45)	1.64(1.68)
Weedy check control	-	7.02(48.22)	3.86(13.88)	3.85(13.8)
LSD (p=0.05)		0.35	0.15	0.22

Data are subjected to square root transformation ($\sqrt{x+1}$) and original data presented in parentheses

Table 3. Effects of weed control measures on weed control efficiency (%) and weed index (%) in soybean at 60 days after crop sowing (pooled data of 2 years)

Treatment	Doses (g/ha)	WCE (%)			Weed index (%)		
		Grasses	Broad-leaf weeds	Sedges	2020	2021	Pooled
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	250	49.75	42.90	32.12	24.89	25.66	25.35
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	312.5	58.69	49.99	36.65	1.72	4.53	3.22
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	500	61.02	52.26	43.35	37.77	35.47	36.42
Quizalofop-ethyl 5% EC	50	54.59	41.68	29.53	0.86	15.09	8.45
Imazethapyr 10% SL	100	52.79	46.30	35.27	11.59	11.70	11.67
Hand weeding at 20 and 40 DAS	-	72.81	68.78	57.45	-	-	-
Weedy check control	-	-	-	-	76.39	74.72	75.45

for weed control. Among the herbicides treated plots, fluazifop-p-butyl 11.1% + fomesafen 11.1% SL (312.5 g/ha) registered highest number of pods/plant (111) and number of seeds/pod (2.95) which was at par with the 2-hand weeding treatment. However, no such significant effect was observed in 100 seed weight.

Pooled data depicted that seed and stover yield were recorded as minimum (0.61 and 0.78 t/ha, respectively) in the weedy check plot receiving no weed control measure throughout the growing season (**Table 5**). The weedy check decreased the grain yield by 75.5% as compared to 2 hands weeding due to increased crop weed competition as a result of unchecked weed development. Highest seed (2.49 t/ha) and stover (2.81 t/ha) yield were observed under the hand weeding at 20 and 40 DAS, followed by fluazifop-p-butyl 11.1% + fomesafen 11.1% SL at 312.5 g/ha (2.41 and 2.73 t/ha) which were at par with the hand weeded plot. Further increase in doses of fluazifop-p-butyl 11.1% + fomesafen 11.1% SL herbicides mixture to 500 g/ha reduced the yield due to lowering the yield attributing characters as a little phytotoxicity generated by the maximum dosage of fomesafen + fluazifop-p-butyl (500 g/ha) on crop plants. This led to inferior yield parameters (Patidar *et al.* 2023). Similarly, when fomesafen + fluazifop-p-butyl was given at a greater dosage (250+250 g/ha), Singh *et al.* (2014) recorded phytotoxicity on soybean and got a lower seed yield than lower doses (125+125 g/ha).

Soil microbial population

After application of the post emergence herbicides at 2-4 leaf stage of weeds (20 days after crop sowing) the microbial population was drastically reduced as compared to the initial soil samples collected from the treated plots. The pooled data of bacteria, fungi and actinomycetes count at the 15 and 30 days after application (DAA) clearly depicted that the microbial population significantly reduced due to the toxic effects of herbicides as compared to hand weeded and weedy check plots (**Table 6**). However, with the advancement of time on the later stages (45 DAA) of the crop herbicidal effect on the microbial population was minimized and there was no significant effect of herbicides on soil total microbial count *viz.* bacteria, fungi and actinomycetes. Total bacterial count under the application of fluazifop-p-butyl 11.1% + fomesafen 11.1% SL (312.5 g/ha) was 24.92×10^6 and 44.21×10^6 CFU/g soil, respectively at 15 and 45 DAA, whereas weedy check plots recorded 31.26×10^6 and 46.18×10^6 CFU /g soil, respectively which coincides with the findings of

Table 4. Effects of weed control measures on growth and yield attributes of soybean

Treatment	Doses (g/ha)	Plant height (cm) at 75 DAS			No. of branches/plant			No. of pods/ plant			No. of seeds/ pod			100 seed wt. (g)		
		2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	250	67.1	68.9	68.0	4.91	5.31	5.11	71	73	72	2.45	2.65	2.55	10.90	10.80	10.85
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	312.5	68.4	72.2	70.3	5.73	6.01	5.87	109	113	111	2.90	3.00	2.95	10.95	11.15	11.05
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	500	66.2	69.2	67.7	4.29	4.49	4.39	60	54	57	2.70	2.40	2.55	10.75	10.65	10.70
Quizalofop-ethyl 5% EC	50	60.3	65.3	62.8	4.27	4.43	4.35	99	109	104	2.85	2.75	2.80	10.70	10.80	10.75
Imazethapyr 10% SL	100	59.8	63.6	61.7	5.35	5.67	5.51	94	98	96	2.55	2.85	2.70	10.85	10.95	10.90
Hand weeding at 20 and 40 DAS	-	70.1	73.7	71.9	6.08	6.58	6.33	114	118	116	2.85	3.15	3.00	11.10	11.30	11.20
Weedy check control	-	52.2	56.8	54.5	1.83	2.27	2.05	29	35	32	2.00	2.30	2.15	10.60	10.60	10.60
LSD (p=0.05)	--	5.96	7.26	6.16	0.46	0.68	0.491	6.51	5.89	5.91	0.19	0.17	0.17	NS*	NS	NS

*NS: Non-significant

Table 5. Effects of weed control measures on seed and stover yield of soybean

Treatment	Doses (g/ha)	Seed yield (t/ha)			Stover yield (t/ha)		
		2020	2021	Pooled	2020	2021	Pooled
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	250	1.75	1.97	1.86	2.15	2.39	2.27
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	312.5	2.29	2.53	2.41	2.59	2.87	2.73
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	500	1.45	1.71	1.58	1.95	2.35	2.15
Quizalofop-ethyl 5% EC	50	2.31	2.25	2.28	2.82	2.52	2.67
Imazethapyr 10% SL	100	2.06	2.34	2.20	2.48	2.74	2.61
Hand weeding at 20 and 40 DAS	-	2.33	2.65	2.49	2.66	2.96	2.81
Weedy check control	-	0.55	0.67	0.61	0.65	0.91	0.78
LSD (p=0.05)	--	0.15	0.10	0.11	0.07	0.14	0.09

Table 6. Effects of weed control measures on soil microbial properties in soybean (pooled data of 2 years)

Treatment	Doses (g/ha)	Bacteria (CFU 1 x 10^6/g soil)				Fungi (CFU 1 x 10^4/g soil)				Actinomycetes (CFU 1 x 10^5/g soil)			
		Initial	15 DAA	30 DAA	45 DAA	Initial	15 DAA	30 DAA	45 DAA	Initial	15 DAA	30 DAA	45 DAA
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	250	27.29	23.46	33.77	42.63	41.72	24.57	38.71	53.14	35.46	24.72	32.69	47.82
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	312.5	28.72	24.92	32.19	44.21	43.25	26.42	37.68	55.21	36.23	23.65	33.24	48.36
Fluazifop-p-butyl 11.1% + fomesafen 11.1% SL	500	29.25	21.84	30.58	41.25	42.65	24.61	34.45	52.63	33.54	21.55	33.87	43.87
Quizalofop ethyl 5% EC	50	27.14	21.86	31.54	43.82	44.16	22.54	34.47	54.74	35.26	25.34	34.93	45.83
Imazethapyr 10% SL	100	28.43	23.17	33.27	40.93	43.79	23.78	32.76	51.93	36.12	26.32	33.72	47.25
Hand weeding at 20 and 40 DAS	-	31.15	30.85	46.95	48.24	42.58	45.73	51.45	55.47	34.36	39.18	47.75	52.18
Weedy check control	-	27.64	31.26	43.86	46.18	43.17	47.47	52.28	56.62	36.43	42.82	45.28	53.26
LSD (p=0.05)	--	NS*	3.09	3.76	NS	NS	2.56	2.94	NS	NS	1.47	2.14	NS

*NS: Non-significant

Latha and Gopal (2010). Similarly, total fungi and actinomycetes count were increased 26.42×10^4 to 55.21×10^4 CFU /g soil and 36.65×10^5 to 48.36×10^5 CFU /g soil, respectively under the fluazifop-p-butyl 11.1% + fomesafen 11.1% SL (312.5 g/ha) treatment. It might be due to these bacteria engaged in the process of herbicide breakdown, which released carbon-rich substrates that boost the number of microorganisms in the soil. On the other hand, it might be because the herbicides have some harmful effects immediately after application (Ramalakshmi *et al.* 2017).

It can be concluded that all post-emergence ready mix herbicide treatments resulted in broad spectrum weed control in soybean thus reducing the crop-weed competition which leads to enhance the crop productivity with respect to weedy check. It is proved that hand weeding twice *i.e.,* 20 and 40 DAS effectively controlled weed population and increased all the growth and yield attributes significantly, but it was quite costly and time and labour consuming control method compared to chemical control. The application of fluazifop-p-butyl 11.1% + fomesafen 11.1% SL (312.5 g/ha) produced the comparable seed and stover yield of soybean with the 2-hand weeding at 20 and 40 DAS. So, early post emergence ready-mix herbicide fluazifop-p-butyl 11.1% + fomesafen 11.1% SL at 312.5 g/ha may be recommended as an effective weed control measure in soybean field.

REFERENCES

Carey JB and Defelice MS. 1991. Timing of chlorimuron and imazaquin application for weed control in no-till soybeans (*Glycine max*). *Weed Science* **39**: 232–237.

Deshmukh JP, Kakade SU and Goud VV. 2023. Tillage and weed management effect on wheat in inceptisols grown under soybean-wheat cropping sequence. *Indian Journal of Weed Science* **55**(4): 448–452.

Dhakad U, Ram B, Jadon CK, Yadav SL, Yadav RK and Meena SN. 2022. Evaluation of ready-mix post-emergence herbicides for controlling weeds in Soybean [*Glycine max* (L.) Merrill] and their residual effect on succeeding Chickpea. *International Journal of Tropical Agriculture* **40**(3-4): 255–261.

Ghosh P and Pramanik K. 2020. Efficacy of fomesafen against broadleaved weeds and productivity improvement in soybean. *Plant cell biotechnology and molecular biology* **21**(11&12): 53-60.

Gidesa A and Kebede M. 2018. Integration effects of herbicide and hand weeding on grain yield of soybean [*Glycine max* (L.) Merrill] in Assossa, Western Ethopia. *Advances in Crop Science and Technology* **6**(5): 400.

Gomez KA and Gomez AA. 1984. Statistical Procedure for Agricultural Research (2nd ed.). John Willey and sons, Singapore.

Harder DB, Sprague CL and Renner KA. 2007. Effect of soybean row width and population on weeds, crop yield, and economic return. *Weed Technology* **21**: 744–752.

Hock SM, Knezevic SZ, Martin AR and Lindquist JL. 2006. Soybean row spacing and weed emergence time influence weed competitiveness and competitive indices. *Weed Science* **54**: 38–46.

IISR. 2024. Soybean Statistics. ICAR-Indian Institute of Soybean Research. https://iisrindore.icar.gov.in/statistics.html (Accessed on 4 February 2024).

Lal S, Kewat ML and Suryavanshi T. 2017. Weed indices are influenced by propaquizafop and imazethapyr mixture in soybean. *International Journal of Current Microbiology and Applied Sciences* **6**(8): 3109–3115.

Latha PC and Gopal H. 2010. Effect of Herbicides on Soil Microorganisms. *Indian Journal of Weed Science* **42**(3&4): 21–222.

Lodha G. 2018. *Evaluation of post-emergence herbicides against weeds in soybean*. M.Sc. Thesis, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, 63–64 p.

Nelson KA and Renner KA. 1998. Weed control in wide- and narrow-row soybean (*Glycine max*) with imazamox, imazethapyr, and CGA-277476 plus quizalofop. *Weed Technology* **12**: 137–144.

Patidar J, Kewat ML, Sharma JK and Jha AK. 2019. Weed dynamics in soybean as affected by early post: Emergence herbicides. *International Journal of Chemical Studies* **7**(4): 1199–1201.

Patidar J, Kewat ML, Sondhia S, Jha AK and Gupta V. 2023. Bio-efficacy of fomesafen+ fluazifop-p-butyl mixture against weeds and its effect on productivity and profitability of soybean (*Glycine max*) in Central India. *The Indian Journal of Agricultural Sciences* **93**(7): 750–755.

Ramalakshmi A, Murali Arthanari P and Chinnusamy C. 2017. Effect of pyrasosulfuron-ethyl, bensulfuron-methyl, pretilachlor and bispyribac-sodium on soil microbial community and soil enzymes under Rice-Rice cropping system. *International Journal of Current Microbiology and Applied Science* **6**(12): 990–998.

Sangeetha C, Chinnusamy C and Prabhakaran NK. 2013. Early post-emergence herbicides for weed control in soybean. *Indian Journal of Weed Science* **45**(2): 140–142.

Sharma NK, Mundra SL, Upadhyaya B, Nepalia V and Kalita S. 2017. Effect of weed management practices on yield and economics of soybean. pp. 266. In: *Proceedings of Biennial Conference on "Doubling Farmers' Income by 2022: The Role of Weed Science"*, 1-3 March, 2017, Udaipur. Indian Society of Weed Science, Jabalpur, India.

Sharma RK and Shrivastava VK. 2002. Weed control in soybean. *Indian Journal of Agronomy* **47**(2): 269–272.

Singh D, Mir NH, Singh N and Kumar J. 2014. Promising early post-emergence herbicides for effective weed management in soybean. *Indian Journal of Weed Science* **46**(2): 135–137.

Singh G and Jolly. 2004. Effect of herbicides on the weed infestation and grain yield of soybean. *Acta Agronomica Hungarica* **52**(2): 199–203.

Singh SP, Rawal S, Dua VK and Sharma SK. 2017. Weed control efficiency of herbicide sulfosulfuron in potato crop. *Potato Journal* **44**(2): 110–116.

Soltani N, Shropshire C and Sikkema PH. 2017. Sensitivity of adzuki bean to acifluorfen, fomesafen, bentazon, imazethapyr and halosulfuron-methyl applied post-emergence. *American Journal of Plant Sciences* **8**: 1092–1099.

Virk HK, Singh G and Sharma P. 2018. Efficacy of post-emergence herbicides for weed control in soybean. *Indian Journal of Weed Science* **50**(2): 182–185.

Wax LM and Pendleton JW. 1968. Effect of row spacing on weed control in soybeans. *Weed Science* **16**: 462–465.

Yadav SL, Singh P, Dhaked U, Yadav GN, Jadon CK, Singh K, Yadav RK, Meena H, Yadav R, Samota SD and Yadav DL. 2022. Bioefficacy evaluation of new generation post emergence herbicides in Urdbean in vertisols under South Eastern Rajasthan. *The Pharma Innovation Journal* **11**(9): 1101–1104.

Yelverton FH and Coble HD. 1991. Narrow row spacing and canopy formation reduces weed resurgence in soybeans (*Glycine max*). *Weed Technology* **5**: 169–174.

Indian Journal of Weed Science (2024) **56**(3): 290–295
http://dx.doi.org/10.5958/0974-8164.2024.00048.2

RESEARCH ARTICLE

Optimizing groundnut production through diclosulam-based weed management and their residual influence on the wheat crop

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Received: 30 December 2023 | Revised: 17 September 2024 | Accepted: 20 September 2024

ABSTRACT

An experiment was conducted at Agricultural Research Station, Mandor during two consecutive rainy (*Kharif*) seasons of 2021 and 2022 and subsequent *Rabi* season of 2021-22 and 2022-23 to optimize groundnut (*Arachis hypogaea* L.) production through diclosulam-based weed management and its residual effect on consecutive wheat crop. The findings disclosed that all the weed management treatment significantly reduced weed density and weed dry matter at 50 days after sowing (DAS) and increased yield attributes and pod yield of groundnut over weedy check. The highest weed control efficiency (WCE) was observed in thrice manual weeding at 25, 50 and 80 DAS/weed free (84.0%) followed by (*fb*) application of diclosulam 25 g/ha pre-emergence (PE) *fb* hand weeding at 30 and 60 DAS (79.2%). The maximum pod yield (2.03 t/ha) was recorded due to thrice hand weeding at 25, 50 and 80 DAS/weed free, which was at par with diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS, pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS, diclosulam 25 g/ha PE *fb* hand weeding at 30 and 60 DAS and diclosulam 20 g/ha *fb* hand weeding at 30 and 60 DAS. Results further indicate that highest net returns and B: C ratio were recorded in pendimethalin1.0 kg/ha PE + quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS followed by diclosulam 25 g/ha PE + quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS.

Keywords: Diclosulam, Groundnut, Pendimethalin, Productivity, Weed dynamics

INTRODUCTION

Groundnut, scientifically known as *Arachis hypogaea* L., is a leguminous plant cultivated extensively in tropical and subtropical regions, typically within latitudes 40°N and 40°S, and is highly prized for its high-oil content and edible seeds. On a global scale, groundnut holds significant importance, ranking fourth among major sources of edible oil. Worldwide, groundnut cultivation spans a vast area of 32.7 m ha, yielding 53.9 m t with a productivity of 1648 kg/ha (Anon. 2021). India, a prominent groundnut-growing nation, takes a leading position with a cultivation area of 4.96 m ha, making it the second-largest producer globally. In the 2022-23 season, India produced 10.30 m t of groundnut with a productivity of 2075 kg/ha (Anon. 2023).

Weeds present a significant challenge to groundnut production during the early growth stages, particularly up to 40 DAS, due to the slow initial growth of groundnut and compact, underground pod-bearing nature. This leads to intense competition with weeds for essential resources such as water, nutrients, sunlight, and space, resulting in yield losses ranging from 17-85% in rainy (*Kharif)* season groundnut crops (Shwetha *et al.* 2016). Effective weed management during the critical crop-weed competition period (40-60 DAS) is crucial to achieve higher pod yields per hectare. While manual weeding is effective, it is characterized by labour-intensiveness, time consumption, and significant costs, especially within the Indian context (Prajapati *et al.* 2015). Delaying weed control can result in decreased economic yields, compromised product quality, and increased vulnerability to diseases and pests. In such scenarios, herbicidal applications offer a practical solution for weed management (Nainwal *et al.* 2010). Pendimethalin and oxyfluorfen are currently common pre-emergence herbicides used in groundnut and other crops (Jat *et al.* 2011), but they face limitations in controlling broad-leaved weeds. Therefore, there is a requirement to explore alternative chemicals for effective management of weed. This study investigates the efficacy of diclosulam 84% WDG, a new herbicide, for pre-emergence weed control in groundnut. Diclosulam, a triazolopyrimidine sulphonamide herbicide, is part of the new generation of low-dose, high-efficiency herbicides that inhibit acetolactate synthase (ALS), halting cell division (Singh *et al.* 2009) and weed growth with lower toxicity to mammals compared to high-volume herbicides like pendimethalin. Pre-emergence herbicides are used to manage early-stage weeds but may allow weed emergence at later stages, while post-emergence herbicides are recommended

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for later-stage weed control (Singh *et al.* 2023). However, there is limited research on the integrated application of PE and PoE herbicides for groundnut weed management. This study aims to identify suitable herbicides, either alone or in combination, for effective weed management in groundnut cultivation, with a specific focus on diclosulam as a potential alternative. The study assesses diclosulam's effectiveness in weed control, its impact on groundnut yield, and its potential as a solution to the challenges posed by weed infestations in groundnut cultivation.

MATERIALS AND METHODS

The field experiment was carried out at Agricultural Research Station, Mandor-Jodhpur, Rajasthan, India. Geographically, it is located between 26^o 15' N to 26^o 45' North latitude and 73^o 00' E to 73^o 29' East longitude at an altitude of 231 meters above mean sea level. This region falls under agro-climatic zone Ia (Arid Western Plains Zone) of Rajasthan.

The soil at the experimental site was sandy loam in texture, with pH of 8.2 and organic carbon content of 0.13, indicating the presence of limited organic matter. Additionally, the soil contained 174 kg/ha of available nitrogen, 22 kg/ha of available phosphorus, 325 kg/ha of available potassium, and 9.24 mg S/kg of soil. The periodical means weekly weather parameters for the period of the experimentation recorded from the Meteorological Observatory of Agricultural Research Station, Mandor-Jodhpur and are presented in figure 1.0. The mean daily minimum and maximum temperatures varied between 23 to 30.8°C and 29.1 to 38.6°C, respectively in 2021 and the corresponding values in the year 2022 were 19.1 to 29.6°C and 29.2 to 40.4°C during the crop growing seasons. The average daily relative humidity fluctuated between 58.6 to 75.2% in 2021 and 56.5 to 71.0% in 2022. Groundnut variety '*HNG*-123' (bunchy type) was manually sown on June 27, 2021, and June 25, 2022, using a seed rate of 80 kg/ha, with row to row spacing of 30 cm and plant to plant spacing of 10 cm. There were ten treatments used in the experiment, namely: diclosulam 20 g/ha PE; diclosulam 25 g/ha PE; pendimethalin 1.0 kg/ha PE; diclosulam 20 g/ha PE *fb* hand weeding at 30 and 60 DAS; diclosulam 25 g/ha PE *fb* hand weeding at 30 and 60 DAS; diclosulam 20 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS; diclosulam 25 g/ha PE *fb quizalofop*-ethyl 50 g/ha PoE at 30 and 60 DAS; pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha (PoE) at 30 and 60 DAS; hand weeding thrice at 25, 50 and 80 DAS/weed free check; weedy check. In the experiment, each treatment occupied an 18 m² plot (5 x 3.6 m²) arranged with three replications in a randomized block design (RBD), and herbicides were applied by knapsack sprayer using a flat fan nozzle at a water volume of 600 L/ha. Groundnut cultivation involved the application of 15, 60 and 250 kg/ha nitrogen, phosphorus and gypsum, respectively with the full dose of nitrogen and phosphorus were applied at sowing and gypsum was applied in two equal doses at sowing and during earthing up at 40 DAS, respectively.

Key parameters such as shelling percentage, WCE, and weed index (WI) were calculated using standard formulas. Shelling percentage reflects the ratio of seed weight to total pod weight. Total weed density/m² and weed dry weight in g/m² were recorded at 25 and 50 DAS. A quadrate of size 0.5 m x 0.5 m (0.25 m²) was used to measure weed density and biomass. To compare the data on weed density and biomass among treatments, the values were transformed using a square root transformation (sqrt (x+0.5)). A carry-over study evaluated the residual effects of diclosulam herbicide, previously used in groundnut cultivation, on the succeeding wheat crop. Wheat variety '*GW 11*' was grown in fixed plots with a row spacing of 22.5 cm. Observations were conducted on germination and yield, and the wheat crop received necessary irrigation and fertilization throughout its growth period. Phytotoxicity signs were monitored, and at crop maturity, yield parameters and overall crop yield were assessed. The experimental data, acquired from multiple observations, underwent statistical analysis using the 'Analysis of Variance' (ANOVA) method. Pooled mean values derived from three replications per year were analyzed, following the approach outlined by Panse and Sukhatme (1985). The Least Significant Difference (LSD) was computed to facilitate treatment comparisons, whenever the variance ratio (F test) exhibited significance at the 5% probability level.

RESULTS AND DISCUSSION

Effect on weed flora

The experimental plot was predominantly infested with broad-leaved weeds such as *Amaranthus viridis, Celosia argentea, Corchorus trilocularis, Digera arvensis, Phyllanthus niruri, Portulaca oleracea* and *Tribulus terristris* and grassy weeds like *Cynodon dactylon, Dactyloctenium aegyptium* and *Eragrostis minor,* and sedge, specifically *Cyperus rotundus*. However, it was evident that broad-leaved weeds held dominance over grassy and sedge weeds. The occurrence and intensity of these weeds varied among different treatment plots. The intensity of weed infestation differed based on the application of different herbicides and manual weeding at various stages of crop growth. Mehriya *et al.* (2021) observed this weed flora in field of groundnut.

Effect on weeds

The data from **Table 1** reveals the impact of different herbicidal treatments on weed density, biomass, and weed control efficiency over two seasons. The hand weeding thrice at 25, 50 and 80 DAS treatment significant reduced total weed density over control and herbicidal treatments. Among the herbicidal treatments, the diclosulam 25 g/ha PE *fb* hand weeding at 30 and 60 DAS and diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS, showed the significantly lower weed density and weed dry weight at 50 DAS. The treatment pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS has reduced weed dry weight by approximately 76.95% compared to the weedy check. Conversely, the untreated control (weedy check) treatment exhibited highest total weed density and weed dry weight during both seasons. Treatment diclosulam 20 g/ha PE *fb* hand weeding at 30 and 60 DAS, diclosulam 25 g/ha PE *fb* hand weeding at 30 and 60 DAS, diclosulam 20 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS, diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS and pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS were found on par with each other in weed dry weight at 50 DAS. Highest weed control efficiency (84.0%) obtained in hand weeding thrice at 25, 50 and 80 DAS/weed free check followed by diclosulam 25 g/ha PE *fb* inter-cultivation at 30 and 60 DAS (79.4%) followed by treatment diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS (78.2%), and pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS (77.1%) and lowest weed index (4.4) was recorded with diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS. Similar findings were also documented by Honnali and Satiha (2022). Musa *et al.* (2022) recorded that effective weed control and a higher groundnut pod yield were achieved through the pre-emergence application of diclosulam at a rate of 25 g/ha (PE) combined with imazethapyr at 100 g/ha (PoE) at 18-20 DAS. This approach offers a viable alternative to the current recommendation of using pendimethalin 1.0 kg/ha (PE) along with imazethapyr 100 g/ha (PoE) at the same stage of 18-20 DAS. The increased weed control effectiveness observed in these treatments may be attributed to the decreased dry weight of weeds. Weed competition was notably diminished through the application of various weed control methods, with pre-emergence diclosulam use proving significantly superior to the other approaches (Musa *et al.*, 2022). This superior efficacy extended to the management of all weed categories, including the most prevalent ones. The extended half-life of diclosulam, combined with its elevated leaching potential index, results in higher concentrations reaching deeper soil layers, effectively controlling not only sedges and broadleaf weeds but also necessitating a longer duration for the management of dicot weeds (Har N *et al.* 2020).

Effect on groundnut crop

All herbicidal treatments were significantly influenced growth and yield parameters of groundnut, *viz.* branches/plant, pods/plant, shelling (%), seed index (g), pods yield (t/ha) and haulms yield (t/ha) over weedy check (**Table 2** & **3**). Any phytotoxicity symptoms were not recorded during crop growing period. Maximum number of branches in groundnut were recorded under hand weeding thrice at 25, 50 and 80 DAS (7.3) followed by diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS (6.8) and diclosulam 25 g/ha PE *fb* hand weeding at 30 and 60 DAS (6.8) which significantly increased number of branches over weedy check plot and diclosulam 20 g/ha PE. The treatment pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS also significantly increased number of branches/plant in groundnut by 61.0% over weedy check. The significantly higher

Table 1. Effect of integrated weed management on weed dynamics of *Kharif* groundnut (pooled data of two years)

Treatment	Weed density (no./m^2		Weed dry weight (g/m^2)		WCE (%) at 50 DAS	WI (%)
	25 DAS	50 DAS	25 DAS	50 DAS		
Diclosulam 20 g/ha PE	5.56 (32.3)	6.1 (37.5)	4.0 (15.9)	5.7 (32.9)	47.2	29.6
Diclosulam 25 g/ha PE	3.41 (11.6)	5.0 (25.5)	3.4 (11.5)	4.4 (19.8)	68.2	12.5
Pendimethalin 1.0 kg/ha PE	3.49 (12.2)	4.9 (24.3)	3.4 (11.7)	4.6 (20.9)	66.4	13.3
Diclosulam 20 g/ha *fb* hand weeding at 30 and 60 DAS	4.48 (20.2)	4.8 (23.3)	3.9 (15.0)	3.9 (14.9)	76.0	9.5
Diclosulam 25 g/ha PE *fb* hand weeding at 30 and 60 DAS	3.44 (11.9)	4.4 (19.7)	3.4 (11.9)	3.6 (12.8)	79.4	5.7
Diclosulam 20 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS	4.49 (20.2)	4.7 (23.5)	3.9 (15.2)	4.0 (17.3)	72.2	17.0
Diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS	3.28 (10.8)	4.4 (19.8)	3.4 (11.3)	3.7 (13.6)	78.22	4.4
Pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30&60 DAS	3.40 (11.6)	4.5 (20.5)	3.5 (12.1)	3.8 (14.3)	77.1	4.6
Hand weeding thrice at 25, 50 and 80 DAS/weed free check	7.42 (55.3)	3.5 (12.5)	4.9 (23.6)	3.2 (10.0)	84.0	0.0
Weedy check	7.65 (59.2)	8.3 (70.0)	4.9 (24.2)	7.9 (62.4)	0.00	52.9
LSD (p=0.05)	0.48	0.48	0.44	0.44		

Where, the original values enclosed in parentheses underwent a square-root transformation ($\sqrt{x+0.5}$) prior to being subjected to statistical analysis number of pods/plant (22.3) was observed in the hand weeding at 25, 50 and 80 DAS/weed free check plot. Among herbicides, application of diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS (20.9) significantly increased pods/plant over diclosulam 20 g/ha PE, diclosulam 25 g/ha PE, pendimethalin 1.0 kg/ha PE, diclosulam 20 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS and weedy check plot. All treatments were significantly enhanced shelling % of groundnut over weedy check treatment and found non-significant with each other. The shelling % increased by 14.7% due to treatment pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS. Maximum seed index was found in hand weeding thrice (50.6) followed by pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS (49.2). Both these treatments have significantly increased seed index over remaining treatments. The highest pod and haulm yield were obtained under hand weeding thrice at 25, 50 and 80 DAS/weed free check (2.03 and 3.76 t/ha) followed by diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha (PoE) at 30 and 60 DAS (1.94 and 3.71 t/ha), pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS (1.93 and 3.73 t/ha), diclosulam 25 g/ha PE *fb* hand weeding at 30 and 60 DAS (1.91 and 3.67 t/ha) and diclosulam 20 g/ha PE *fb* hand weeding at 30 and 60 DAS (1.84 and 3.51 t/ha) which were statistically at par with each other. Application of diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha (PoE) at 30 and 60 DAS and pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS significantly increased pod yield by 102.0 and 101.0% over weedy plot. In a similar vein, Har N *et al.* (2020) also reported increased groundnut pod yield through pre-emergence application of diclosulam 26 g/ha. In a study, Singh *et al.* (2023) highlighted that the use of pre-emergence herbicide application followed by post-emergence herbicide application or hand weeding led to significantly improved yield components and overall crop yield. Whereas, significantly lower pod yield and seed index were recorded under weedy check and the highest were recorded under thrice hand weeding (**Table 2** and **3**). This could be attributed due to low crop-weed competition in this treatment. Honnali and Satihal (2022) recorded that the use of diclosulam 84% WDG at a rate of 26 g/ha proved highly effective in controlling weeds in groundnut crops. This treatment resulted in the highest pod yield, pod dry weight, and number of pods per plant, comparable to hand weeding at specific time points. Importantly, it did not adversely impact the germination, growth, or yield of subsequent sunflower crops.

Economics

The net returns (₹ 62816/-) and B: C (1.95) ratio were found maximum in application of pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS followed by diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS (62527 and 1.94), while lowest net return (₹ 2820/ha) and B: C ratio (1.05) were observed in the weedy check (**Table 3**). Among various weed management strategies; these results highlight the substantial impact of weed control on net returns. The lowest B:C ratio with weedy check and higher values with application of pre-emergence application of pendimethalin followed by post emergence application of herbicides at 20 to 30 days after sowing were also reported earlier by Har *et al.* (2020).

Table 2. Effect of integrated weed management on growth and yield attributes of *Kharif* groundnut (pooled data of two years)

Treatment	Phyto-toxicity rating (DAS- Days after spray)		Plant Population		No. of branches/ plant	No. of pods/ plant	Shelling (%)	Seed index (g)
	15 DAS	30 DAS	Initial	Final				
Diclosulam 20 g/ha PE	0	0	376	369	5.6	14.8	66.1	47.0
Diclosulam 25 g/ha PE	0	0	373	368	6.6	18.2	68.1	48.3
Pendimethalin 1.0 kg/ha PE	0	0	382	375	6.5	18.2	67.9	47.8
Diclosulam 20 g/ha *fb* hand weeding at 30 and 60 DAS	0	0	382	377	6.7	19.7	68.5	47.4
Diclosulam 25 g/ha PE *fb* hand weeding at 30 and 60 DAS	0	0	386	382	6.8	19.7	70.0	48.0
Diclosulam 20 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS	0	0	376	372	6.2	17.7	67.0	47.8
Diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS	0	0	383	378	6.8	20.9	69.5	48.3
Pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS	0	0	371	364	6.6	19.6	69.5	49.2
Hand weeding thrice at 25, 50 and 80 DAS/weed free check	0	0	380	373	7.3	22.3	71.0	50.6
Weedy check	0	0	378	368	4.1	8.9	60.6	43.4
LSD (p=0.05)			15.2	14.5	1.03	2.42	5.16	1.88

Where, the original values enclosed in parentheses underwent a square-root transformation ($\sqrt{x+0.5}$) prior to being subjected to statistical analysis

Correlation analysis

In the conducted correlation analysis, a comprehensive matrix was generated to assess the relationships between various agricultural parameters in the research study (**Figure 2**). The variables included weed density at both 25 days after sowing (DAS) and 50 DAS, as well as the corresponding dry weed weights. Additionally, the analysis considered plant attributes such as the number of branches and pods per plant, shelling percentage, seed index, and pod yield. The results reveal several noteworthy findings. Firstly, a strong positive correlation was observed between weed density at 25 DAS and weed dry weight at both 25 DAS with correlation coefficients of 0.989. Similarly, weed density at 50 DAS exhibited a positive correlation of 0.989 with weed dry weight at 50 DAS. Conversely, negative correlations were observed between weed density and several crop attributes, including branches, pods per plant, selling percentage, seed index, and pod yield. These correlations were particularly strong, with coefficients ranging from -0.91 to -0.98, suggesting that higher weed density is associated with lower values for these crop attributes.

Principal component analysis

Principal Component Analysis (PCA) was employed to explore the underlying structure of the dataset, which contains information related to weed density at 25 and 50 days after sowing, weed dry weight at the same time, number of branches, pods per plant, selling factors, seed index, and pod yield (**Figure 3**). The loadings of each variable on the principal components (PC1 to PC9) were also examined. These loadings represent the contribution of each variable to the principal components. Notably, PC1 showed the highest loadings for weed density at 50 DAS and weed dry weight at 25 DAS, indicating a strong relationship between these variables. PC2, on the other hand, had high loadings for weed density 25 DAS and weed dry weight at 25 DAS, suggesting their connection. Eigen values and the percentage of variance explained by each principal component were computed (**Table 5**). PC1 emerged as the dominant component, explaining 81.65% of the total variance, followed by PC2 with 16.46%. This suggests that the majority of the variance in the dataset is captured by these two components. PC3 and subsequent components explained progressively smaller amounts of variance.

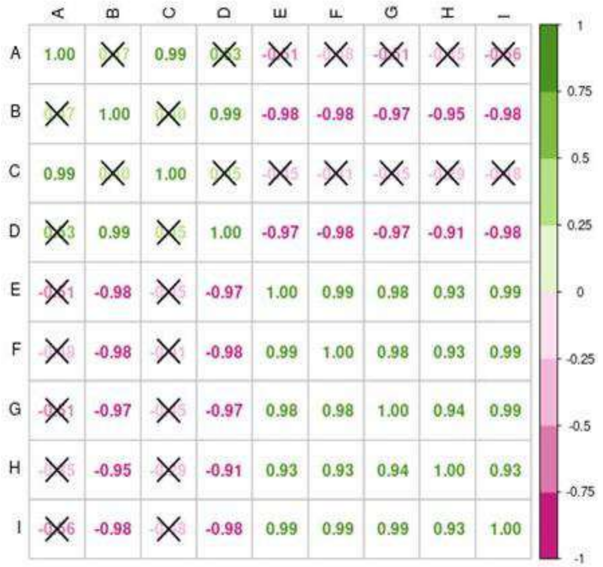

Figure 2. Correlations between variables

Where, A- Weed density at 25 DAS; B- Weed density at 50 DAS; C- Weed dry weight at 25 DAS; D- Weed dry weight at 50 DAS; E- No. of branches/plant; F- No. of pods/plant, G- shelling %; H- Seed index; I- Pod yield

Residual study on succeeding crop

Table 4 presents the residual effect of various herbicide treatments on the subsequent growth and yield attributes of wheat for two consecutive cropping seasons (2021-22 and 2022-23). The table provides valuable insights into the impact of these herbicides on plant population, plant height, no. of tillers per plant, grain yield, biological yield, and test weight. It’s worth noting that there were no significant differences (NS) at the 5% level for

Table 3. Effect of integrated weed management on yield and economics of *Kharif* groundnut (pooled data of two years)

Treatment	Pod yield (t/ha)			Haulm yield (t/ha)	Gross returns (₹/ha)	Net returns ₹/ha)	B:C ratio
	2021-22	2022-23	Pooled				
Diclosulam 20 g/ha PE	1.55	1.31	1.43	2.80	95202	33348	1.54
Diclosulam 25 g/ha PE	1.85	1.70	1.77	3.37	117815	55621	1.89
Pendimethalin 1.0 kg/ha PE	1.83	1.68	1.76	3.35	116851	54852	1.88
Diclosulam 20 g/ha *fb* hand weeding at 30 and 60 DAS	1.93	1.75	1.84	3.51	122050	51196	1.72
Diclosulam 25 g/ha PE *fb* hand weeding at 30 and 60 DAS	2.02	1.80	1.91	3.67	127194	56000	1.79
Diclosulam 20 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS	1.68	1.69	1.68	3.21	112015	46161	1.70
Diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS	1.98	1.89	1.94	3.71	128986	62527	1.94
Pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 & 60 DAS	1.98	1.89	1.93	3.73	128815	62816	1.95
Hand weeding thrice at 25, 50 and 80 DAS/weed free check	2.10	1.96	2.03	3.76	134310	62060	1.86
Weedy check	1.00	0.91	0.96	1.69	62820	2820	1.05
LSD (p=0.05)	278.9	264.8	233.1	397.1	14903	-	-

Table 4. Residual effect of herbicides on growth and yield attributes, yield and economics of succeeding wheat crop (pooled data of two years)

Treatment	Plant height (cm)	No. of tillers/ plant	Grain yield (t/ha) 2021-22	Grain yield (t/ha) 2022-23	Grain yield (t/ha) Pooled	Biological yield (t/ha)	Test weight (%)
Diclosulam 20 g/ha PE	82.1	7.0	4.08	3.25	3.67	8.26	46.4
Diclosulam 25 g/ha PE	81.6	6.6	4.14	3.47	3.80	8.73	46.3
Pendimethalin 1.0 kg/ha PE	82.3	7.0	4.10	3.48	3.79	8.96	46.0
Diclosulam 20 g/ha *fb* hand weeding at 30 and 60 DAS	81.5	6.8	4.20	3.24	3.72	8.65	46.7
Diclosulam 25 g/ha PE *fb* hand weeding at 30 and 60 DAS	82.4	7.1	3.92	3.37	3.64	8.78	46.9
Diclosulam 20 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS	80.4	7.0	4.23	3.43	3.83	9.00	46.0
Diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS	79.1	6.7	3.98	3.34	3.66	8.74	45.7
Pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 & 60 DAS	81.8	6.5	4.05	3.34	3.69	8.51	46.5
Hand weeding thrice at 25, 50 and 80 DAS/weed free check	83.4	7.0	4.20	3.47	3.84	8.94	46.3
Diclosulam 20 g/ha PE	81.2	6.8	4.16	3.50	3.83	8.99	46.5
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS

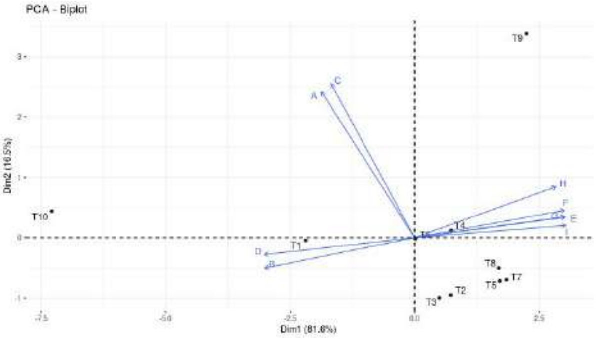

Figure 3. Principal component analysis of parameters.

Where, A- Weed density at 25 DAS; B- Weed density at 50 DAS; C- Weed dry weight at 25 DAS; D- Weed dry weight at 50 DAS; E- No. of branches/plant; F- No. of pods/plant, G- shelling %; H- Seed index; I- Pod yield

Table 5. Eigen values of principal component analysis

Principal component analysis	Eigen value	% of variance
PC1	7.348	81.648
PC2	1.481	16.461
PC3	0.091	1.007
PC4	0.041	0.459
PC5	0.016	0.18
PC6	0.014	0.155
PC7	0.005	0.057
PC8	0.003	0.033
PC9	0	0

various comparisons, as indicated by the critical difference (CD) values. Honnali and Satihal (2022) observed that diclosulam was applied on groundnut crop in the previous season at recommended (26 g/ha) and double the recommended dose (52 g/ha) and results were no adverse effect of diclosulam treatment 26 g/ha on sunflower as there was no injury on sunflower crop.

Effective weed control and higher groundnut pod yield were possible with pre-emergence application of diclosulam 25 g/ha PE *fb* quizalofop-ethyl 50 g/ha PoE at 30 and 60 DAS which could be an alternative to present recommendation of pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha POE at 30 and 60 DAS.

REFERENCES

Anonymous, 2023. https://upag.gov.in/crop-production.

Anonymous, 2021. *World Food and Agriculture - Statistical Yearbook 2021*. Rome

Har NM, Ranjeet SY, Navin KJ and Mayank Y. 2020. A novel preemergence herbicide (diclosulam) as an environmentally friendly weed management option in peanut and its phytotoxicity evaluation in India. *Weed Biology and Management* **21**: 1927.

Honnali SN, and Satihal DG. 2022. Effect of herbicides on weed infestation, productivity of groundnut, and their residual effect on sunflower. *Ecology, Environment & Consservation* **28**(3): 1390–1394.

Jat RS, Meena, HN Singh AL, Surya NJ and Mishra JB. 2011. Weed management in groundnut (*Arachis hypogaea* L.) in India – a review. *Agricultural Reviews* **32**: 155–171.

Mehriya ML, Sarita, Borana H and Geat N. (2021). Effective and profitable weed management in rainy season groundnut grown under arid zone of Rajasthan. *Indian Journal of Weed Science* **53**(3): 269–274.

Musa RM, Yenagi BS, Patil LC and Biradar DP. 2022. Effect of diclosulam pre-emergence herbicide on weed dynamics, yield, and economics of groundnut (*Arachis hypogaea* L.). *Journal of Farm Science* **35**(1): 58–62.

Nainwal RC, Saxena SC and Singh VP. 2010. Effect of pre-and post-emergence herbicides on weed infestation and productivity of soybean. *Indian Journal of Weed Science* **42** (1&2): 17–20.

Panse, VG and Sukhatme PV. 1985. *Statistical Methods for Agricultural Workers*. Indian Council of Agricultural Research Publication, pp 87–89.

Prajapati B, Singh TC, Giri P and Kewalanand. 2015. Efficacy of herbicide for weed management in Berseem. *The Bioscan* **10**(1): 347–350.

Shwetha BN, Umesh MR and Agna MB. 2016. Post-emergence herbicides for weed management in groundnut. *Indian Journal of Weed Science* **48**(3): 294–296.

Singh S, Singh V, Nainwal R, Tripathi N & Kumar A. (2009). Efficacy of diclosulam on weeds and yield of soybean. *Indian journal of weed science* **41**(3&4): 170–173.

Singh V, Sepat S., Singh J, Gautam A and Aulakh GS. 2023. Effect of nitrogen levels and weed management on weed flora and yield of direct-seeded rice (*Oryza sativa*) in southern part of Punjab. *Indian Journal of Agricultural Sciences* **93** (10): 1055–1060.

Indian Journal of Weed Science (2024) **56**(3): 296–300
http://dx.doi.org/10.5958/0974-8164.2024.00049.9

RESEARCH ARTICLE

Integrated weed management in ginger for higher productivity in coastal zone of Odisha

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Received: 2 March 2024 | Revised: 24 July 2024 | Accepted: 27 July 2024

ABSTRACT

Ginger (*Zingiber officinale)* is highly susceptible to weed infestation because of its slow initial growth. The weed problem severely influences crop productivity and economic returns. Mostly the weed control strategies rely on the manual method which is costly and time-consuming. Therefore, the current investigation was carried out at the central research farm of Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India in 2014-2016 to find out the effective and feasible methods for weed control in ginger. Nine treatments which included the use of pendimethalin, oxyfluorfen, pendimethalin followed by (*fb*) hand weeding, oxyfluorfen *fb* hand weeding, glyphosate, glyphosate + pendimethalin, glyphosate + oxyfluorfen, 4 hand weeding and unweeded control. Among the treatments, tank mix application of glyphosate + pendimethalin was most effective in controlling weeds with high weed control efficiency (53.8%), minimum weed index (1.09%) and weed persistence index (0.49) as compared to other treatments. Pre-emergence application of glyphosate + pendimethalin also resulted in the highest rhizome yield 27.2 t/ha and B: C of 3.78. Hence, tank mix of Glyphosate 0.80 kg/ha + pendimethalin 1.5 kg/ha applied after mulching and just before emergence of sprouts of ginger is a remunerative method in controlling weeds effectively and giving highest yield in Coastal zone of Odisha.

Key words: B: C ratio, weeds control efficiency, weed index, weed persistence index, *Zingiber officinale*

INTRODUCTION

Ginger (*Zingiber officinale* Roscoe) of the family *Zingiberaceae*, is an herbaceous perennial, usually grown as an important commercial annual spice crop. Srinivasan *et al*. (2018) reported that ginger is extensively cultivated for its flavor, pungency, aroma and healing characteristics associated with its essential oil and oleoresin contents. India has the largest share in the total area under ginger cultivation (34.6%) and annual production (29%) in the world and exports 10–15% of its produce (Kallappa *et al*. 2015). As per the reports of the National Horticulture Board, 2021-22, among the ginger-producing states in India, Madhya Pradesh contributes the highest share of 31.18% while Odisha contributes 5.77%. The low production of ginger in Odisha is due to weed infestation. As the crop is of long duration and slows in sprouting, it is highly susceptible to weed competition, especially at the initial stages of crop growth resulting in higher yield loss. All India Coordinated Research Project on Weed management, Kerala center, has reported that uncontrolled weed growth leads to a significant reduction in ginger yield, ranging from 30% to 45% (KAU, 2006). Osunleti *et al*. (2021) reported that there is a reduction of 91.9% and 92.1% rhizome yield reduction in 2016 and 2017, respectively due to weed infestation. Weeds compete with ginger for moisture, nutrients, and space. Weed competition has also been identified as a constraint to root and rhizome production. In practice, two to three-hand weeding is done depending on the weed intensity and growth. The manual method of weed control is not effective and economical considering the intensity of weed persistence, labor charges and availability. The use of herbicides is an important practice for most crops as it is easier, has superior weed control efficacy (Roy *et al*. 2023), increases yields (Baruah and Deka 2020), time and labor-saving and is economical compared to other weed control measures (Rekha *et al*. 2003). Hence, this study was formulated to identify a remunerative approach in controlling weeds in ginger in the Coastal Zone of Odisha.

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MATERIALS AND METHODS

A field experiment was conducted for two years (2014–15 and 2015–16) at the central research farm of Orissa University of Agriculture and Technology (OUAT), Bhubaneswar (20°152 N, 85°482 E, 30.6 m ASL). The region is designated by subtropical climate having an average annual rainfall of 1484 mm. The experimental soil status was sandy clay loam having uniform texture up to a depth of 100 cm. The soil pH was 6.4 and EC was 0.18dS/m with organic carbon of 4.8 g/kg, available N, P and K were 143.5 kg/ha, 38.5 kg/ha and 117 kg/ha, respectively. The experiment was laid out in randomized block design with three replications. The experimental field was cultivated and leveled. Farm yard manure was applied at 10 t/ha. The ginger variety '*Suruchi'* was sown in raised beds of 5m × 1m on 8th July 2014 and harvested on 16th March 2015 in the first year and second year sowing was done on 28th June 2015 which was harvested on 24th February 2016. Paddy straw mulch was applied 5 t/ha in plots 7 days after sowing (DAS).

In total 9 herbicidal treatments: Pendimethalin 1.5 kg/ha applied after sowing but before mulching; oxyfluorfen 0.20 kg/ha applied after sowing but before mulching; pendimethalin 1.5 kg/ha applied after sowing but before mulching followed by (*fb*)HW at 30-35 days after planting (DAP); oxyfluorfen 0.20 kg/ha applied after sowing but before mulching *fb* HW at 30-35 DAP; glyphosate 0.80 kg/ha applied after mulching and just before emergence of sprouts of ginger; tank mix of Glyphosate 0.80 kg/ha+ pendimethalin 1.5 kg/ha applied after mulching and just before emergence of sprouts of ginger; tank mix of glyphosate 0.80 kg/ha+ oxyfluorfen 0.2 kg/ha applied after mulching and just before emergence of sprouts of ginger; four hand weeding at 20, 40, 60 and 90 DAP; weedy check. Pre-emergence application of herbicides like oxyfluorfen and pendimethalin was done in respective treatments at 2 days after sowing (DAS). The post-emergence herbicide like glyphosate was applied sole at 0.8 kg/ha and along with other pre-emergence herbicides at 10 DAS (after mulching and just before the emergence of sprouts of ginger). The density of weeds consisting of grasses, sedges and broad-leaved weeds was estimated by taking a quadrate of 0.5 × 0.5 m at three randomly selected places in each plot at 30, 60 and 90 DAS. After measuring, the roots were separated from the shoots and were oven-dried at 70±1°C for 72 hours and weighed to record the weed-dry biomass. It was expressed in per m^2.

Further, the weed indices were calculated as follows:

Weed control efficiency (WCE) defines the effect of treatments in controlling the weeds based on weed dry weight. WCE was determined by the formula given by Mani *et al.* (1973) as follows:

$$WCE(\%) = \frac{X - Y}{X} x\ 100$$

Where, X = Weed dry matter in weedy check and Y = Weed dry mater in treatment plot

Weed index (WI) defines the percent reduction in yield due to the presence of weeds in the treated plot in comparison to the yield obtained in the weed-free plot. It is computed by using the following formulas suggested by Gill and Kumar (1969):

$$WI = \frac{X - Y}{X} x\ 100$$

Where, X= yield in weed free plot and Y = yield in treated plot

Weed persistence index (WPI) specifies the resistance in weeds against the treated herbicide and confirms its effectiveness. It is calculated by the formula outlined by Mishra and Mishra (1997)

$$WPI = \frac{Drymatterofweedintreatedplot}{Drymatterofweedsincontrolplot} x \frac{Weedcountincontrolplot}{Weedcountintreatedplot}$$

The rhizome yield was estimated by taking the weight of the produce from an area of 1m × 1m and then converted into t/ha. Economic analysis was carried out by calculating the cost of cultivation by taking the cost of land preparation, rhizome and manure, chemicals, labour, and mulch materials, etc. into account. The wholesale market price of the produce was used to calculate the gross and net returns and the benefit: cost (B:C) was calculated taking gross return over cost of cultivation.

All experimental data were analyzed by analysis of variance (ANOVA) using STAR 2.0.1.For normalization of weed data the square root transformation (“X) was performed and then analyzed. Treatment means were compared by critical difference (CD) at 5% probability (p=0.05).

RESULTS AND DISCUSSION

The common weed species at the site of study included grasses like *Cynodon dactylon, Digitaria ciliaris, Dactyloctenium aegyptium*: sedges included *Cyperus rotundus* and *Cyperus esculentus* and broad-leaved weeds included *Phylllanthus niruri,Ageratum conyzoides, Oxalis latifolia, Solanum nigrum, Physalis minima, Commelina benghalensis* and *Euphorbia hirta.*

Among all the treatments, weed density was found to be the lowest in hand-weeded plots and the plots applied with glyphosate + pendimethalin (**Table 1**). The weed density increased upto 90 DAS. Since the emergence and early growth of ginger is inherently slow and there is considerable time elapse between sowing and development of foliage cover, the crop competes very poorly with weeds (Thankamani *et al.* 2016). However, weed biomass (g/m^2) was found to be the least with the application of glyphosate at all the stages (30, 60 and 90DAS) (**Table 2**).

Weed indices are used to draw interpretations regarding better treatment in weed control. The highest weed control efficiency (WCE) was observed in the pre-emergence herbicide use of glyphosate + pendimethalin (53.8%) at 90 DAS followed by pendimethalin *fb* hand weeding and oxyfluorfen *fb* hand weeding (39.1) (**Table 3**). The WCE was 83% higher than the hand-weeded plot. Weed control efficiency which indicates the comparative magnitude of reduction in weed dry matter was highly influenced by different weed control treatments. Similar results were obtained by Sah *et al.* (2017).

Weed index indicates the percent yield loss caused due to weeds as compared to a weed-free check. The results reveal that the lowest value of WI was obtained with the combined under hand weeding where the field was kept weed free followed by the herbicidal treatment of glyphosate + pendimethalin (1.09%). Also, a higher yield loss was observed in weedy check plots followed by using pendimethalin alone. Since ginger is a long-duration crop, its initial growth is slow and it faces a lot of competition with weeds at the initial stage. Hence application of pre-emergence herbicides in combination controlled the weeds effectively.

Weed persistence index indicating relative dry matter accumulation of weeds per count (**Table 3**) indicated that the combined application of glyphosate

Table 1. Effect of weed management on weed density of ginger (2014-15 and 2015-16)

Treatment	Weed density (no./m^2)					
	2014-15			2015-16		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Pendimethalin	4.52(20.5)	5.23(27.1)	6.74(45.5)	4.39(19.3)	5.08(25.9)	6.59(43.5)
Oxyfluorfen	4.3(18.5)	4.67(21.9)	6.20(39.5)	4.11(16.9)	4.84(23.5)	6.43(41.1)
Pendimethalin *fb* hand weeding	3.34(11.18)	3.72(13.9)	5.36(28.8)	3.19(10.22)	3.93(15.5)	5.53(30.6)
Oxyfluorfen *fb* hand weeding	3.70(13.7)	4.97(24.8)	6.23(38.9)	3.86(14.9)	5.07(25.8)	5.87(34.5)
Glyphosate	3.04(9.3)	4.72(22.9)	6.46(41.8)	2.66(7.1)	4.96(24.7)	6.54(42.8)
Glyphosate+ pendimethalin	2.38(5.7)	3.3(11.0)	6.28(39.5)	2.21(4.9)	3.09(9.6)	6.09(37.1)
Glyphosate + oxyfluorfen	2.94(8.7)	4.88(23.9)	6.89(43.5)	2.84(8.1)	5.10(26.1)	6.44(41.5)
Hand weeding (4)	4.51(20.4)	5.27(27.8)	6.69(44.8)	4.31(18.6)	4.9(24.5)	6.54(42.8)
Weedy check	4.85(23.6)	4.67(21.9)	5.50(30.3)	5.07(25.8)	4.52(20.5)	5.78(33.5)
LSD (p=0.05)	0.34	0.51	0.33	0.29	0.48	0.32

Data are the square root ($\sqrt{x+0.5}$) transformation of the original value in parentheses

Table 2. Effect of weed management on weed biomass (g/m^2) of ginger (2014-15 and 2015-16)

Treatment	Weed biomass (g/m^2)					
	2014-15			2015-16		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Pendimethalin	2.97(8.85)	3.62(13.1)	5.66(32)	3.12(9.75)	3.5(11.89)	5.56(30.9)
Oxyfluorfen	2.89(8.40)	3.03(9.19)	5.14(26.5)	2.66(7.2)	2.93(8.01)	5.33(28.5)
Pendimethalin *fb* hand weeding	1.81(3.30)	2.55(6.53)	5.10(26.1)	1.58(2.5)	2.40(5.07)	5.02(25.3)
Oxyfluorfen *fb* hand weeding	2.60(7.1)	2.77(7.7)	5.27(27.8)	2.50(6.3)	2.68(6.7)	5.07(25.8)
Glyphosate	2.94(8.7)	3.10(10.2)	5.42(29.4)	2.58(6.7)	3.08(8.8)	5.05(25.6)
Glyphosate+ pendimethalin	1.89(3.6)	2.09(4.4)	4.49(20.2)	2.04(4.2)	1.94(3.2)	4.42(19.6)
Glyphosate + oxyfluorfen	2.81(7.9)	3.24(10.5)	5.24(27.5)	3.01(9.1)	3.13(9.1)	5.33(28.5)
Hand weeding (4)	3.08(9.5)	3.40(11.6)	5.53(30.6)	2.81(7.9)	3.24(9.4)	5.38(29.0)
Weedy check	4.80(23.1)	5.74(33)	6.57(43.2)	4.98(24.9)	5.64 (30.8)	6.41(41.2)
LSD (p=0.05)	0.34	0.55	0.33	0.24	0.31	0.24

Data are the square root ($\sqrt{x+0.5}$) transformation of the original value in parentheses

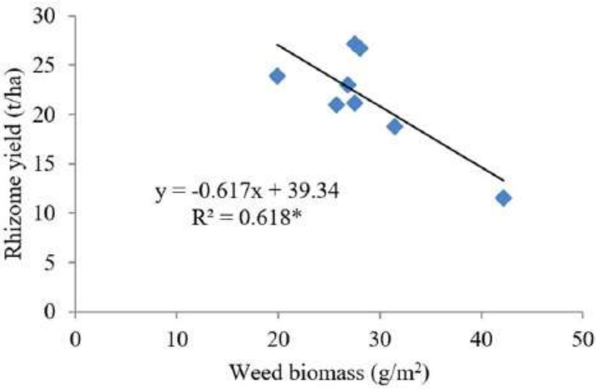

Figure 1. Relationship analysis of weed biomass at 90DAS and rhizome yield of ginger

+ pendimethalin gave the lowest WPI (0.49) followed by glyphosate + oxyfluorfen (0.71) (**Table 3**). Similar findings were also corroborated by Mishra *et al.* (2016).

The highest rhizome yield of 27.2 t/ha was obtained in the treatment of glyphosate + pendimethalin (**Table 4**). Since there is a negative relation between weed density and rhizome yield in ginger. Hence, due to less number of weeds in this treatment, the yield was higher. Similar results were obtained by Sah *et al.* (2017).

The economic parameters *i.e.* net returns and benefit: cost are influenced by herbicidal treatments in ginger. The maximum net returns were obtained under the hand-weeded plot and herbicidal treatment of glyphosate + pendimethalin with an amount of ¹ . 1,85,000 (**Table 4**). The B: C was highest with the treatment of glyphosate + pendimethalin (3.78) which is at par with glyphosate, glyphosate + oxyfluorfen.

The regression analysis between weed biomass (g/m^2) and grain yield (t/ha) shows a significant negative correlation with an R^2 value of 0.618. The data showed that with per unit addition of weed biomass negatively affected the yield to the tune of 0.61%.

It can be concluded that the pre-emergence application of glyphosate + pendimethalin gave the highest weed control efficiency and maximum yield was also obtained. Hence, pre-emergence herbicide application of tank mix of glyphosate 0.8 kg/ha + pendimethalin 1.5 kg/ha applied after mulching and just before the emergence of sprouts substantially reduced the labor requirement and higher economic returns were obtained compared to the complete hand weeding situation.

Table 3. Effect of weed management on weed indices at 90 DAS in ginger (2014-15 and 2015-16)

Treatment	Weed control efficiency (%)		Weed Index (%)		WPI	
	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Pendimethalin	26.5	24.3	30.39	32.89	0.82	0.70
Oxyfluorfen	35.6	34	21.83	23.99	0.69	0.77
Pendimethalin *fb* hand weeding	38.3	39.9	23.56	23.72	1.02	0.84
Oxyfluorfen *fb* hand weeding	38.2	34.8	17.02	15.7	0.84	0.72
Glyphosate	36.9	34.7	2.99	3.19	0.88	0.66
Glyphosate + pendimethalin	55.6	52	1.16	1.02	0.52	0.46
Glyphosate + oxyfluorfen	34.15	33.05	2.71	3.11	0.78	0.64
Hand weeding (4)	30.2	28.6	-	-	1.02	0.98
Weedy check	-	-	57.88	58.48	1.11	0.95

Table 4. Effect of weed management on rhizome yield, net returns and benefit: cost of ginger (pooled data of 2014-15 and 2015-16)

Treatment	Rhizome yield (t/ha)			Net returns (×10^4 Rs/ha)	Benefit: cost
	2014-15	2015-16	Pooled		
Pendimethalin	19.4	18.2	18.8	14.6	3.39
Oxyfluorfen	21.8	20.6	21.2	15.4	3.50
Pendimethalin *fb* hand weeding	22.4	19.6	21.0	15.4	3.39
Oxyfluorfen *fb* hand weeding	23.7	22.3	23.0	16.2	3.59
Glyphosate	24.6	23.2	23.9	16.5	3.72
Glyphosate+ pendimethalin	27.0	27.4	27.2	18.3	3.78
Glyphosate + oxyfluorfen	27.5	25.9	26.7	17.5	3.66
Hand weeding (4)	27.9	27.1	27.5	18.5	3.55
Weedy check	12.1	10.9	11.5	10.7	2.32
LSD (p=0.05)	0.94	0.87	0.84	0.75	0.42

REFERENCES

Baruah A and Deka J. 2020. Weed Management for Higher Productivity of Ginger (*Zingiber officinale)* in Plains of Assam. *Current Journal of Applied Science and Technology* **39**(31): 21–28.

Gill GS and Kumar V. 1969. Weed index, a new method for reporting weed control trials. *Indian Journal of Agronomy* **14**(2): 96–98.

Kallappa N, Shetty R, Nagaraj G, Ravi GP, Sudeep HP and Shivakumar HJ. 2015. Performance of ginger *(Zingiber officinale* Rosc.) varieties for yield and quality attributes under hill zone of Karnataka. *Ecology, Environment and Conservation* **21**(3): 259–262.

KAU (Kerala Agricultural University). 2006. In: Annual Progress Report of the AICRP on Weed management. Kerala Agricultural University, Vellanikkara, Thrissur pp.16.

Mani VS, Malla ML, Gautam KC and Das B. 1973. Weed killing chemicals in potato cultivation. *Indian Farming* **23**(1): 17–18.

Mishra M and Mishra A. 1997. Estimation of IPM index in Jute: A new approach. *Indian Journalof Weed Science* **29**(1):39–42.

Mishra MM, Dash R and Mishra M. 2016. Weed persistence, crop resistance and phytotoxic effects of herbicides in direct seeded rice. *Indian Journal of Weed Science***48** (1): 13–16.

Osunleti SO, Olorunmaiye PM, Adeyemi OR and Osunleti TO. 2021. Influence of different weed control methods on weed biomass, growth and yield of mango ginger (*Curcuma mada* Roxb.) in forest savannah transition agro-ecological zone of Nigeria. *Acta fytotechnica et zootechnica* **24**(4): 272–278.

Rekha BK, Raju MS and Reddy MD. 2003. Effect of herbicides on weed growth, grain yieldand nutrient uptake in rainfed lowland rice. *Indian Journal of Weed Science* **35**: 121–122.

Roy DK, Ranjan S and Sow S. 2023. Production potential and economics of integrated weed control measures in ginger. *Indian Journal of Weed Science* **55**(3): 328–332.

Sah D, Heisnam P, Mahato NK and Pandey AK.2017. Weed Management in Ginger (*Zingiber officinale* Roscoe) through Integrated Approaches. *International Journal of Current Microbiology and Applied Sciences* **6**(10): 1839–1845.

Srinivasan V, Thankamani CK, Dinesh R, Kandiannan K, Hamza S, Leela NK and Zachariah TJ. 2018. Variations in soil properties, rhizome yield and quality as influenced by different nutrient management schedules in rainfed ginger. *Agricultural Research* ***8***(8): 1–15.

Thankamani CK, Kandiannan K, Hamza S and Saji KV. 2016. Effect of mulches on weed suppression and yield of ginger (*Zingiber officinale* Roscoe). *Scientia Horticulturae*. 207: 125–130.

Indian Journal of Weed Science (2024) **56**(3): 301–306
http://dx.doi.org/10.5958/0974-8164.2024.00050.X

RESEARCH ARTICLE

Management of invasive aquatic weeds *Limnocharis* and *Monochoria* in wetland rice

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Received: 12 July 2024 | Revised: 21 September 2024 | Accepted: 24 September 2024

ABSTRACT

Aquatic weeds often pose a serious threat to wetland rice production. An experiment was conducted at All India Coordinated Research Project (AICRP) on Weed Management, Kerala Agricultural University, India to evaluate the performance of post-emergence herbicides for the management of two broad-leaf aquatic weeds *Limnocharis flava* and *Monochoria vaginalis* during the rainy *(Kharif)* and winter *(Rabi)* seasons of 2022. The experiment was laid out with eleven treatments, consisting of recommended dose of 2,4-D-sodium salt, penoxsulam + butachlor, penoxsulam + pendimethalin, metsulfuron-methyl + chlorimuron-ethyl, florpyrauxifen-benzyl, bispyribac-sodium, penoxsulam + cyhalofop-butyl, carfentrazone-ethyl, pretilachlor + pyrazosulfuron-ethyl, hand weeding at 20 and 40 days after transplanting and un-weeded control. Weed management treatments had significant effect on the weed density, weed dry matter, and crop yield. Post-emergence application of 2,4-D-sodium salt and florpyrauxifen-benzyl as well as hand weeding twice resulted in total control of both *Limnocharis falva* and *Monochoria vaginalis*. All the herbicides applied along with a wetting agent recorded 70-100% weed control efficiency. 2,4-D Na salt and hand weeding twice produced the highest grain yield and straw yields followed by florpyrauxifen-benzyl. Season-long weed competition caused 68% reduction in the grain yield in un-weeded plot. The findings provide an array of herbicides which can be included in herbicide rotation for broad-spectrum weed control, especially *Limnocharis* and *Monochoria* in wetland rice fields

Keywords: Correlation, Florpyrauxifen, Rice herbicides, Principal component analysis, Weed control efficiency

INTRODUCTION

A wide variety of aquatic weeds infest rice fields, including submerged, emergent, and floating species. Their rapid growth rates, efficient reproduction, and highly competitive ability reduce crop yield and impair ecosystem services. *Limnocharis flava* (L.) Buchenau, commonly known as water cabbage or yellow burr head, is an emergent aquatic plant belonging to the family Limnocharitaceae. It is native to tropical and subtropical America, and it has become naturalized in Southern and Southeast Asia, including parts of India. *L. flava* inhabits shallow swamps, ditches, and wet rice fields, occurring usually in stagnant fresh water. *Monochoria vaginalis* (Burm. f.) Kunth commonly called as oval-leaf pond weed or heartleaf false pickerel weed, is a submerged or emergent weed that features slender stems and lilac flowers. It is also a native of Southeast Asia and Africa, and now common in tropical and subtropical regions and reproduces both through seeds and vegetative means. It readily adapts to various water depths and thrives in nutrient-rich environments. Its rapid vegetative spread and high seed production facilitate its establishment and dominance in wetland rice fields (Brooks *et al*. 2008). In Iran, *Monochoria* reduced rice yields to the tune of 32% when the infestation lasted throughout the season (Hazrati *et al*. 2003). It is often gregarious and highly competitive because of its discontinuous germination, rapid growth, and high plasticity (Athira *et al*. 2019).

Severe infestation of these two weeds has been observed recently in the wetland rice ecosystems of Kerala. *L. flava* exhibits vigorous vegetative growth, smothering the rice crop by the time of harvest. During mechanized harvesting, weeds get along with the harvested rice grains, increasing their moisture content, creating conditions conducive for fungal growth. The mouldy appearance on the grains significantly impacts the quality and marketability of the produce.

Management of these aquatic weeds is not easy and varied strategies have to be adopted depending on the agro-ecology. Chemical management using herbicides is an easy and cost-effective option for managing aquatic weeds in wetland rice. Several herbicides such as paraquat, glyphosate, glufosinate ammonium, carfentrazone-ethyl, imazethapyr, 2,4-D, endothall, diquat, fluoridone, florpyrauxifen-benzyl,

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penoxsulam, cyhalofop-butyl, butachlor, and imazamox have been evaluated in different countries for management of these weeds with varying degree of success in tank cultures (Wersal and Madsen 2012, Garlich *et al*. 2021). The present study was conducted to evaluate the efficacy of new herbicide molecules against aquatic weeds *L. flava* and *M. vaginalis* in transplanted rice under wetland ecology of Kerala.

MATERIALS AND METHODS

The study was conducted at the State Seed Farm, Mannuthy (10°32’27"N 76°15’46"E), Kerala, India during rainy *(Kharif)* and early winter *(Rabi)* seasons of 2022. The study period extended from June to September and September to December. The average maximum temperature and minimum temperature were 30.2 °C and 23.6°C for *Kharif*, and 31.8°C and 23.4°C for early *Rabi*, respectively. The corresponding weather data are illustrated in **Figure 1**. The soil of the experimental field was clay loam (20.5% sand, 22.3% silt, and 57.28% clay) with a pH of 5.10, EC 0.004 dS/m, OC 0.82%, available N 265 kg/ha, available P 35 kg/ha, and available K 214 kg/ha.

The experiment was laid out in a randomized block design with eleven treatments replicated thrice. The treatments were 2,4-D Na salt (80 WP) 1000 g/ha (2,4-D); penoxsulam + butachlor (0.97+38.8 SE) 820 g/ha (PX + BU); penoxsulam + pendimethalin (1+24 SE) 625 g/ha (PX + PE); metsulfuron-ethyl + chlorimuron-ethyl (10+10WP) 4 g/ha (ME + CE); florpyrauxifen-benzyl (25 EC) 31.5 g/ha (FB); bispyribac-sodium (10SC) 25 g/ha (BS); cyhalofop-butyl + penoxsulam (5.1+1.02 OD) 150 g/ha (CY + PX); carfentrazone-ethyl (40 DF) 25 g/ha (CZE); pretilachlor + pyrazosulfuron-ethyl (30+0.75 WG) 600 + 15 g/ha (PR + PY); hand weeding at 20 and 40 DAT (HW); unweeded control (UWC). In the case of combination sprays, premix herbicides were used.

The rice variety ‘*Jyothi*’ (a short-duration high-yielding variety released from Kerala Agricultural University) was chosen for the experiment. The crop was transplanted at a spacing of 20 x 10 cm. FYM (5 t/ha) was incorporated at the time of the last ploughing. Fertilizers were applied 70:35:35kg/ha (N:P:K kg/ha). All the herbicides were applied as post-emergence at 18 DAT along with wetting agent 2ml/L. The spray volume used was 500 L/ha and backpack sprayer fitted with flat-fan nozzle was used for spraying.

Observations on density and dry weight of *L. flava* and *M. vaginalis* were recorded separately at 20, 40, and 60 DAT and at harvest. Weed control efficiency (WCE) was also computed. Yield and yield attributes were recorded at harvest.

Data on weed count and dry weight were subjected to square root transformation. The data generated were subjected to analysis of variance of RBD using the statistical package GRAPES (General R-shiny based Analysis Platform Empowered by Statistics) (Gopinath *et al*., 2023).

RESULTS AND DISCUSSION

Weed spectrum

The weed spectrum constituted *Limnocharis flava* (70%), *Monochoria vaginalis* (20%) and other weeds (10%) including *Echinochloa* spp., *Ludwigia parviflora* and *Sagittaria* sp.

Weed density and dry weight

Limnocharis flava

Treatments had significant effect on the density and dry weight of *L. flava* at 40 and 60 DAT and at harvest (**Table 1** and **2**). Post-emergence application of 2,4-D Na salt 1000 g/ha recorded the lowest weed density at 40 DAT during both seasons (1.00 and 1.67/m^2, respectively). However, at 60 DAT and

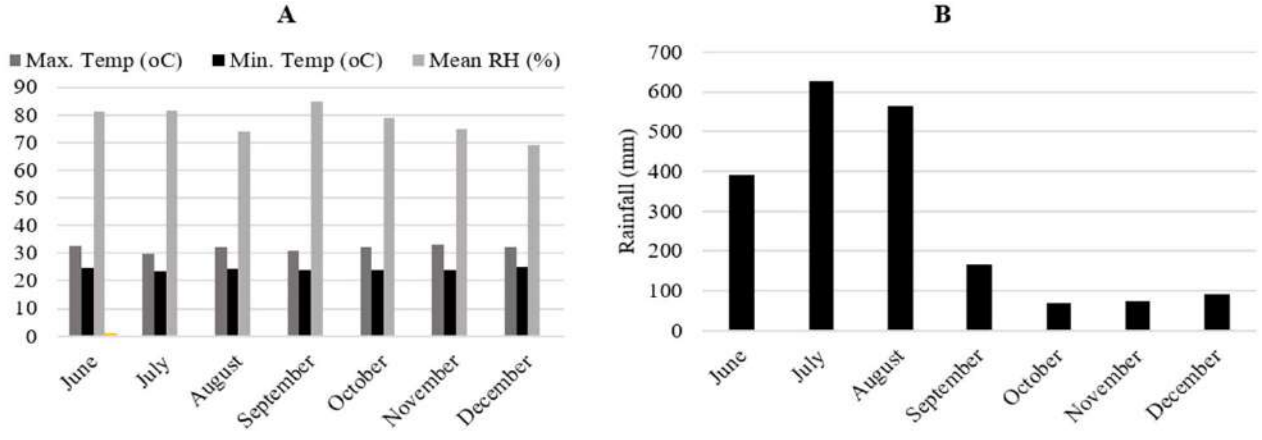


Figure 1. Monthly weather data - maximum and minimum temperature, mean relative humidity (A) and rainfall (B) during 2022

harvest, hand weeding twice registered the lowest weed density. All the herbicidal treatments were statistically comparable during both seasons at 40 DAT in terms of weed density. Un-weeded control had the highest weed density irrespective of the growth stages and seasons.

Post-emergence application of 2,4-D Na salt 1000 g/ha and florpyrauxifen-benzyl 31.5 g/ha registered negligible dry matter production of *L. flava* at 40 DAT during both the seasons, recording less than 1 g/m^2. At 60 DAT, all the herbicidal treatments recorded statistically comparable dry matter of weed during both seasons. HW twice at 20 and 40 DAT had a lower dry weight at all stages. The dry weight of *L. flava* was the highest in the unweeded control at all growth stages. Notably, the dry weight at harvest in the unweeded control was three times greater than that observed at 20 DAT

Monochoria vaginalis

The occurrence of *M. vaginalis* was observed exclusively during the *Kharif* season, attributed to the substantial rainfall from June to August (**Figure 1**). This weed was absent in the field during the later stages of the *Kharif* crop as well as during the *Rabi* season due to low rainfall. Chen and Kuo (1999) reported that flooding conditions and seasonal variation in light and temperature affected the seed germination of *Monochoria*. However, as *Limnocharis* can survive under wide regime of soil moisture and temperature (Lakitan *et al.* 2018); it was present in both seasons.

In the *Kharif* season, treatments had a significant effect on the density and dry weight of *M. vaginalis.* The weed density ranged from a maximum of 13 plants per square meter to a minimum of one plant per square meter. By 40 DAT, the post-emergence application of 2,4-D Na salt at 1000 g/ha resulted in the lowest density, while the un-weeded control exhibited the highest (**Figure 2**). All the herbicides were comparable with respect to weed density. In all the treatments the weed dry matter was less by 70 % over un-weeded plot.

Weed control efficiency

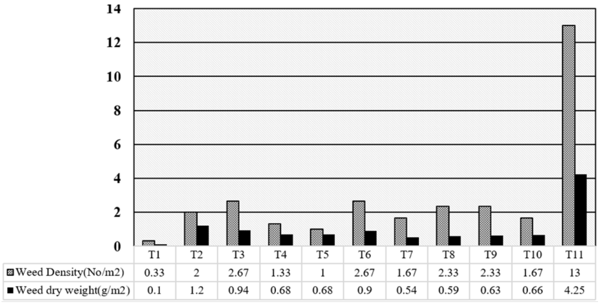
Limnocharis flava

Application of 2,4-D Na salt 1000 g/ha registered the highest weed control efficiency (WCE) during both seasons at 40 DAT (94 and 96 %, respectively), followed by bispyribac-sodium 25 g/ha in *Kharif* (91%) and florpyrauxifen-benzyl 31.5 g/ha in *Rabi* (93 %). In Malaysia, Juraimi, *et al* (2012) reported that though 2, 4-D is effective against *L. flava*, resistant

Table 1. Effect of weed management practices on density (no./m^2) of *L. flava* at different growth stages of rice

Treatment	20 DAT		40 DAT		60 DAT		Harvest	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
2,4-D Na salt, 1000 g/ha	3.62 (12.67)	4.18 (17.00)	1.17^{c} (1.00)	1.25^{d} (1.67)	2.99^{b} (8.67)	3.29^{e} (10.33)	3.64^{b} (12.77)	3.75^{d} (13.67)
Penoxsulam + butachlor, 820g/ha	3.81 (14.00)	4.03 (16.00)	1.68^{bc} (2.33)	2.10^{bcd} (4.00)	3.02^{b} (8.67)	4.01^{bc} (15.67)	2.90^{cd} (7.97)	4.22^{bcd} (17.33)
Penoxsulam + pendimethalin, 625g/ha	3.38 (11.00)	4.13 (16.67)	1.56^{bc} (2.00)	2.74^{b} (7.00)	2.88^{bc} (8.00)	4.18^{b} (17.00)	3.23^{bc} (10.17)	4.37^{b} (18.67)
Metsulfuron-ethyl + chlorimuron-ethyl, 4 g/ha	3.39 (11.00)	4.15 (17.00)	1.95^{b} (3.33)	2.36^{bc} (5.33)	3.12^{b} (9.33)	3.87^{bcd} (14.67)	3.09^{bcd} (9.07)	4.25^{bcd} (17.67)
Florpyrauxifen-benzyl, 31.5 g/ha	3.21 (10.00)	3.99 (15.67)	1.39^{bc} (1.67)	1.54^{cd} (2.33)	3.06^{b} (9.00)	3.44^{de} (11.33)	3.19^{bc} (9.93)	3.80^{cd} (14.00)
Bispyribac sodium, 25 g/ha	3.44 (11.33)	4.05 (16.00)	1.17^{c} (1.00)	2.90^{b} (8.00)	3.18^{b} (9.67)	3.85^{bcd} (14.33)	3.07^{bcd} (9.00)	4.37^{b} (18.67)
Cyhalofop-butyl + penoxsulam, 150 g/ha	3.23 (10.00)	4.41 (19.00)	1.46^{bc} (1.67)	2.54^{b} (6.00)	3.06^{b} (9.00)	3.89^{b} (14.67)	2.57^{cd} (6.13)	4.22^{bcd} (17.33)
Carfentrazone-ethyl, 25g/ha	3.28 (10.33)	3.96 (15.33)	1.47^{bc} (2.00)	2.46^{bc} (5.67)	3.11^{b} (9.33)	3.72^{cde} (13.33)	3.20^{bc} (9.93)	4.34^{b} (18.33)
Pretilachlor + pyrazosulfuron-ethyl, 600 + 15 g/ha	2.91 (8.00)	4.06 (16.33)	1.39^{bc} (1.67)	2.67^{b} (6.67)	2.72^{bc} (7.00)	4.14^{b} (16.67)	2.79^{cd} (7.43)	4.30^{bc} (18.00)
Hand weeding at 20 and 40 DAT	3.38 (11.00)	4.14 (16.67)	1.94^{b} (3.33)	2.59^{b} (6.33)	2.29^{c} (5.00)	2.47^{f} (5.67)	2.48^{d} (5.67)	3.23^{e} (10.00)
Un-weeded control	3.44 (11.33)	3.90 (15.00)	3.72^{a} (13.33)	4.00^{a} (15.67)	7.66^{a} (58.33)	9.28^{a} (85.67)	7.03^{a} (49.0)	8.94^{a} (79.67)
LSD (p=0.05)	NS	NS	0.749	0.92	0.667	0.444	0.665	0.519

*DAT – days after transplanting; In a column, means followed by common alphabet do not differ significantly at 5 % level in DMRT biotypes can tolerates four times the recommended dose. Nishan and George (2018) also noted the efficacy of ALS inhibiting herbicides like metsulfuron-methyl + chlorimuron-ethyl 6 g/ha or bispyribac-sodium 30 g/ha as substitutes for 2,4-D in managing *L. flava*. However, bispyribac-sodium 25 g/ha recorded the lowest WCE of 79% and 82% at 60 DAT among the herbicidal treatments during during *Kharif* and *Rabi*, respectively*)*. At 60 DAT, HW twice at 20 and 40 DAT resulted in the highest WCE of 91 and 94% during *Kharif* and *Rabi* respectively. All the herbicidal treatments recorded more than 70% WCE at harvest during both seasons (**Table 3**). Raj and Syriac (2015) reported good control of *Limnocharis w*ith the pre-mix herbicide (cyhalofop-butyl + penoxsulam, 130-135 g/ha). Penoxsulam and bispyribac-sodium were effective for management of *L. flava* where it showed resistance to 2,4-D (Zakaria 2018)



[Treatments : post-emergent application of -T$_1$ 2,4-D Na salt, 1000 g/ha; T$_2$: penoxsulam + butachlor, 820g/ha; T$_3$: penoxsulam + pendimethalin, 625 g/ha; T$_4$: metsulfuron-ethyl + chlorimuron-ethyl 4 g/ha; T5 : florpyrauxifen-benzyl 31.5 g/ha; T$_6$: bispyribac sodium 25 g/ha; T$_7$: cyhalofop-butyl + penoxsulam 150 g/ha; T$_8$: carfentrazone-ethyl 25g/ha; T$_9$: pretilachlor + pyrazosulfuron-ethyl 600 + 15 g/ha; T$_{10}$: hand weeding at 20 and 40 DAT; T$_{10}$: un-weeded control]

(LSD (p=0.05)- Weed density-2.66; Weed dry weight-0.95)

Figure 2. Effect of weed management practices on density (no./m^2) and dry weight (g/m^2) of *Monochoria vaginalis* at 40 DAT

Monochoria vaginalis

Weed control efficiency of various herbicides ranged from 72-98 %, 2,4-D being the superior treatment. All other herbicides registered weed control efficiency in the range of 72-86%. Pooled WCE data of *M. vaginalis* (**Table 4**) revealed that post-emergent application of 2,4-D Na salt registered the highest WCE of 95 % at 40 DAT followed by florpyrauxifen-benzyl (88 %). Premix herbicides (cyhalofop-butyl + penoxsulam) and (pretilachlor + pyrazosulfuron) were also effective. All the herbicidal treatments recorded 70-80 % WCE.

Crop yield

Application of 2,4-D Na salt 1000 g/ha and HW twice at 20 and 40 DAT produced higher and

Table 2. Effect of weed management practices on weed dry weight (g/m^2) of *L. flava* at different growth stages of rice

Treatment	40 DAT		60 DAT		Harvest	
	Kharif	*Rabi*	*Kharif*	*rabi*	*Kharif*	*Rabi*
2,4-D Na salt, 1000 g/ha	0.81$^{c(}$0.17)	0.82^{d}(0.20)	2.86$^{bc(}$7.70)	3.23$^{b(}$10.03)	3.97$^{b(}$15.33)	4.70^{b}(21.93)
Penoxsulam + butachlor, 820 g/ha	1.38$^{b(}$1.47)	1.55^{c}(1.90)	2.96$^{b(}$8.36)	3.46$^{b(}$11.7)	3.25$^{bcd(}$10.20)	4.66^{b}(21.63)
Penoxsulam + pendimethalin, 625 g/ha	1.14$^{bc(}$0.80)	1.53^{c}(1.83)	2.77$^{bc(}$7.21)	3.50^{b}(12.07)	3.63$^{bc(}$12.97)	4.51^{b}(20.03)
Metsulfuron-ethyl + chlorimuron-ethyl,4 g/ha	1.10$^{bc(}$0.72)	1.61^{c}(2.10)	3.06$^{b(}$9.07)	3.52^{b}(12.00)	3.23$^{cd(}$10.00)	4.74^{b}(22.17)
Florpyrauxifen-benzyl, 31.5 g/ha	1.02$^{bc(}$0.61)	0.94^{d}(0.40)	2.95$^{b(}$8.25)	3.21^{b}(9.90)	3.62$^{bc(}$12.80)	4.56^{b}(20.77)
Bispyribac sodium, 25 g/ha	0.92$^{c(}$0.37)	1.86^{b}(2.97)	3.16$^{b(}$10.00)	3.63^{b}(12.83)	3.50$^{bc(}$11.80)	5.13^{b}(26.00)
Cyhalofop-butyl + penoxsulam, 150 g/ha	1.16$^{bc(}$0.87)	1.53^{c}(1.83)	2.99$^{b(}$8.60)	3.59^{b}(12.43)	2.70$^{d(}$6.87)	5.06^{b}(25.40)
Carfentrazone-ethyl, 25 g/ha	0.95$^{bc(}$0.43)	1.56^{c}(1.93)	3.00$^{b(}$8.50)	3.33^{b}(10.60)	3.48$^{bc(}$11.90)	4.75^{b}(22.50)
Pretilachlor + pyrazosulfuron-ethyl, 600 + 15 g/ha	1.02$^{bc(}$0.60)	1.58^{c}(2.00)	2.63$^{bc(}$6.45)	3.53^{b}(12.07)	3.09$^{cd(}$9.23)	4.73^{b}(21.93)
Hand weeding at 20 and 40 DAT	1.00$^{bc(}$0.57)	1.47^{c}(1.70)	2.17$^{c(}$4.28)	2.17 $^{c(}$4.27)	2.62$^{d(}$6.47)	5.47^{b}(29.43)
Unweeded control	2.29$^{a(}$4.83)	2.57^{a}(6.100)	6.86$^{a(}$46.78)	8.41$^{a(}$70.17)	7.42$^{a(}$54.93)	10.0$^{a(}$99.47)
LSD (p=0.05)	0.432	0.226	0.715	0.725	0.729	1.001

*DAT – days after transplanting; In a column, means followed by common alphabet do not differ significantly at 5% level in DMRT

Table 3. Effect of treatments on weed control efficiency (%) of *L. flava*

Treatment	*Kharif*			*Rabi*		
	40 DAT	60 DAT	Harvest	40 DAT	60 DAT	Harvest
2,4-D Na salt, 1000 g/ha	94.44	83.59	71.97	96.15	85.60	77.70
Penoxsulam + butachlor, 820g/ha	71.57	81.79	80.93	68.30	83.15	78.05
Penoxsulam + pendimethalin, 625g/ha	80.81	84.14	75.47	71.97	82.89	79.98
Metsulfuron-ethyl + chlorimuron-ethyl, 4 g/ha	83.36	80.03	81.51	64.99	82.99	77.62
Florpyrauxifen-benzyl, 31.5 g/ha	82.60	82.41	76.98	93.21	85.77	78.87
Bispyribac sodium, 25 g/ha	91.27	78.58	78.06	50.38	81.67	73.95
Cyhalofop-butyl + penoxsulam, 150 g/ha	78.59	81.03	87.23	69.51	82.18	74.19
Carfentrazone-ethyl, 25g/ha	89.32	81.78	78.76	67.62	84.94	77.22
Pretilachlor + pyrazosulfuron-ethyl, 600 + 15 g/ha	87.57	85.89	82.55	66.53	82.75	77.79
Hand weeding at 20 and 40 DAT	88.10	90.63	88.35	70.94	93.90	70.28
Un-weeded control	0	0	0	0	0	0

*DAT – days after transplanting

statistically similar grain yield and straw yield followed by florpyrauxifen-benzyl 31.5 g/ha (**Table 5**). The grain yield ranged from 2765.73 to 3804.71 kg/ha in various treatments where herbicides were applied. The better yield in herbicide applied plots was the result of increased resource utilization by the crop due to decreased dry matter accumulation by the weeds. Season-long weed competition in unweeded check caused 68 % reduction in grain yield and 65 % reduction in straw yield compared to the treatments with the highest grain yield (HW twice at 20 and 40 DAT and 2,4-D Na salt 1000 g/ha). All other herbicidal treatments except florpyrauxifen-benzyl 31.5 g/ha were statistically comparable to each other in grain yield and straw yield.

Correlation analysis

The correlation analysis of weed density, weed dry matter production, weed control efficiency and grain yield of rice was also performed. The weed density was significantly and positively correlated with weed dry weight (r = 0.999; p=0.01) (**Table 6**). It implies that the grain yield of rice decreased with proportional increase in weed interference. A highly significant and negative correlation was found between weed dry weight with WCE (r = -1) and grain yield (r = -0.869) at 1% significance level. A significant and positive correlation was observed between WCE and grain yield (r = 0.868; p = 0.01). Zhou *et al*. (2021) also reported that more than 45% reduction in gross returns from rice when the Monochoria population increased from 0 to 24 plants/m^2.

Principal component analysis (PCA)

To assess variation among different treatments, parameters such as weed density, weed dry weight, and WCE along with grain yield from eleven treatments underwent PCA. The scree plot revealed two principal components (Dim1 and Dim2) within the data. The subsequent PCA plot illustrated that the first two principal components captured a substantial amount of variance, with PC1 and PC2 collectively explaining 100% of the total variance. PC1, labelled “Dim1 (95.2%),” primarily contributed to the data variance (95.2%), while PC2, labelled “Dim2 (4.8%),” accounted for a smaller percentage (4.8%) (**Figure 3**).

The biplot depicted a discernible impact of herbicide treatments on wetland rice yield. PC1 (95.2%) indicated a positive correlation with weed density and weed dry weight and a negative correlation with WCE and grain yield.

In the scree plot, four distinct clusters emerged. Cluster I (2,4-D, HW) exhibited the lowest weed density and weed dry weight but the highest grain yield. Cluster II (FB) displayed a moderately lower weed population and weed dry matter, coupled with a moderately higher grain yield compared to the control. Cluster III (BS, CZE, ME+CE, PX+BU, PR+PY, PX+PE, CY+PX) showed higher WCE but a lower grain yield compared to Cluster I and II. Cluster IV (UWC) featured the highest weed population and weed dry matter, accompanied by the lowest grain yield.

The two troublesome aquatic weeds in wetland rice that is *Limnocharis flava* and *Monochoria vaginalis* can be managed through herbicidal application. The post-emergent application of herbicides 2,4-D-sodium salt, penoxsulam + butachlor, penoxsulam + pendimethalin, metsulfuron-methyl +

Table 4. Effect of weed management practices on weed control efficiency (%) (pooled) of *M. vaginalis*

Treatment	40 DAT	60 DAT	Harvest
2,4-D Na salt, 1 kg/ha	95	85	75
Penoxsulam + butachlor, 820g/ha	70	83	80
Penoxsulam + pendimethalin, 625g/ha	76	84	78
Metsulfuron-ethyl + chlorimuron-ethyl, 4 g/ha	74	82	80
Florpyrauxifen-benzyl, 31.5 g/ha	88	84	78
Bispyribac sodium, 25 g/ha	71	80	76
Cyhalofop-butyl + penoxsulam, 150 g/ha	74	82	81
Carfentrazone-ethyl, 25g/ha	79	83	78
Pretilachlor + pyrazosulfuron-ethyl, 600 + 15 g/ha	77	84	80
Hand weeding at 20 and 40 DAT	80	92	79
Unweeded control	0	0	0

Table 5. Effect of treatments on yield of rice

Treatment	Grain yield (kg/ha)			Straw yield (kg/ha)		
	Kharif	*Rabi*	Pooled	*Kharif*	*Rabi*	Pooled
2,4-D Na salt, 1 kg/ha	2976.10	4597.67	3786.89	3967.33	5512.67	4740.00
Penoxsulam + butachlor, 820g/ha	2192.48	3498.00	2845.24	2921.00	4529.00	3725.00
Penoxsulam + pendimethalin,625g/ha	2107.78	3423.67	2765.73	2814.00	4481.00	3647.50
Metsulfuron-ethyl + chlorimuron-ethyl 4 g/ha	2133.13	3647.33	2890.23	2850.33	4484.33	3667.33
Florpyrauxifen-benzyl 31.5g/ha	2056.74	4555.67	3306.21	2741.33	5363.33	4052.33
Bispyribac-sodium 25 g/ha	2293.26	3541.00	2917.13	3055.67	4541.00	3798.34
Cyhalofop-butyl + penoxsulam 150 g/ha	1878.86	3597.67	2738.27	2503.67	4469.67	3486.67
Carfentrazone-ethyl 25 g/ha	2319.20	3544.67	2931.94	3092.67	4629.00	3860.84
Pretilachlor + pyrazosulfuron-ethyl 600 + 15 g/ha	2210.99	3409.33	2810.16	2949.00	4529.00	3739.00
Hand weeding at 20 and 40 DAT	3099.75	4509.67	3804.71	4130.67	5327.00	4728.84
Unweeded control	947.59	1476.33	1211.96	1173.67	2188.67	1681.17
LSD (p=0.05)	261.42	248.74	284.96	368.25	338.20	348.81

Table 6. Correlation matrix among weed parameters and grain yield

	Weed density	Weed dry weight	Weed control efficiency	Grain yield
Weed density	1	0.999***	-0.999***	-0.874***
Weed dry weight	0.999***	1	-1***	-0.869***
Weed control efficiency	-0.999***	-1***	1	0.868***
Grain yield	-0.874***	-0.869***	0.868***	1

The mean values of the two years' pooled data of the corresponding treatments were used
***indicates correlation is significant at 0.001 level (two tailed)

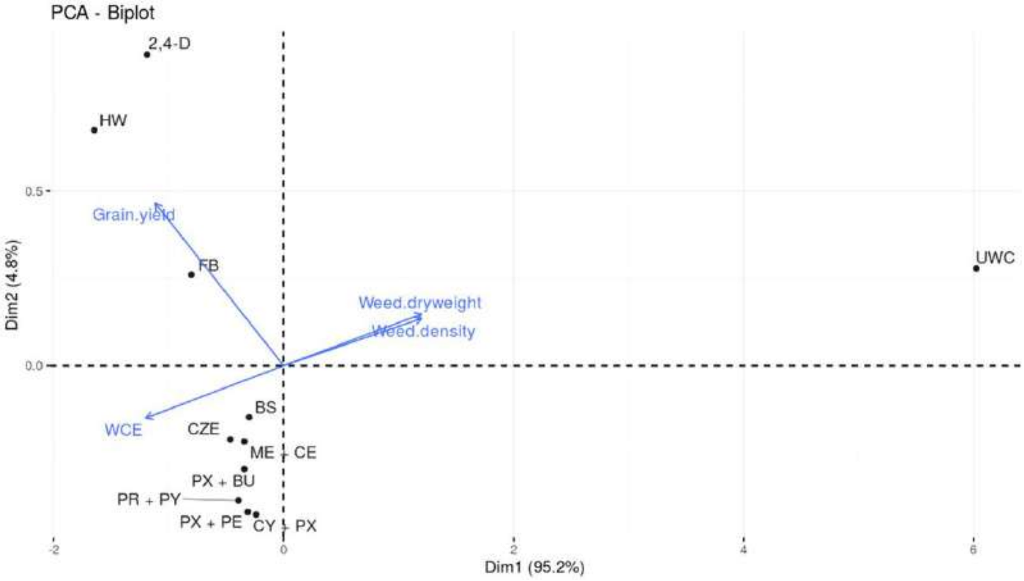


Figure 3. Principal component analysis of weed parameters and yield data. PC 1 and PC 2 jointly explained 100% of the total variation

chlorimuron-ethyl, florpyrauxifen-benzyl, bispyribac-sodium, penoxsulam + cyhalofop-butyl, carfentrazone-ethyl and pretilachlor + pyrazosulfuron- ethyl along with a wetting agent were effective in managing *Limnocharis flava* and *Monochoria vaginalis* in wetland rice.

REFERENCES

Athira GR, Menon MV, Sindhu PV and Prameela P. 2019. Seed germination and emergence ecology of *Monochoria vaginalis* (Burm. f.) Kunth. *Journal of Tropical Agriculture* **57**(2): 186–190.

Brooks SJ, Panetta FD, Galway KE. 2008. Progress towards the eradication of Mikania vine (*Mikania micrantha*) and Limnocharis (*Limnocharis flava*) in Northern Australia. *Invasive Plant Science and Management* **1**: 296–303, https://doi.org/10.1614/IPSM-08-067.1

Chen and Kuo. 1999. Seasonal changes in the germination of buried seeds of *Monochoria vaginalis*. *Weed Research* **39**(2): 107–115.

Garlich N, Garcia GL, De Oliveira AC, Dos Santos KP, Pitelli RA, Ferreira MC and Da Cruz C. 2021. Electrostatic spraying of imazamox to control the floating aquatic plant *Salvinia molesta* and its effects on environmental indicators of water quality. *Journal of Environment Science and Health* **56**(3): 251–258.

Gopinath PP, Prasad R, Joseph B, Adarsh VS. 2020. GRAPES: General R-shiny Based Analysis Platform Empowered by Statistics. DOI: 10.5281/zenodo .49 23220.

Hazrati Z, Yaghoubi B, Hosseini P and Chauhan BS. 2023. Herbicides for monochoria (*Monochoria vaginalis*) control in transplanted rice. *Weed Technology* **37**(6): 598–605.

Juraimi AS, Begum M, Anwar P, Shari ES, Sahid I and Man A. 2012. Controlling resistant *Limnocharis flava* (L.) Buchenau biotype through herbicide mixture. *Journal of Food Agriculture and Environment*. **10**. 1344–1348.

Lakitan B, Iwanaga H, Kartika K, Kriswantoro H and Sakagami JI. 2018. Adaptability to varying water levels and responsiveness to NPK fertilizer in yellow velvetleaf plant (*Limnocharis flava*). *Australian Journal of Crop Science* **12**(11):1757–1764.

Nishan MA and George S. 2018. Management of water cabbage [*Limnocharis flava* (L.) Buchenau] using new generation herbicides. *Agricultural Science Digest-A Research Journal* **38**(3): 228–230.

Raj SK and Syriac EK. 2015. Bio-efficacy of penoxsulam+ cyhalofop-butyl 6% OD, a new pre-mix herbicide mixture for weed control in direct seeded puddled irrigated rice (*Oryza sativa* L.). *Research on Crops* **16**(3): 406–415.

Wersal RM and Madsen JD. 2012. Combinations of diquat and carfentrazone-ethyl for control of floating aquatic plants. *Journal of Aquatic Plant Management* **50**: 46–48.

Zakaria N, Ahmad-hamdani MS, Juraimi AS. 2018. Patterns of resistance to AHAS inhibitors in *Limnocharis flava* from Malaysia. *Plant Protection Science* **54** (1):48–59. doi: 10.17221/131/2016-PPS.

Zhou W, Luo J, Li B, Tang L, Zheng X and Li Y. 2021. Effects of *Monochoria vaginalis* density on yield losses, economic thresholds, and gross returns in paddy rice (*Oryza sativa* L.). *Crop Science* **61**(5), doi: 10.1002/csc2.20564.

Indian Journal of Weed Science (2024) **56**(3): 307–311
http://dx.doi.org/10.5958/0974-8164.2024.00051.6

RESEARCH NOTE

Comparison of UAV and knapsack herbicide application methods on weed spectrum, crop growth and yield in dry direct-seeded rice

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Received: 12 January 2024 | Revised: 17 September 2024 | Accepted: 21 September 2024

ABSTRACT

A field experiment was conducted to compare the Unmanned Aerial Vehicle (UAV) and knapsack herbicide application on the diverse weed flora, growth and yield attributes of dry-direct seeded rice in randomized block design replicated thrice during 2023 at Pandit Jawaharlal Nehru College of Agriculture & Research Institute, Karaikal, Puducherry UT, India. Grasses dominated the weed flora, with 80.5% relative density of *Echinochloa colona*. UAV spray volume at 50 L/ha with application of pendimethalin + penoxsulam on 3 DAS 625 g/ha *fb* bispyribac-sodium on 20 DAS 25 g/ha reduced total weed density (39.4/m^2) and biomass (23.4 g/m^2), resulted better rice growth (plant height and tillers/plant), yield parameters (panicle weight and 1000 grain weight) and yield (3.87 t/ha). Negative linear relationship was observed between rice grain yield and total weed biomass at harvest stage. Uncontrolled weeds caused 65.6% yield loss in dry-DSR of the coastal deltaic ecosystem.

Keywords: Dry direct seeded rice, Herbicide dose, Unmanned aerial vehicle, Weed management

Rice (*Oryza sativa* L.) is the foremost staple food, sustains over half the world population. Conventional transplanted rice is cumbersome, demands huge amount of labour, energy, water and deteriorates soil health due to repeated tillage and puddling operations (Ojha and Kwatra 2014). So, direct-seeded rice (DSR) constitutes an emerging approach, where rice seeds are directly sown into dry soil, bypassing the need for water-filled nurseries and transplanting. One major challenge of DSR method is weed growth due to the absence of standing water. To tackle this, various weed management strategies were practiced. Initially, single application of herbicide became popular due to labour unavailability. But later, sequential application of herbicides proved more effective in sustaining weed suppression throughout the critical growth phase (Saravanane 2020) than single application.

Normally, manual knapsack sprayers were used to apply herbicides, requiring significant amounts of water, energy and time. Moreover, knapsack sprayers require higher spray liquid which leads to herbicide wastage. During recent times, Unmanned Aerial Vehicle (UAV) spray technology for herbicide applications emerges as a promising alternative to optimize the resource usage. This approach minimized herbicide wastage, water consumption, time investment and energy expenditure (Supriya *et al.* 2021) and increased the efficiency of herbicides making an efficient method for herbicide application. However, the utilization of UAVs is a new concept for spraying both pre- and post-emergence herbicides in this coastal region and the volume of efficient spray fluid was not standardized in dry-DSR for weed management practices. Hence, a field experiment was conducted to evaluate the efficacy of varying weed management options in UAV compared with standardized knapsack spray to manage the weeds in direct-seeded rice at Karaikal, Puducherry UT, India.

A field experiment was conducted at eastern research farm of Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry UT (10° 552 N latitude and 79° 492 E longitude, 4 m above mean sea level), India during February – April 2023 (Navarai season). The rainfall distribution is furnished in **Figure 1**. The soil was neutral in pH (6.61) with the texture of sandy clay loam, low in available N (141.1 kg/ha), high in available P (31.8 kg/ha) and medium in available K (188.8 kg/ha).

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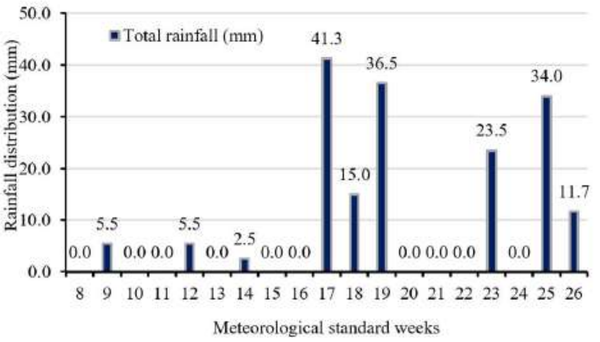

Figure 1. Rainfall prevailed during the cropping period from February to June 2023

The experiment was arranged in randomized block design replicated thrice with twelve treatments of varying spray fluids for UAV spray at 25, 50, 75 and 100 L/ha and knapsack spray fluid at 500 L/ha. Each spray fluid consisted of two herbicide concentrations, *viz*. 75% HRD (pendimethalin + penoxsulam on 3rd DAS at 468.8 g/ha *fb* bispyribac-sodium on 20th DAS at 18.8 g/ha) and 100% HRD (pendimethalin + penoxsulam on 3rd DAS at 625 g/ha *fb* bispyribac-sodium on 20th DAS at 25 g/ha). It also included hand weeding twice at 20 and 40 DAS and unweeded control.

Rice (cultivar '*ASD 16*' with duration of 110 days) was sown on the fourth week of February and harvested during the fourth week of June. Experimental area was ploughed twice using tractor-drawn cultivator and was levelled with power tiller for even water distribution, respectively. Germination test was conducted to determine the seed viability on the *ASD 16* certified seed, sown on petri dish and subsequently evaluated after 3 days. The results indicated average germination rate of 96.0%, highlighting the tested seeds to sprout and develop into healthy plants. Manual seeding was done with seed rate of 75 kg/ha, adopting a spacing of 15 cm x 10 cm and covered with soil. The size of the experimental plots was 12 m x 3.9 m. The field was surface irrigated immediately after the sowing with the water available in the farm ponds, to have enough moisture at pre-emergence herbicide application. Herbicides were applied using UAV and knapsack sprayer both fitted with a flat fan nozzle with water as a spray fluid at 25, 50, 75 and 100 L/ha for UAV and 500 L/ha for knapsack sprayer on both herbicide concentrations (75 and 100% herbicide recommended dose (HRD). Hand weeding was carried out in the experimental plots using hand hoe at 20 and 40 DAS. Entire quantity of phosphorus (50 kg/ha), ¼th of nitrogen (37.5 kg/ha) and ½ of potassium (25 kg/ha) were applied basal. Remaining nitrogen was applied in three equal splits starting from 15 DAS, maximum tillering stage and flowering stage. The remaining ½ of potassium was applied in two splits along with N at the maximum tillering stage and flowering stage, respectively. Pre-emergence and post-emergence herbicides were used as per the treatment. The data on weed density and dry matter accumulation were recorded at 60 DAS using quadrate size of 0.5 m x 0.5 m (Saravanane 2020) placed at two random places in each plot and the relative density (RD) was computed using standard formula. Weeds were uprooted at ground level during weed observation at 60 DAS, washed with running water, sun-dried, oven-dried at 70°C for 48 h, and then weighed to record weed biomass. Rice grain yield was measured from the net plot leaving the border rows and expressed in t/ha at 14% moisture content.

The data on weed density and dry weight was transformed to square root transformation ($\sqrt{x + 0.5}$) to normalize their distribution before analysis. Grain yield and weed biomass relationships at harvest were assessed using linear regression analysis. The experimental data were subjected to standard statistical analysis (Panse and Sukhatme, 1967).

Weed floristic composition

Experimental field infested with diverse weed flora comprised of five grasses (*Echinochloa colona*, *Echinochloa crus-galli*, *Dactyloctenium aegyptium*, *Leptochloa chinensis* and *Panicum repens*), eight broad-leaved weeds (*Cleome viscosa*, *Aeschynomene indica*, *Corchorus tridens*, *Eclipta alba*, *Ludwigia parviflora*, *Phyllanthus niruri*, *Sphaeranthus indicus* and *Trianthema portulacastrum*) and three sedges (*Cyperus difformis*, *Cyperus iria* and *Fimbristylis miliacea*) at 60 days after sowing (DAS). Analysis of the relative density revealed that *Echinochloa colona* was major weed species (80.5%) in the experimental field which was followed by *Cleome viscosa* (4.5%), *Leptochloa chinensis* (3.4%) and *Fimbristylis miliacea* (2.9%). This study revealed that dry DSR extremely favoured the growth of *Echinochloa colona* in the experimental field as it is an annual C_4 grass which made it heavy competitor for solar radiation, capacity to withstand high temperatures and required less moisture regime that made it dominant than any other weed species. The results also corroborated the finding of Wang *et al.* (2019). Nguyen *et al.* (2016) have suggested that higher temperatures made *E. colona* harder to control in less moisture regime.

Weed density, biomass and weed control efficiency

The weed density of all weed species was lowered in herbicide applied plots. But, *Echinochloa colona* density has significantly reduced in UAV spray of 50 and 25 L/ha with 100% HRD (36.7 and 47.3

weeds/m^2) and the density reduction was found to be 89.4 and 86.4% compared to the unweeded control (347.3 weeds/m^2) (**Table 1**). Lower spray fluid volumes result in more concentrated, potentially enhancing its effectiveness in inhibiting germinating weeds. The spray fluid of 25 and 50 L/ha were lower which made the herbicide dosage more concentrated compared to 75, 100 and 500 L/ha. Moreover, coverage under the spray fluid in 50 L/ha was better than 25 L/ha to cover the entire field. When pendimethalin + penoxsulam, a synergistic herbicide (Mann *et al*. 2016) was applied to the soil, it was absorbed via root hairs, which inhibited microtubule formation in weeds and controlled the weeds, particularly *E. colona*. Similar result was found by Khalik and Matloob (2012). When the bispyribac sodium (hydrophilic) was applied on the foliage, the presence of hydrophilic pectin strands in leaves made herbicide absorption easier. This inhibited the ALS pathway in post-emerged weeds. Similar result was aligned with Saravanane (2020) with the application of pendimethalin followed by bispyribac-sodium would effectively control the weeds, particularly *E. colona*.

The weed biomass of all weed species was reduced in herbicide applied plots. But, biomass of *Echinochloa colona* (22.2 and 25.3 g/m^2) had decreased significantly in UAV spray of 50 and 25 L/ha with 100% HRD and the biomass reduction was found to be 84.2 and 82.0% compared to the unweeded control (**Table 2**). The spray fluid of 25 and 50 L/ha was lower which made the herbicide dosage more concentrated compared to 75, 100 and 500 L/ha that effectively controlled the weeds. This led to reduction in weed biomass in the experimental field. However, the spray fluid of 25 L/ha was not sufficient to cover the entire field. Whereas, higher biomass was under unweeded control plots due to the absence of weed management practices leading to establishment of new weeds and resulting in higher accumulation of essential resources like sunlight, water and nutrients. Similar results were obtained with the findings of Pooja and Saravanane (2021) and Pavithra *et al.* (2021).

Weed control efficiency was influenced due to weed biomass recorded in various treatments (**Table 2**). Higher weed control efficiency (85.2%) was recorded in UAV spray of 50 L/ha with 100% HRD, which was followed by UAV spray of 25 L/ha with 100% HRD (83.5%). Comparatively, 100% HRD effectively controlled the weeds than 75% HRD because the dosage reduction did not effectively control the weeds in UAV and knapsack spray. Similar result obtained by Supriya *et al.* (2021) when the herbicide concentration was reduced for UAV application. The results of current study are also in

Table 1. Effect of various weed management treatments on weed density at 60 DAS in dry direct-seeded rice

Treatment	Weed density (no./m^2)							
	E. colona	*L. chinensis*	Other grasses	*F. miliacea*	Other sedges	*C. viscosa*	Other BLW	Total weeds
UAV spray of 25 L/ha with 75% of HRD	8.15	0.71	1.48	0.71	1.10	0.71	0.71	8.30
	(66.0)	(0.0)	(1.7)	(0.0)	(0.7)	(0.0)	(0.0)	(68.4)
UAV spray of 25 L/hawith 100% of HRD	6.92	1.35	1.34	1.35	0.71	0.71	0.71	7.19
	(47.3)	(1.3)	(1.3)	(1.3)	(0.0)	(0.0)	(0.0)	(51.2)
UAV spray of 50 L/ha with 75% of HRD	8.11	1.08	1.58	1.68	1.22	0.71	0.71	8.47
	(65.3)	(0.7)	(2.0)	(2.3)	(1.0)	(0.0)	(0.0)	(71.3)
UAV spray of 50 L/ha with 100% of HRD	6.10	0.71	1.79	0.71	0.71	0.71	0.71	6.32
	(36.7)	(0.0)	(2.7)	(0.0)	(0.0)	(0.0)	(0.0)	(39.4)
UAV spray of 75 L/ha with 75% of HRD	10.95	0.71	0.71	1.68	1.34	0.71	0.71	11.11
	(119.3)	(0.0)	(0.0)	(2.3)	(1.3)	(0.0)	(0.0)	(122.9)
UAV spray of 75 L/ha with 100% of HRD	9.16	1.47	1.87	0.71	1.58	0.71	0.71	9.51
	(83.3)	(1.7)	(3.0)	(0.0)	(2.0)	(0.0)	(0.0)	(90.0)
UAV spray of 100 L/ha with 75% of HRD	9.86	1.08	1.58	0.71	1.34	1.96	1.10	10.26
	(96.7)	(0.7)	(2.0)	(0.0)	(1.3)	(3.3)	(0.7)	(104.7)
UAV spray of 100 L/ha with 100% of HRD	9.16	1.87	2.35	1.78	1.58	0.71	0.71	9.82
	(83.3)	(3.0)	(5.0)	(2.7)	(2.0)	(0.0)	(0.0)	(96.0)
Knapsack spray of 500 L/ha with 75% of HRD	14.18	2.27	3.10	0.71	0.71	2.68	1.34	14.93
	(200.7)	(4.7)	(9.1)	(0.0)	(0.0)	(6.7)	(1.3)	(222.5)
Knapsack spray of 500 L/ha with 100% of HRD	12.51	1.08	2.43	1.87	0.71	0.71	1.10	12.90
	(156.0)	(0.7)	(5.4)	(3.0)	(0.0)	(0.0)	(0.7)	(165.8)
Hand weeding twice at 20 and 40 DAS	11.91	2.20	2.76	1.08	2.81	0.71	1.10	12.73
	(141.3)	(4.3)	(7.1)	(0.7)	(7.4)	(0.0)	(0.7)	(161.5)
Unweeded control	18.65	3.89	6.44	3.58	3.39	4.45	2.86	21.30
	(347.3)	(14.7)	(41.0)	(12.3)	(11.0)	(19.3)	(7.7)	(453.3)
LSD (p=0.05)	3.4	1.3	1.4	1.2	0.8	1.3	0.6	3.2

agreement with earlier findings of better weed suppression with proper use of sequential application of pre- and post-herbicides in DSR (Saravanane 2020 Pooja and Saravanane 2021).

Growth, yield attributes, yield and weed index

Implementing weed management measures led to better growth and yield attributes compared to the unweeded control (**Table 3**). Application of UAV spray at a rate of 50 L/ha with a 100% HRD resulted in increased plant height by 24.9 per cent (118.8 cm) compared to the unweeded control (95.1 cm). When weeds left uncontrolled, could induce stress on rice crops by competing for resources and hindering overall plant growth (Dass *et al.* 2017). Furthermore, UAV spray at 50 L/ha led to 40.4 percent increase in tillers (8.7 tillers per plant) compared to the unweeded control (6.2 tillers per plant), indicating improved tiller production due to reduced competition for resources among rice crops. Dass *et al.* (2017) agreed rice in weed-free plots exhibited higher tiller production due to the absence of weed competition.

Table 2. Effect of various weed management treatments on weed biomass and weed control efficiency at 60 DAS in dry direct-seeded rice

Treatment	Weed biomass (g/m^2)								WCE (%)
	E. colona	*L. chinensis*	Other grasses	*F. miliacea*	Other sedges	*C. viscosa*	Other BLW	Total weeds	
UAV spray of 25 L/ha with 75% of HRD	6.24 (38.4)	0.71 (0.0)	1.10 (0.7)	0.71 (0.0)	0.77 (0.1)	0.71 (0.0)	0.71 (0.0)	6.30 (39.2)	75.2
UAV spray of 25 L/hawith 100% of HRD	5.08 (25.3)	1.00 (0.5)	0.84 (0.2)	0.77 (0.1)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	5.16 (26.1)	83.5
UAV spray of 50 L/ha with 75% of HRD	5.94 (34.8)	0.87 (0.3)	1.10 (0.7)	0.77 (0.1)	0.77 (0.1)	0.71 (0.0)	0.71 (0.0)	6.04 (36.0)	77.2
UAV spray of 50 L/ha with 100% of HRD	4.76 (22.2)	0.71 (0.0)	1.30 (1.2)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	4.89 (23.4)	85.2
UAV spray of 75 L/ha with 75% of HRD	7.29 (52.7)	0.71 (0.0)	0.71 (0.0)	1.00 (0.5)	0.77 (0.1)	0.71 (0.0)	0.71 (0.0)	7.33 (53.3)	66.3
UAV spray of 75 L/ha with 100% of HRD	6.56 (42.6)	1.02 (0.5)	1.10 (0.7)	0.71 (0.0)	0.89 (0.3)	0.71 (0.0)	0.71 (0.0)	6.68 (44.1)	72.1
UAV spray of 100 L/ha with 75% of HRD	7.01 (48.6)	0.84 (0.2)	1.22 (1.0)	0.71 (0.0)	0.84 (0.2)	0.95 (0.4)	0.77 (0.1)	7.14 (50.5)	68.1
UAV spray of 100 L/ha with 100% of HRD	6.98 (48.3)	1.29 (1.2)	0.95 (0.4)	1.00 (0.5)	0.89 (0.3)	0.71 (0.0)	0.71 (0.0)	7.16 (50.7)	67.9
Knapsack spray of 500 L/ha with 75% of HRD	8.64 (74.1)	1.45 (1.6)	1.92 (3.2)	0.71 (0.0)	0.71 (0.0)	0.95 (0.4)	0.77 (0.1)	8.94 (79.4)	49.8
Knapsack spray of 500 L/ha with 100% of HRD	7.08 (49.7)	1.32 (1.2)	1.97 (3.4)	0.77 (0.1)	0.71 (0.0)	0.71 (0.0)	0.78 (0.1)	7.41 (54.5)	65.6
Hand weeding twice at 20 and 40 DAS	5.38 (28.4)	1.12 (0.8)	1.70 (2.4)	0.77 (0.1)	1.70 (2.4)	0.71 (0.0)	0.77 (0.1)	5.88 (34.2)	78.4
Unweeded control	11.88 (140.7)	2.28 (4.7)	1.61 (2.1)	1.41 (1.5)	2.07 (3.8)	2.02 (3.6)	1.48 (1.7)	12.59 (158.1)	–
LSD (p=0.05)	2.5	0.7	0.4	0.3	0.4	0.4	0.2	2.5	

Table 3. Effect of various weed management treatments on growth, yield and weed index in dry direct-seeded rice

Treatment	Plant height (cm)	Productive tillers/plant	Panicle weight (g)	1000 seed weight (g)	Grain yield (t/ha)	Weed index
UAV spray of 25 L/ha with 75% of HRD	113.9	8.5	2.7	22.0	3.39	12.1
UAV spray of 25 L/ha with 100% of HRD	114.9	8.5	2.8	22.3	3.66	5.3
UAV spray of 50 L/ha with 75% of HRD	117.1	8.7	2.8	22.2	3.40	11.6
UAV spray of 50 L/ha with 100% of HRD	118.8	8.7	2.8	22.9	3.87	–
UAV spray of 75 L/ha with 75% of HRD	110.9	8.4	2.4	22.0	2.92	24.2
UAV spray of 75 L/ha with 100% of HRD	105.7	8.0	2.4	22.0	3.22	16.1
UAV spray of 100 L/ha with 75% of HRD	110.6	8.2	2.5	21.9	2.83	26.3
UAV spray of 100 L/ha with 100% of HRD	112.6	7.1	2.8	21.7	3.12	18.7
Knapsack spray of 500 L/ha with 75% of HRD	111.7	8.2	2.0	21.8	2.82	26.6
Knapsack spray of 500 L/ha with 100% of HRD	109.5	8.0	2.6	21.4	2.92	24.4
Hand weeding twice at 20 and 40 DAS	109.2	7.1	2.4	21.7	2.71	29.8
Unweeded control	95.1	6.2	1.8	21.4	1.33	65.6
LSD (p=0.05)	6.2	0.8	0.6	NS	0.3	–

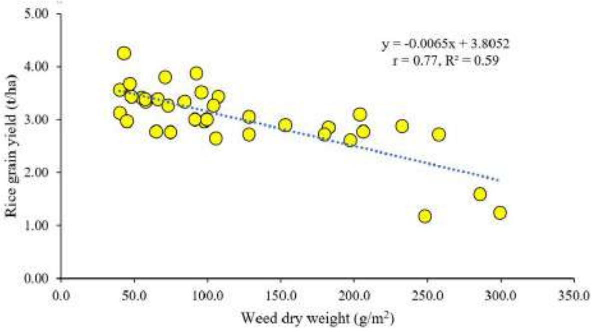

Figure 2. Relationship between grain yield and weed biomass at harvest stage in dry direct-seeded rice

UAV spray of 50 L/ha with 100% HRD significantly increased the grain yield compared to unweeded control. The efficient suppression of weed growth in 50 L/ha, enhanced nutrient absorption, higher interception of sunlight resulting in greater resource allocation of photosynthates to the yield-attributes, thus it increased the grain yield. Findings of Awan *et al*. (2015) proved higher grain yield was due to pre- and post-emergence herbicide application. Lower yield was recorded in unweeded control plots due to dense weed growth. Panicle weight was higher in UAV spray of 50 L/ha with 100% HRD and on par with UAV spray of 25 L/ha with 100% HRD (2.8 g). The response for 1000 grain weight was not significant among each other (**Table 3**). Poor filling and less panicle weight in unweeded control may be due to strong crop-weed competition for nutrient, space, light and carbon dioxide (Dass *et al*. 2017). The scatter plot reveals a strong negative correlation (r = 0.77, R^2 = 0.59, almost 0.60) between rice grain yield and weed dry weight, indicating that as weed dry weight increases, rice grain yield significantly decreases (**Figure 2)**. Application of UAV spray at 50 L/ha at 100 % HRD recorded lower weed index due lower weed density, biomass and higher weed control efficiency. But, when weeds were left uncontrolled throughout the growing season, pulled down the yield of dry-seeded rice to 65.6%. Earlier, yield losses due to weeds in dry direct seeded rice in coastal deltaic ecosystem were recorded from 51.9 to 93.1% (Pooja and Saravanane 2021 Saravanane 2020 Pavithra *et al*. 2021). When the spray volume decreased, drift also decreased and vice versa. Although controlling drift within the adjacent plot was challenging, it was manageable beyond the distance. Hence, using a lower spray volume can effectively control drift. Similar findings by Dengeru *et al*. (2022) indicated a significant reduction in drift after 5 meters from the treatment plot.

It was concluded that farmers can opt UAV spray of 50 L/ha with application of pendimethalin + penoxsulam on 3 DAS 625 g/ha *fb* bispyribac-sodium on 20 DAS 25 g/ha to effectively manage the diverse weed flora and enhance the rice yield of dry direct seeded rice in the coastal deltaic ecosystem of Karaikal, Puducherry UT.

REFERENCES

Awan TH, Cruz PCS and Chauhan BS. 2015. Agronomic indices, growth, yield-contributing traits and yield of dry-seeded rice under varying herbicides. *Field Crops Research* **177**: 15-25.

Dass A, Shekhawat K, Choudhary AK, Sepat S, Rathore SS, Mahajan G and Chauhan BS. 2017. Weed management in rice using crop competition-a review. *Crop protection* **95**: 45-52.

Dengeru Y, Ramasamy K, Allimuthu S, Balakrishnan S, Kumar APM, Kannan B and Karuppasami KM. 2022. Study on spray deposition and drift characteristics of UAV agricultural sprayer for application of insecticide in red gram crop (*Cajanus cajan* L. *Millsp*.). *Agronomy* **12**(12): 3196.

Khalik A and Matloob A. 2012. Germination and growth response of rice and weeds to herbicides under aerobic conditions. *International Journal of Agriculture and Biology*, **14**: 775–780.

Mann RK, Nguyen LN and Samanwong S. 2016. Synergetic herbicide composition containing penoxsulam and pendimethalin (Patent No. RU2597405C2). Russian Federation Patent Office. https://patents.google.com/patent/RU2597405C2

Nguyen TH, Malone JM, Boutsalis P, Shirley N and Preston C. 2016. Temperature influences the level of glyphosate resistance in barnyardgrass (*Echinochloa colona*). *Pest Management Science* **72**(5): 1031–1039.

Panse VG and Sukhatame PU. 1967. *Statistical Methods for Agricultural Workers*. ICAR, New Delhi.

Pavithra M, Poonguzhalan R, Narayanan AL and Saravanane P. 2021. Weed management in aerobic rice with sequential application of pendimethalin and bispyribac-sodium under coastal deltaic ecosystem. *Indian Journal of Weed Science* **53**(1): 85–87.

Pooja K and Saravanane P. 2021. Performance of rice cultivars with weed management practices in dry direct-seeded rice. *Indian Journal of Weed Science* **53**(1): 92–94.

Saravanane P. 2020. Effect of different weed management options on weed flora, rice grain yield and economics in dry direct-seeded rice. *Indian Journal of Weed Science* **52**(2): 102–106.

Supriya C, Muraliarthanari P, Kumaraperumal R and Sivamurugan AP. 2021. Optimization of Spray Fluid for Herbicide Application for Drones in Irrigated Maize (*Zea mays* L.). *International Journal of Plant and Soil Science* **33**(21): 137–145.

Wang Y, Mo S, Kong M, Chao J, Chen X, Yang J, Yan Y, Shi Z, Qiang S, Song X and Dai W. 2019. Better performance of germination in hyperosmotic solutions in conspecific weedy rice than cultivated rice. *Journal of Systematics and Evolution* **57**(5): 519–529.

Indian Journal of Weed Science (2024) **56**(3): 312–315
http://dx.doi.org/10.5958/0974-8164.2024.00052.2

RESEARCH NOTE

Chemical weed control strategies in grain sorghum

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Received: 3 March 2024 | Revised: 4 August 2024 | Accepted: 8 August 2024

ABSTRACT

A field investigation was carried out during rainy *(Kharif)* 2022 at the Instructional Farm, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, India (*Sorghum bicolor* (L.) Moench). The study involved twelve treatments, including pre-emergence application of atrazine and bentazone, both either alone or in combination and atrazine in combination with varying doses of 2,4-D dimethylamine salt, mesotrione and topramezone as well as mechanical and hand weeding practices. and it was found that application of atrazine 500 g/ha PE *fb* mechanical weeding at 30 DAS registered the lowest density and dry matter of monocot, dicot and total weeds at 30 DAS (0.00) along with highest grain yield (3.88 t/ha), net return (₹ 82966/ha) and B C ratio (2.57). this treatment further registered a gain of 70.6 and 92.7% gain in grain yield and net return over weedy check.

Keywords: 2,4-D, Atrazine, Bentazone, Mesotrione, Sorghum, Topramezone, Weed management

Sorghum (*Sorghum bicolor* (L.) Moench), known as ‘jowar’ in Hindi speaking belt of India, holds a vital position in global cereal production, especially in regions with semi-arid climates. Weeds pose a significant challenge to sorghum cultivation, reducing yields substantially by 15-97% (Thakur *et al*. 2016), prompting the need for effective management strategies. Chemical weed control, notably with atrazine, which is cost-effective and efficient, faces resistance challenges (Vinayaka *et al.* 2020). The advent of p-hydroxy-phenyl-pyruvate dioxygenase (HPPD) inhibitive herbicides, such as topramezone and tembotrione, marks a pivotal shift, offering comprehensive weed control while addressing resistance problems. Additionally, integrating mechanical techniques with pre and post-emergence herbicides proves to be an effective strategy, synergistically curbing weed growth and promoting optimal crop development (Verma *et al*. 2017). This study aims to identify sustainable weed management practices in sorghum for semi-arid regions of the country.

A field investigation was carried out during rainy *(Kharif)* 2022 at the Instructional Farm, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur (24° 35’ N, 73° 42’ E, 579.5 m above mean sea level). The soil of the experimental site was non-saline (electrical conductivity: 0.76 dS/m), alkaline (8.1 pH), sandy clay loam soil with medium organic carbon (0.61%), available N and K (286.4 and 354.4 kg/ha) and high available P (21.2 kg/ha). Sorghum variety ‘*SPV 2510*’ was sown on 2nd July 2022 at a crop geometry of 45 x 15 cm and was later thinned to one plant per stand at 15 DAS. Fertilizers, *viz*. 80 kg N, 40 kg P and 40 kg K/ha were applied as recommended for grain sorghum in the area. Application of herbicides was done as per treatment with knapsack sprayer using 500 litres of water per hectare. A rainfall of 699.1 mm was received during the crop season (*Kharif* 2022) and the crop did not face any moisture stress. The experiment comprising 12 weed management treatments *i.e.*, atrazine 750 ha PE *fb* 2,4-D ethyl ester 500 g/ha PoE, atrazine 750 g/ha PE *fb* 2,4-D dimethylamine salt 750 g/ha PoE, atrazine + mesotrione (RM) 438 g/ha PoE, atrazine + mesotrione (RM) 656 g/ha PoE, atrazine 500 g/ha + topramezone 18.9 g/ha EPoE (tank mix), atrazine 500 g/ha + topramezone 25.2 g/ha EPoE (tank mix), atrazine 500 g/ha PE *fb* mechanical weeding at 30 DAS, bentazone 960 g/ha PoE, atrazine 500 g/ha PE, atrazine 500 g/ha PE *fb* bentazone 960 g/ha PoE, two hand weeding at 20 DAS and 40 DAS and weedy check was laid out in a randomized complete block design (RCBD) with 3 replications. Data on species-wise weed density (no./m^2) was recorded at 30 DAS at 3 quadrates of 0.5 × 0.5 m/plot. These weeds were categorized as monocots and dicots and their dry weight was recorded. Data on weed density and

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weed dry matter was subjected to $\sqrt{x+0.5}$ transformation before analysis. However, for better understanding, original values are given in parenthesis. Weed control efficiency (WCE %) was calculated as per the standard formulae considering weed dry matter. At harvest, the plant population in each net plot was counted and and converted to 000/ha. Data on yield attributes were recorded from 5 randomly selected plants, while yield was on net plot basis at harvesting. Based on the phytotoxicity-rating scale (PRS) for the sprayed herbicides, observations of phytotoxicity were done on sorghum plants at 7, 14, and 21 days after treatment (DAT) at 0-10 scale. All the parameters were subjected to statistical analysis at 5% level of significance and interpretation as per Gomez and Gomez (1984).

The weed flora in the sorghum field at the experimental location was *Echinochloa colona* (L.) Link (25.75%)., *Commelina benghalensis* (L.) Beauv. (22.29%), *Setaria glauca* (L.) (15.17%) and *Eleusine indica* (L.) (13.79%) among monocot weed species whereas, *Physalis minima* L. (11.04%) and *Digera arvensis* L. (11.95%) were major dicot weeds. Verma *et al.* (2022) also reported the domination of these monocot and dicot weeds in sorghum.

When compared to weedy check, weed management techniques dramatically decreased the number of weeds and their dry weight (**Table 1**). The lowest values of weed density and weed dry weight were recorded with the application of atrazine 500 g/ha PE *fb* mechanical weeding at 30 DAS and atrazine 500 g/ha + topramezone 25.2 g/ha EPoE (tank mix). This might be due prolonged effectiveness of HPPD inhibiting herbicide which reduced weed growth by targeting photosystem II of both grassy and broadleaved weeds. Further, atrazine supplemented with mechanical weeding reduced the weed density and dry matter. The present study's outcomes are consistent with the research conducted by Verma *et al.* (2022) in sorghum. Moreover, atrazine 500 g/ha PE *fb* mechanical weeding at 30 DAS and atrazine 500 g/ha + topramezone 25.2 g/ha EPoE (tank mix) produced the maximum weed control efficacy (**Table 2**). The variation in weed control efficiency is directly

Table 1. Effect of weed management on weed density at 30 DAS

Treatment	Weed density (no./m^2)						Weed dry matter (g/m^2)					
	Echinochloa colona	*Eleusine indica*	*Setaria glauca*	*Commelina benghalensis*	*Physalis minima*	*Digera arvensis*	*Echinochloa colona*	*Eleusine indica*	*Setaria glauca*	*Commelina benghalensis*	*Physalis minima*	*Digera arvensis*
Atrazine 750 g/ha PE *fb* 2,4-D ethyl ester 500 g/ha PoE	2.50 (6.00)	2.29 (5.00)	2.34 (5.00)	2.39 (5.33)	1.93 (3.33)	2.21 (4.50)	2.37 (5.10)	2.17 (4.25)	2.18 (4.25)	2.24 (4.53)	1.82 (2.83)	2.08 (3.83)
Atrazine 750 g/ha PE *fb* 2,4-D dimethylamine salt 750 g/ha PoE	2.58 (6.33)	2.36 (5.33)	2.43 (5.67)	2.45 (5.67)	2.12 (4.00)	2.32 (5.00)	2.42 (5.38)	2.24 (4.53)	2.30 (4.82)	2.30 (4.82)	1.97 (3.40)	2.18 (4.25)
Atrazine + mesotrione (RM) 438 g/ha PoE	2.18 (4.33)	2.10 (4.00)	2.03 (3.75)	1.90 (3.22)	1.68 (2.33)	1.91 (3.17)	2.03 (3.68)	1.97 (3.40)	1.92 (3.19)	1.80 (2.74)	1.57 (1.98)	1.79 (2.69)
Atrazine + mesotrione (RM) 656 g/ha PoE	1.94 (3.33)	1.86 (3.11)	1.84 (2.95)	1.74 (2.56)	1.43 (1.56)	1.77 (2.67)	1.82 (2.83)	1.77 (2.64)	1.73 (2.51)	1.63 (2.17)	1.34 (1.32)	1.66 (2.27)
Atrazine 500 g/ha + topramezone 18.9 g/ha EPoE (tank mix)	2.00 (3.67)	2.04 (3.67)	1.87 (3.11)	1.82 (2.83)	1.44 (1.83)	1.82 (2.89)	1.87 (3.12)	1.90 (3.12)	1.77 (2.64)	1.70 (2.41)	1.42 (1.56)	1.72 (2.46)
Atrazine 500 g/ha + topramezone 25.2 g/ha EPoE (tank mix)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Atrazine 500 g/ha PE *fb* mechanical weeding at 30 DAS	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Bentazone 960 g/ha PoE	2.41 (5.33)	2.31 (4.83)	2.23 (4.50)	2.31 (4.83)	1.91 (3.17)	2.14 (4.11)	2.24 (4.53)	2.15 (4.11)	2.08 (3.83)	2.14 (4.11)	1.78 (2.69)	1.99 (3.49)
Atrazine 500 g/ha PE	2.73 (7.00)	2.54 (6.00)	2.55 (6.00)	2.58 (6.17)	2.41 (5.33)	2.41 (5.33)	2.54 (5.95)	2.36 (5.10)	2.37 (5.10)	2.40 (5.24)	2.24 (4.53)	2.24 (4.53)
Atrazine 500 g/ha PE *fb* bentazone 960 g/ha PoE	2.27 (4.67)	2.21 (4.38)	2.16 (4.17)	2.15 (4.22)	1.80 (2.75)	2.09 (3.89)	2.11 (3.97)	2.05 (3.73)	2.01 (3.54)	2.00 (3.59)	1.68 (2.34)	1.95 (3.30)
Two hand weeding at 20 DAS and 40 DAS	1.83 (2.89)	1.68 (2.33)	1.78 (2.67)	1.48 (1.78)	1.09 (0.78)	1.58 (2.00)	1.71 (2.46)	1.57 (1.98)	1.66 (2.27)	1.40 (1.51)	1.05 (0.66)	1.48 (1.70)
Weedy check	6.15 (37.3)	4.53 (20.0)	4.74 (22.0)	5.73 (32.3)	4.06 (16.0)	4.22 (17.3)	5.68 (31.7)	4.18 (17.0)	4.38 (18.70)	5.29 (27.48)	3.75 (13.60)	3.90 (14.73)
LSD (p=0.05)	0.54	0.56	0.50	0.51	0.45	0.41	0.32	0.24	0.17	0.28	0.24	0.21

Data subjected to $\sqrt{x+0.5}$ transformation and figures in parentheses are original weed count and weed dry matter.

associated with the amount of weed biomass accumulated under various treatments. Further, the integration of herbicide with weeding resulted in higher weed control efficiency which was also reported by Vinayaka *et al.* (2020) in sorghum.

Yield and economics of sorghum

The highest grain yield was recorded with atrazine 500 g/ha PE *fb* mechanical weeding at 30 DAS (**Table 2**). However, it was at par with two hand weeding at 20 and 40 DAS and atrazine 750 g/ha PE *fb* 2,4-D Ethyl ester 500 g/ha PoE. The highest stover and biological yield were observed in atrazine 500 g/ha PE *fb* mechanical weeding 30 DAS which was at par with stover and biological yield of two hand weeding at 20 and 40 DAS. This increased yield can be attributed to improved weed management, which eliminated competition for resources and provided favourable conditions such as increased availability of nutrients, moisture and light for the crop plants. In contrast, the application of atrazine 500 g/ha + topramezone 25.2 g/ha EPoE (tank mix), atrazine 500 g/ha + topramezone 18.9 g/ha EPoE (tank mix) and atrazine + mesotrione (RM) 656 g/ha resulted in lower crop growth despite achieving higher weed control efficiency. This can be attributed to phytotoxicity, which adversely affected the growth and yield of sorghum. These outcomes are highly consistent with the findings of Vinayaka *et al.* (2020) in sorghum. The maximum net returns (**Table 2**) were realized by applying atrazine 500 g/ha PE *fb* mechanical weeding at 30 DAS which was succeeded by atrazine 750 g/ha PE *fb* 2,4-D Ethyl ester 500 g/ha PoE. The highest B C ratio was achieved by weed control through atrazine 500 g/ha PE *fb* mechanical weeding at 30 DAS which was superior to the remaining treatments. The comparatively lower cost of treatment application coupled with a good economic yield might be the reason for higher net monetary return and B C ratio. The outcomes of the current study are cognizant of the findings of Mahto *et al.* (2020).

Phytotoxicity scoring

The data about phytotoxicity scoring at different intervals is depicted in **Table 3**. The data highlights that slight injury was observed in atrazine + mesotrione (RM) 438 g/ha PoE, atrazine + mesotrione (RM) 656 g/ha PoE, atrazine 500 g/ha + topramezone 18.9 g/ha EPoE (tank mix), bentazone 960 g/ha PoE and atrazine 500 g g/ha PE *fb* Bentazone 960 g/ha PoE. The highest phytotoxicity was recorded in atrazine 500 g/ha + topramezone 25.2 g/ha EPoE (tank mix) which causes moderate toxicity on crop plants. Identical results were also published by Verma *et al.* (2018).

Table 2. Effect of weed management on weed control efficiency, plant population grain, stover and biological yield and harvest index

Treatment	Weed control efficiency (%)	Plant population at harvest (000/ha)	Grain yield (t/ha)	Stover yield (t/ha)	Biological yield (t/ha)	Harvest Index (%)	Net returns (₹/ha)	B-C ratio
	Total weeds							
Atrazine 750 g/ha PE *fb* 2,4-D ethyl ester 500 g/ha PoE	79.88	183	3.39	10.18	1.38	24.99	70185	2.28
Atrazine 750 g/ha PE *fb* 2,4-D dimethylamine salt 750 g/ha PoE	77.93	180	3.32	9.95	1.36	24.90	67644	2.18
Atrazine + mesotrione (RM) 438 g/ha PoE	85.64	150	1.89	5.76	7.65	24.64	25040	0.80
Atrazine + mesotrione (RM) 656 g/ha PoE	88.84	141	1.69	5.07	6.77	25.06	17697	0.54
Atrazine 500 g/ha + topramezone 18.9 g/ha EPoE (tank mix)	87.59	145	1.82	5.47	7.30	24.87	21316	0.65
Atrazine 500 g/ha + topramezone 25.2 g/ha EPoE (tank mix)	100.00	125	1.46	4.38	5.84	25.00	9262	0.27
Atrazine 500 g/ha PE *fb* mechanical weeding at 30 DAS	100.00	195	3.88	11.63	15.50	24.93	82966	2.57
Bentazone 960 g/ha PoE	81.52	156	1.99	5.99	7.99	24.94	28996	0.95
Atrazine 500 g/ha PE	75.28	174	3.17	9.52	12.69	24.96	65041	2.22
Atrazine 500 g/ha PE *fb* bentazone 960 g/ha PoE	83.38	161	2.19	6.57	8.75	24.93	33569	1.06
Two hand weeding at 20 DAS and 40 DAS	91.41	188	3.65	11.02	14.67	24.92	66516	1.57
Weedy check	0.00	101	1.14	3.53	4.67	24.46	6040	0.21
LSD (p=0.05)	-	0.20	0.53	0.93	1.30	**NS**	12.58	0.38

Table 3. Effect of weed management on visual phytotoxicity scoring of herbicides at different stages

Treatment	Herbicidal phytotoxicity (0-10)		
	7 DAHA	14 DAHA	21 DAHA
Atrazine 750 g/ha PE *fb* 2,4-D ethyl ester 500 g/ha PoE	0	0	0
Atrazine 750 g/ha PE *fb* 2,4-D dimethylamine salt 750 g/ha PoE	0	0	0
Atrazine + mesotrione (RM) 438 g/ha PoE	2	1	0
Atrazine + mesotrione (RM) 656 g/ha PoE	3	2	0
Atrazine 500 g/ha + topramezone 18.9 g/ha EPoE (tank mix)	3	2	0
Atrazine 500 g/ha + topramezone 25.2 g/ha EPoE (tank mix)	4	2	0
Atrazine 500 g/ha PE *fb* mechanical weeding at 30 DAS	0	0	0
Bentazone 960 g/ha PoE	2	1	0
Atrazine 500 g/ha PE	0	0	0
Atrazine 500 g/ha PE *fb* bentazone 960 g/ha PoE	2	1	0
Two hand weeding at 20 DAS and 40 DAS	0	0	0
Weedy check	0	0	0

Conclusion

The study found that applying atrazine at a rate of 500 g/ha followed by mechanical weeding at 30 days after sowing (DAS) emerged as the most effective herbicide weed management strategy for rainy season grain sorghum in Rajasthan. However, the investigation also revealed that while newer post-emergence herbicides like topramezone and tembotrione exhibited high efficacy in weed control, their application at tested doses resulted in significant phytotoxicity, rendering them currently impractical. Further research avenues should explore the possibility of testing these herbicides at lower doses for effective weed management.

REFERENCES

Mahto R, Kumar C and Singh R K. 2020. Weed management in maize (*Zea mays* L.) through 4-hydroxyphenylpyruvate dioxygenase inhibitor herbicide with or without a methylated seed oil adjuvant. *Pesticide Research Journal* **32**(1): 179–185.

Thakur N, Kushwaha, B, Girothia O, Sinha N & Mishra J. 2016. Effect of integrated weed management on growth and yields of rainy-season sorghum (Sorghum bicolor). *Indian Journal of Agronomy* **61**(2): 217–222.

Verma A, Gangaiah B and Tonapi V. 2022. Efficacy of p-hydroxy-phenyl-pyruvate dioxygenase enzyme-inhibitive tembotrione and topramezone herbicides for weed management in rainy season grain sorghum (*Sorghum bicolor*). *Indian Journal of Agronomy* **67**(2): 67–73.

Verma B R, Virdia H M and Kumar D. 2017. Effect of integrated weed management on yield, quality and economics of summer sorghum (*Sorghum bicolor). International Journal of Current Microbiology and Applied Sciences* **6**(8): 1630–1636.

Verma G S K, Meena R S, Maurya AC and Kumar S. 2018. Nutrients uptake and available nutrients status in soil as influenced by sowing methods and herbicides in *kharif* maize (*Zea mays* L.). *International Journal of Agriculture, Environment and Biotechnology* **11**(1): 17–24.

Vinayaka S S, Krishnamurthy D, Channabasavanna A S, Ramesha Y M and Bhanuvalli M. 2020. Effective weed management practices in *kharif* sorghum (*Sorghum bicolor* L.) for higher yield and economics. *International Journal of Farm Sciences* **33**(3): 330–337.

Indian Journal of Weed Science (2024) **56**(3): 316–318
http://dx.doi.org/10.5958/0974-8164.2024.00053.9

RESEARCH NOTE

Quality parameters and root nodules of soybean as influenced by weed management practices

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Received: 27 October 2023 | Revised: 24 July 2024 | Accepted: 27 July 2024

ABSTRACT

A field experiment was conducted at Agricultural Research Station, Ummedganj, Kota during rainy *(Kharif)*, 2019 to study the comparative efficacy of pre- and post-emergence herbicides in managing weeds and improving productivity and quality of soybean (*Glycine max* L. Merrill). The experimental field was infested with grassy weeds, broad-leaved weeds and sedges. Maximum number and dry weight of root nodules/plant recorded in hand weeding twice at 20 and 40 days after sowing (DAS) followed by application of acifluorfen-sodium 16.5% + clodinafop-propargyl 8% (pre-mix) 165 + 80 g/ha at 20 DAS, at 50 days after sowing. The lowest dry weight of root nodules/plant was recorded under weedy check. Significantly higher protein content and protein yield were recorded under two hand weeding at 20 and 40 DAS found maximum protein yield followed by application of acifluorfen-sodium 16.5% + clodinafop-propargyl 8% EC (pre-mix) 165 + 80 g/ha at 20 DAS. Oil content in seeds was not significantly influenced by different weed control treatments whereas, oil yield was significantly enhanced by them over weedy check. Oil and protein yield are largely a function of seed yield. Strong positive correlation between oil, protein yield and seed yield support the fact. The data further revealed that two hand weeding at 20 and 40 DAS recorded maximum oil yield followed by application of acifluorfen-sodium 16.5% + clodinafop-propargyl 8% EC (pre-mix) 165 + 80 g/ha at 20 DAS.

Keywords: Herbicides, Protein, Soybean, Oil, Root nodules, Yield

Soybean [*Glycine max* (L.) Merrill] is also known as golden/miracle/wonder bean crop because it contains 38–42% good quality protein, 18–20% oil, rich in polyunsaturated fatty acids, good amount of minerals (Ca, P, Mg, Fe and K) and vitamins especially B-complex and tocopherols. It provides high amounts of phyto-chemicals and good quality dietary fibre which enables to protect human body against cancers and diabetes (Chouhan 2007). Soybean plays a pivotal role in meeting the continuously increasing demand of the edible oil across the world; it contributes 25% in total edible oil production. Presently soybean is contributing 42 percent share of total oilseed and 22 percent to total edible oil production in the country (ICAR-IISR 2023). With increase in population the demand of edible oil is increasing and 40 percent of the demand is being fulfilled by different oilseed crops and rest 60 percent demand is being made up by import. The cost of import of edible oil put a high pressure on our foreign exchange. Among all the oilseed crops, soybean is having the highest potential to meet the challenge of being self-sufficient in production of edible oil. The national productivity of soybean (1.16 t/ha) is quite lower than the world average (2.76 t/ha).

Soybean is a rainy season crop and it faces severe crop weed competition during growth phases. Yield reductions in soybean due to poor weed management ranges from 12 to 85% depending on weed flora and their density (Nagaraju and Kumar 2009). Although weeds pose problems during the entire crop period but maintaining weed free condition during critical period (first 45 days after sowing) is very much essential (Hosmath 2014). Therefore, keeping in view the present study was undertaken to find out the effect of different weed management practices on root nodules and quality parameters of soybean.

The experiment was conducted at Agricultural Research Station, Ummedganj, Kota (Rajasthan), India during rainy *(Kharif)*, 2019. The experiment was laid out in randomized block design with eight treatments and three replications was used. Eight treatments include pre-emergence application (PE) of pendimethalin 1.0 kg/ha, pendimethalin 30% EC + imazethapyr 2% SL (pre-mix) 960 g/ha PE, post-

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emergence application (PoE) of acifluorfen- sodium 16.5% + clodinafop-propargyl 8% EC (pre-mix) 165 + 80 g/ha at 20 DAS, quizalofop-ethyl 50 g/ha PoE at 20 DAS, imazethapyr 100 g/ha PoE at 20 DAS, imazethapyr 3.75% + propaquizafop 2.5% ME (pre-mix) 50 + 75 g/ha PoE at 20 DAS, hand weeding twice at 20 and 40 days after seeding (DAS) and weedy check. The soil of the experimental field was clay loam in texture and the soil having medium fertility status. Soybean variety RKS-113 (Kota Soya-1) was used as experimental material developed at ARS, Kota (Rajasthan).

The numbers of root nodules recorded by uprooting carefully five randomly selected plants and after washing root nodules were separated from the roots of the plants. The root nodules were dried in the sun then transferred to thermostatic controlled drying oven regulated at 80°C±2°C for 45 hours and dried up to a constant weight and finally their weight was recorded in mg with the help of electronic balance. Oil content in seeds from each net plot sample was determined by Soxhlet ether extraction method (AOAC 1965) expressed as per cent oil content in seed. Oil yield was worked out by multiplying the seed yield with oil content for each corresponding treatment.

Oil yield (kg/ha) = Oil content in seed (%) × seed yield (kg/ha)/100

The protein content in seed was calculated by multiplying per cent nitrogen in the seed by the factor 6.25 (Simson *et al.* 1965) and expressed as per cent protein content. Protein yield was worked out by formula;

Protein yield (kg/ha) = Protein content in seed (%) × seed yield (kg/ha)/100

Effect on root nodules

Data presented in **Table 1** showed that, the number of root nodules/plant recorded significantly higher in two hand weeding (50.80), which was at par with application of acifluorfen- sodium 16.5% + clodinafop-propargyl 8% EC (pre-mix) 165 + 80 g/ha (46.37). Among herbicidal treatments, application of acifluorfen- sodium 16.5% + clodinafop-propargyl 8% EC (pre-mix) 165 + 80 g/ha recorded higher number of root nodules/plant, which was at par with all herbicidal treatments.

Data further depicted in **Table 1** showed that at 50 DAS dry weight of root nodules/plant recorded significantly higher in two hand weeding (84.0 mg) which was superior over all herbicidal treatments. Among herbicidal treatments, application of acifluorfen- sodium 16.5% + clodinafop-propargyl 8% EC (pre-mix) 165 + 80 g/ha (75.7 mg) recorded higher weight of root nodules/plant, which was at par with application of pendimethalin 30% EC 1.0 kg/ha (72.7 mg), application of imazethapyr 3.75% + propaquizafop 2.5% ME (pre-mix) 50 + 75 g/ha (72.0 mg) and application of quizalofop-ethyl 5% EC 50 g/ha at (71.7 mg) and closely followed by application of imazethapyr 10% SL 100 g/ha (71.0 mg) and application of pendimethalin 30% EC + imazethapyr 2% SL (pre-mix) 960 g/ha (70.3 mg). The minimum number (40.57) and lowest dry weight of root nodules/plant was recorded under weedy check (64.0 mg).

The both parameters were higher in two hand weeding followed by application of acifluorfen-sodium 16.5% + clodinafop-propargyl 8% EC (pre-mix) 165 + 80 g/ha. This variation in number and dry weight of root nodules in different treatments could be explained in terms of crop-weed competition for space, nutrient and light for less competition. Since the presence of more weeds in treatments will provide less Rhizospheric space for crop, which results in less effective nodules both quantitatively as well as qualitatively. The results are in agreement with the findings of Verma and Kushwaha 2019.

Table 1. Effect of weed management practices on number of nodules/plant, their dry weight at 50 DAS and oil, protein content in seed

Treatment	No. of nodules/plant	Dry weight of nodules (mg/plant)	Oil content (%)	Protein content (%)
Pendimethalin 30% EC 1.0 kg/ha as PE	44.47	72.7	19.80	39.06
Pendimethalin 30% EC + imazethapyr 2% SL (pre-mix) 960 g/ha as PE	42.70	70.4	19.93	40.10
Acifluorfen- sodium 16.5% + clodinafop-propargyl 8% EC (pre-mix) 165 + 80 g/ha at 20 DAS	46.37	75.7	20.23	40.63
Quizalofop ethyl 5% EC 50 g/ha at 20 DAS	43.73	71.7	19.83	39.52
Imazethapyr 10% SL 100 g/ha at 20 DAS	42.93	71.0	19.87	39.90
Imazethapyr 3.75% + propaquizafop 2.5% ME (pre-mix) 50 + 75 g/ha at 20 DAS	43.93	72.0	20.00	40.31
Hand weeding at 20 and 40 DAS	50.80	84.0	20.37	41.04
Weedy check	40.57	64.0	19.67	38.02
LSD (p=0.05)	5.18	4.64	NS	1.73

Table 2. Effect of weed management practices on different quality parameters yield and economics of soybean

Treatment	Oil yield (kg/ha)	Protein yield (kg/ha)	Seed yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	B:C ratio
Pendimethalin 30% EC 1.0 kg/ha as PE	243	479	1225	1792	3017	1.07
Pendimethalin 30% EC + imazethapyr 2% SL (pre-mix) 960 g/ha as PE	294	592	1475	2128	3603	1.42
Acifluorfen- sodium 16.5% + clodinafop-propargyl 8% EC (pre-mix) 165 + 80 g/ha at 20 DAS	313	630	1550	2233	3783	1.61
Quizalofop ethyl 5% EC 50 g/ha at 20 DAS	263	523	1325	1930	3255	1.24
Imazethapyr 10% SL 100 g/ha at 20 DAS	283	569	1425	2091	3516	1.47
Imazethapyr 3.75% + propaquizafop 2.5% ME (pre-mix) 50 + 75 g/ha at 20 DAS	304	613	1520	2190	3710	1.54
Hand weeding at 20 & 40 DAS	366	739	1800	2592	4392	1.22
Weedy check	138	267	700	1028	1728	0.26
LSD (p=0.05)	29.16	60.73	122.93	193.28	310.69	0.20

Effect on oil content and oil yield

A perusal of data (**Table 2**) revealed that all the weed control treatments were non-significantly influenced the oil content of soybean seed. The highest oil content (%) was recorded in two hand weeding (20.37%) and oil yield (366 kg/ha) followed by application of acifluorfen-sodium 16.5% + clodinafop-propargyl 8% EC (pre-mix) 165 + 80 g/ha (20.23%) and oil yield (313 kg/ha), respectively. The minimum oil content (19.67%) and oil yield (138 kg/ha) was recorded under weedy check.

Oil yield is largely a function of seed yield. Oil yield was found to increase significantly due to weed control treatments. Strong positive correlation between oil yield and seed yield (r = 0.999**) support the fact. Two hand weeding at 20 and 40 DAS registered highest oil yield followed by application of acifluorfen- sodium 16.5% + clodinafop-propargyl 8% EC (pre-mix) 165 + 80 g/ha, which was statistically at par with application of imazethapyr 3.75% + propaquizafop 2.5% ME (pre-mix) 50 + 75 g/ha at 20 DAS and application of pendimethalin 30% EC + imazethapyr 2% SL (pre-mix) 960 g/ha as pre-emergence and significantly superior over weedy check. The results are in agreement with the findings of Jadon *et al.* 2019.

Effect on protein content and protein yield

The data presented in **Table 2** revealed that significantly higher protein content and protein yield were recorded over weedy check by adopting various weed management practices. Protein yield was found to increase significantly due to weed management practices. Protein yield is largely a function of seed yield. Strong positive correlation coefficient value between protein yield and seed yield (r = 0.999**) support the fact. Hand weeding twice at 20 and 40 DAS was recorded highest protein content, which was statistically at par with application of acifluorfen-sodium 16.5% + clodinafop-propargyl 8% EC (pre-mix) 165 + 80 g/ha. Data of **Table 2** further revealed that two hand weeding registered highest protein yield (739 kg/ha) followed by application of acifluorfen-sodium 16.5% + clodinafop-propargyl 8% EC (pre-mix) 165 + 80 g/ha (630 kg/ha), which was statistically at par with application of imazethapyr 3.75% + propaquizafop 2.5% ME (pre-mix) 50 + 75 g/ha (613 kg/ha) and application of pendimethalin 30% EC + imazethapyr 2% SL (pre-mix) 960 g/ha as pre-emergence (592 kg/ha) and significantly superior over weedy check (267 kg/ha). Jadon *et al.* 2019 was also reported highest protein yield under two hand weeding.

REFERENCES

AOAC. 1965. *Official methods of analysis.* (10th ed.) Association of Official Agricultural Chemists, Washington.

Chouhan GS. 2007. Soybean products and their export potential. *Green Farming* **1**(3): 55–57.

Hosmath JA. 2014. Bioefficacy of quizalofop-p-tefuryl 4.41 EC against weeds in soybean ecosystems in India. In: Proceedings of SOYCON-2014. p. 194. *International Soybean Research Conference on Mitigating Productivity Constraints in Soybean for Sustainable Agriculture*, 22-24 Feb., 2014 held at Directorate of Soybean Research, Indore.

Nagaraju AP and Kumar HKM. 2009. Critical period of weed interference in soybean under alfisols. *Mysore Journal of Agricultural Sciences* **43**(1): 28–31.

ICAR-IISR. 2023. Director's Desk, ICAR- Indian Institute of Soybean Research, Indore, MP. www.iisrindore.icar.gov.in/readmore.html.

Jadon CK, Dashora LN, Meena SN and Singh P. 2019. Growth, yield and quality of soybean [*Glycine max* (L.) Merr.] as influenced by weed management and fertility levels in vertisols of S-E Rajasthan. *International Journal of Bio-resource and Stress Management* **10**(2): 177–180.

Simson TE, Adair CR, Kohler GP, Dabald HA, Kestar FB and Hlick JT, 1965. Quality evaluation studies of foreign and domestic rices. *Technical Bulletin No.* 1331, USDA, 1–16.

Verma L and Kushwaha HS. 2020. Evaluation of different herbicides against weeds in mungbean (*Vigna radiata* L.). *Legume Research* **43**(6): 866–871.

Indian Journal of Weed Science (2024) **56**(3): 319–322
http://dx.doi.org/10.5958/0974-8164.2024.00054.5

RESEARCH NOTE

Common ruderals weed diversity along Naag Tibba trek in district Tehri Garhwal, Uttarakhand, India

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Received: 4 January 2024 | Revised: 23 July 2024 | Accepted: 27 July 2024

ABSTRACT

A botanical trip was undertaken for collecting information on ruderals weeds along Naag Tibba trek in the district of Tehri, Uttarakhand, India. The weed inventories were done in the year January 2021 – February 2022. A total of 43 weed species, divided into 37 genera, 22 Families, 14 APG-IV Orders and (8) APG-Grades of Angiosperm Phylogeny Group-IV System were located at the study site. The most dominant Grades were Campanulids and supersterids and two dominant Orders were Asterales and Caryophyllales. The study also revealed that most of the recorded species were annuals 57%, followed by perennials and biennials with 36% and 7%, respectively. The analysis of the habitat included Road sites (23 spp., 34%), Mountain slope (15 spp., 19%), Wasteland (13 spp., 19%), moist area (6 spp., 9%), crop fields and the edge of a field (4 spp., 6%). Out of the 43 weed species *Ageratum conyzoides* L., *Oxalis corniculata* L., *Parthenium hysterophorus* L., *Solanum virginianum* L., *Urtica dioica* L. were common weeds showing maximum diversity in the study site. The current study was conducted to generate baseline data on the weeds along the Nag Tibba Trek it could serve as a manual for future weed identification and recognizing their diversity.

Keywords – APG-IV, Grade, Mussoorie, Ruderals, Weed diversity

Weeds are pernicious plants that grow luxuriantly and choke out other plants that have valuable nutritive properties. (Rautela *et al.* 2020). There are an estimated 8,000 weed species worldwide (Holm *et al.* 1979). Out of these, 250 weeds are particularly problematic for crops used in agriculture. These plants are not native to the area and can cause harm or damage to groups of native plants. Ruderals are weed plants that grow along roadsides, waste land etc. in undesirable places. In the early days of intentionally cultivating plants, the concept of a “weed” as an undesirable plant came about (Dangwal *et al.* 2012). Weeds are more aggressive and possess unique characteristics that make them highly competitive compared to other plants (Jim Blackburn 2008). Their ability to spread over long distances and reproduce in large numbers allows them to quickly take over an area, displacing native plant species.

Weeds are more adaptable and have unique traits compared to other plants, making them more competitive (Dangwal *et al.* 2010). As atmospheric CO_2 concentration increases, weeds grow more rapidly than other plant species (Ziska *et al.* 2004). Climate change provides an opportunity for invasive species to establish themselves in native ecosystems (Ziska *et al.* 2004). When climate change and invasive species act together, they become key factors in biodiversity loss and have serious adverse impacts on native biodiversity and ecosystems. Invasive noxious weeds show a larger growth in response to increased atmospheric CO_2 concentration compared to other plant species (Mainka *et al.* 2010). International collaboration is necessary for managing these weeds. Previously, the three main strategies for controlling weed management were preventive, regulated, and eradicative. To effectively tackle the challenges that weeds present, thorough and effective weed control strategies are necessary. Weed management includes various components such as biological, chemical, and allelopathic treatments, mechanical and manual techniques, as well as cultural, ecological, and agricultural approaches (Raj *et al.* 2018).

Study site

The study was conducted along the Naag Tibba route which comes under the Mussoorie Forest Division, which is in the Tehri Garhwal Himalayas. It lies between the latitudes 30°25.002 –30°33.00’N and longitudes 78°3.00'–078°15.00’E and represents a temperate forest. A field survey of the study area

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was done from January 2021 to February 2022. January was the coldest month, and June was the hottest. The highest rainfall was recorded in July. The mean annual maximum temperature is 24.54°C, and the minimum temperature is 16.07°C.

The trek commenced at Pant Wadi Village, situated within the Devalsari Range (**Figure 1**) Naag Tibba, a constituent of the Jaunpur Range, is positioned at an elevation of 2700 m. A distance of 3 km was covered from Naag Tibba to Jhandi (**Figure 2**), which is located at an altitude of 3000 m.

Data collection

To document the flora of the study area, extensive field studies were conducted throughout the year 2021-22. The herbarium adhered to the standard procedures for collecting, preserving, and maintaining specimens (Jain and Rao 1977). To ensure a comprehensive collection, multiple attempts were made to collect plant specimens during various seasons, specifically targeting those in the flowering and fruiting stages. Additionally, field notes detailing the vernacular names, habits, habitat, flower colour, and the time of flowering and fruiting for each taxon were recorded alongside the plant collection. The collected weed species were cross-verified using authentic herbarium specimens from BSI Herbarium Dehradun, Northern Circle. Plant name citations were validated with the assistance of www.ipni.org.in. Recorded weed species were systematically categorized into different families, orders, and grades according to the APG-IV Grade system (Chase *et al.* 2016).

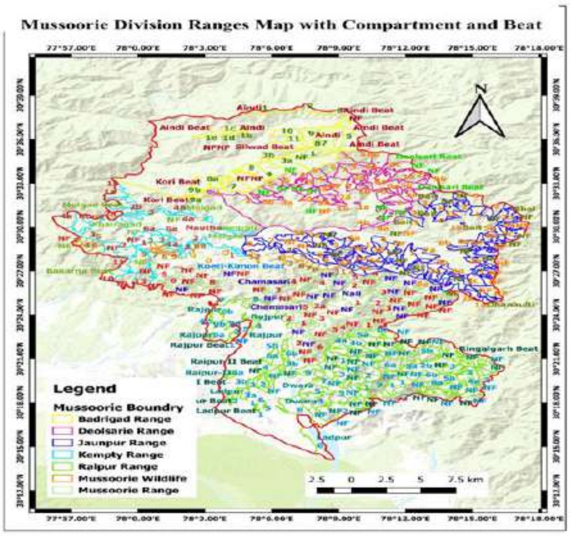

Figure 1. Study Site map

Figure 2. Trekking route of Naag Tibba and Jhandi

There was a total of 43 weed species (**Table 1**), divided into 37 genera, 22 Families, 14 APG-IV orders and (8) APG-Grades of Angiosperm Phylogeny Group-IV System were located at the study site.

The distribution of weed species reported 8 APG IV Grade. The most dominated were Garde Campanulids and supersterids with 10 families each followed by lamiids with 7 families, Fabids with 6 families, Commelinids with 5 families, Eudicots and Malvids with 2 families each and 1 family from Asterids Grades (**Figure 3**).

The distribution of weed species (14) reported weed APG-IV Order, their two dominated Order Asterales and Caryophyllales with 10 (25 %) families each followed by Poales with 5 (12%), Lamiids with 4 (10%), Rosales with 3 (8%), Rananculales and Solanales 2 (6%) each, and Brassicales, Ericales, Fabales, Gentianales, Geraniales, Malpighiales, Oxalidales with 1 (2%) each family.

Asteraceae was found to be the most dominant APG – IV family at the study =site contributing 11 (23%) species followed by Amaranthaceae with 5

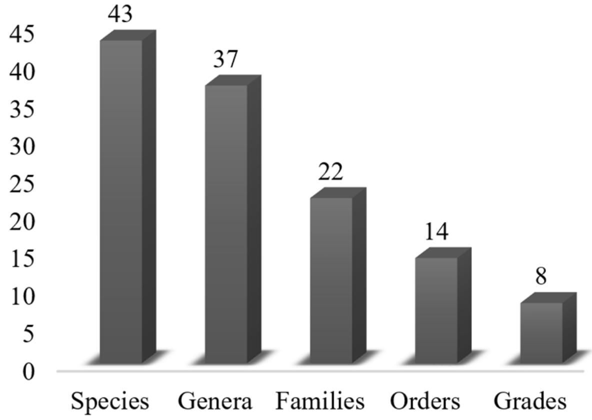

Figure 3. Complete distribution of the weed species

(14%) Poaceae and polygonaceae with 3 (7%), cyperaceae Plantaginaceae and Ranunculaceae with 2 (5%) species. The remaining families i.e., Primulaceae, Cannabinaceae, Brassicaceae, Rosaceae, Acanthaceae, Geraniaceae, Convolvulaceae, Verbenaceae, Oxalidaceae, Rubiaceae, Solanaceae, Caryophyllaceae, Fabaceae, Urticaceae, Violaceae contributed collectively 1 (2%) species each. (**Figure 4**).

During trekking observation revealed that most of the species were annual (24 spp., 57%) in occurrence to the study area followed by perennial (16 spp., 36%) and biennial (3spp., 7%). The number of the weed species that come from the highest herb were 41, and it was followed by 2 climber and 1 shrub. The analysis of the habitat comprised of as follows; roadside (23 spp., 34%), Mountain's slope (15 spp., 22%), wasteland (13 spp., 19%), moist area (6 spp.,9%), crop field and edges of field (4 spp., 6% each), dry place and all over (1 spp., 2%).

The plants collected from the study area are distributed based on their period of fruiting and flowering. The study revealed the maximum fruiting season is December and the minimum fruiting season is January and March (in these months no fruit was available on the studied weeds). The maximum flowering was found in March and the minimum flowering was in December month.

The present investigation is the first attempt from the study site to investigate and identify the primary Ruderals weeds. Additionally, this paper will

Table 1. Weed diversity along Naag- Tibba trek

Botanical Name	APG-IV Family	APG-IV Order	APG-IV Grade	Growth Form	Elevation	Life Forms	Habitat characteristics	Flowering and fruiting seasons
Achyranthes aspera L.	Amaranthaceae	Caryophyllales	Superasterids	H	1000-2000m	Bi	Dry place and Roadside	Aug-Dec.
Achyranthes bidentata Blume	Amaranthaceae	Caryophyllales	Superasterids	H	1200-2400m	Bi	Along roade side	Aug-Dec
Ageratum conyzoides L.	Asteraceae	Asterales	Campanulids	H	up to 900m	An	Along the side and wasteland	Sept-Oct.
Amaranthus tricolor L.	Amaranthaceae	Caryophyllales	Superasterids	H	up to 1000m	An	fields, along roadsides	Aug-Nov.
Amaranthus viridis L.	Amaranthaceae	Caryophyllales	Superasterids	H	600-1000m	An	fields, along roadsides	Jan-Dec.
Lysimachia arvensis (L.) U.Manns & Anderb.	Primulaceae	Ericales	Asterids	H	600-1000m	An	fields, along roadsides	Jul-Aug
Artemisia nilagirica (C.B.Clarke) Pamp.	Asteraceae	Asterales	Campanulids	H	Up to 2400m	An	Road Side, Waste land, Mountains	Jul- Sep
Avena fatua L.	Poaceae	Poales	Commelinids	H	Up to 2000m	An	Crop field	Apr-May
Bidens pilosa L.	Asteraceae	Caryophyllales	Superasterids	H	Up to 2500m	An	Road side, mountain slopes	Mar-Aug
Cannabis sativa L.	Cannabaceae	Rosales	Fabids	H	800- 3000m	Pe	Road Side, Waste land, Mountains	Jul-Sep
Cardamine impatiens L.	Brassicaceae	Brassicales	Malvids	H	1700-3000m	Bi	Moist area	Mar-jul
Chenopodium album L.	Amaranthaceae	Caryophyllales	Superasterids	H	up to 2500m	An	growing in waste sites, farmland	Jan-Dec.
Erigeron bonariensis L.	Asteraceae	Asterales	Campanulids	H	up to 2000m	An	Along road side	Feb- Sept.
Erigeron canadensis L.	Asteraceae	Asterales	Campanulids	H	up to 2000m	An	Along road side	Feb- Sept.
Cynodon dactylon (L.) Pers.	Poaceae	Poales	Commelinids	H	up to 3000m	Pe	Road Side, Waste land, Mountains	Apr-Jul
Cyperus compressus L.	Cyperaceae	Poales	Commelinids	H	900- 1200m	Pe	Road side, mountain slopes	Jul-Nov
Cyperus rotundus L.	Cyperaceae	Poales	Commelinids	H	900-1200m	Pe	Road side, mountain slopes	Jul-Dec.
Dicliptera bupleuroides Nees	Acanthaceae	Lamiales	Lamiids	H	Up to 2200m	An	Road side, mountain slopes	Jan-Dec
Potentilla indica (Andrews) Th.Wolf	Rosaceae	Rosales	Fabids	H	Up to 1800m	Pe	Moist area.	Mar-Sept
Eleusine indica (L.) Gaertn.	Poaceae	Poales	Commelinids	H	up to 2300m	An	Waste field and Road side	Jul-Nov
Erigeron annuus (L.) Desf	Asteraceae	Asterales	Campanulids	H	up to 3000m	An	Road side, edges of mountains	Jun-Dec
Ageratina adenophora (Spreng.) R.M.King & H.Rob.	Asteraceae	Asterales	Campanulids	H	up to 3000m	Pe	Road side, mountain slopes	Feb-Aug
Galinsoga parviflora Cav.	Asteraceae	Asterales	Campanulids	H	up to 2000m	An	Road side	Apr-Oct
Geranium ocellatum Jacquem. ex Cambess.	Geraniaceae	Geraniales	Malvids	H	up to 1800m	An	Road side	Mar- Apr
Ipomoea nil (L.) Roth	Convolvulaceae	Solanales	Lamiids	CL	up to 1800m	An	Road side, mountain slopes	Mar-Dec
Lantana camara L.	Verbenaceae	Lamiales	Lamiids	S	up to 2000m	An	waste land, road side.	Jan-Dec
Oxalis corniculata L.	Oxalidaceae	Oxalidales	Fabids	H	up to 3000m	Pe	agricultural fields	Feb-Nov
Parthenium hysterophorus L.	Asteraceae	Asterales	Campanulids	H	up to 2500m	An	fields, along roadsides	Jan-Dec
Plantago major L.	Plantaginaceae	Lamiales	Lamiids	H	900-2500m	Pe	fields, along roadsides	Apr-Oct
Persicaria barbata (L.) H.Hara	Polygonaceae	Caryophyllales	Superasterids	H	1600-1700m	Pe	Moist area and Hill	Jun-Dec
Persicaria maculosa Gray	Polygonaceae	Caryophyllales	Superasterids	H	1600- 1900m	An	Moist area and Hill	Feb-Nov
Ranunculus muricatus L.	Ranunculaceae	Ranunculales	Eudicots	H	1000-2500m	An	Edges of fields	Mar- Jun
Rubia cordifolia L.	Rubiaceae	Gentianales	Lamiids	CL	1000-2000m	Pe	Mountain slopes	Jul-Nov
Rumex hastatus D.Don	Polygonaceae	Caryophyllales	Superasterids	H	800- 2400m	Pe	Road side and Edges of fields	Feb- Oct
Solanum virginianum L.	Solanaceae	Solanales	Lamiids	H	up to 2000m	An	Road side	Nov-May
Stellaria media (L.) Vill.	Caryophyllaceae	Caryophyllales	Superasterids	H	900-2500m	An	Moist area, Edges of fields	May- Oct
Taraxacum sect. Taraxacum F.H.Wigg.	Asteraceae	Asterales	Campanulids	H	up to 1000m	Pe	road side and waste field	Feb-Oct
Thalictrum foliolosum DC.	Ranunculaceae	Ranunculales	Eudicots	H	1000-3000m	Pe	Hill	Jun-Oct
Tridax procumbens L.	Asteraceae	Asterales	Campanulids	H	1000-2000m	Pe	Field, crop land and road side	Jan-Dec
Trifolium repens L.	Fabaceae	Fabales	Fabids	H	900 -2200m	Pe	Waste field	Jan-Dec
Urtica dioica L.	Urticaceae	Rosales	Fabids	H	Up to 2500m	An	Found all over	Mar- Nov
Veronica persica Poir.	Plantaginaceae	Lamiales	Lamiids	H	Up to 2000m	An	Moist area, Edges of fields	Nov-Feb
Viola pilosa Blume	Violaceae	Malpighiales	Fabids	H	900- 3000m	Pe	Edges of field, grasslands	Mar- Jul

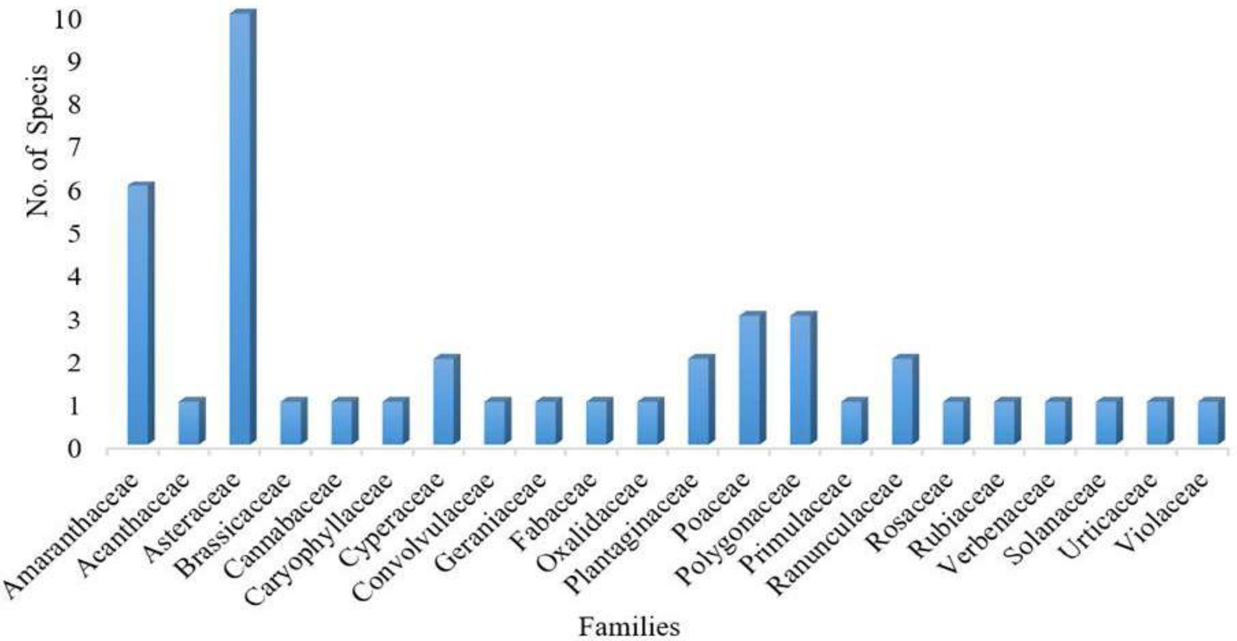

Figure 4. Representing the number of weed species in each family

serve as a guide for identifying and recognizing Ruderals weeds in future. Farmers may find it useful to identify weeds to create an effective control strategy. It will be valuable for researchers as well as those working in grades APG–IV.

REFERENCES

Dangwal LR, Singh A and Sharma A. 2012. Major weeds of rabi crops in block Chamba district Tehri Garhwal (Uttarakhand) India. *Journal of Plant Development Sciences* **4**(2): 201–205.

Dangwal LR, Singh A, Singh T and Sharma C. 2010. Effect of weeds on the yield of wheat crop in Tehsil Nowshera. *Journal of American Sciences* **6**(10): 405–407.

Holm L, Pancho JV, Herberger JP and Plucknett DL. 1979. *A Geographical Atlas of World Weeds*. John Wiley and Sons, 1391p.

http://uttarakhandexplorer.blogspot.com/2015/03/nagtibba-trek-1213-th-march2015-iam_13.html.

https://en.wikipedia.org/wiki/Weed.

Jain SK and Rao RR. 1976. *A Handbook of Field and Herbarium Methods*. Today and Tomorrow's Printers and Publishers, New Delhi, 157p.

Chase MW, Christenhusz MJM, Fay MF, Byng JW, Judd WS, DE Soltis, Mabberley DJ, Sennikov AN, Soltis PS and Stevens PF. 2016. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG IV. *Botanical Journal of the Linnean Society* 181(1): 1–20. https://doi.org/10.1111/boj.12385

Mainka SA and Howard GW. 2010. Climate change and invasive species: double jeopardy. *Integrative Zoology* **5**(2):102–111.

Raj R, Das TK, Kaur R, Singh R and Shekhawat K. 2018. Invasive noxious weed management research in India with special reference to *Cyperus rotundus, Eichhornia crassipes* and *Lantana camara*. *Indian Journal of Agricultural Sciences* **88**(2):181–196.

Rautela B and Tiwari P. 2020. Weed flora of district Rudraprayag, Uttarakhand, India. *International Journal of Botany Studies* **5**(6): 361–367.

Ziska LH and George K. 2004. Rising carbon dioxide and invasive, noxious plants: potential threats and consequences. *World Resource Review* **16**(4): 427–447.