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ANALYSIS ARTICLE

Trends in global herbicides research during 2011-2020: A web of science-based scientometric study

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ABSTRACT

Herbicides are continuing to be an integral part of weed control in global agriculture and hence the research related to herbicides have paramount importance. Therefore, the present study attempts a scientometric analysis of global herbicide research undertaken during the last decade (2011 to 2020). For this, we collected the bibliometric data on published literature from the ISI Web of science core collection database in March 2021. A combination of search strings was used to obtain the appropriate data on herbicide research and VOSviewer was used for analyzing the networks among authors, organizations, journals, and countries. The study showed that 9,980 research papers were published on herbicide research with an average citation per article of 9.94 during this period. The volume of publications exhibited an increasing trend over the years. Further, the leading countries involved in the herbicide research domain were the USA, China and Brazil. The co-occurrence analysis of author keywords indicted "herbicide resistance" as the most focussed field in the herbicide research domain.

Keywords: Bibliometric analysis, Herbicide research, Scientometric study, VOSviewer, Web of Science

INTRODUCTION

Weeds cause crop yield losses and increase the cost of cultivation to farmers. Being a botanical pest, its adaptability to the cropping system and damage potential is significantly high (Ramesh *et al.* 2017, Swanton *et al.* 2015, Rao *et al.* 2020). Before the introduction of selective herbicides, farmers adopted a combination of different methods like crop rotation, cover crop, proper tillage *etc*. to control the weed menace (Bolliger *et al.* 2006, Mishra *et al.* 2016). Considering the drudgery of manual weeding in agriculture, research continued across the globe and the late 1940s witnessed the introduction of selective herbicides. Subsequently, several new herbicides were developed and this provided a new tool of weed management called 'Chemical hoe" to the farmers (Kudsk and Streibig 2003). Herbicides reduced the farmers dependence on the manual weed control operations. Further, the contribution of herbicides along with other pesticides was very crucial in the success of the green revolution, particularly in developing countries of Asia (Pimentel 1996). The discovery of different molecules of selective herbicides revolutionized the modern agriculture system as it is more productive-oriented (Hamill *et al.* 2004). However, the public realized it as a double-edged sword because of the environmental issues that emerged in the late 1980s due to the over usage of herbicides. Henceforth, public consciousness increased and many countries brought the stringent policy of registration process for herbicides. This along with other factors like rising costs of herbicide development are partially responsible for the decline in the introduction of new herbicides over the years (Kudsk and Streibig 2003, Sharma and Singhvi 2017).

Herbicides are most simpler and more economical technology for weed management in agriculture and this hastened the wider adoption of the same (Johnson *et al*. 2009, Rao *et al.* 2014, Chauhan *et al.* 2017). Although herbicide dependent agriculture production benefitted the farmers in many ways, the heavy reliance on herbicides resulted in many issues like herbicide-resistant weeds, changing spectrum of weed flora, environmental pollutions *etc*. (Duary 2008). Several studies describe these kinds of issues in various parts of the world. The presence of multiple herbicide-resistant weed species in pulses,

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oilseeds and cereals constrained the options of available herbicides (Beckie and Tardif 2012, Heap and Duke 2018). Glyphosate-resistant *Sorghum halepense* evolved in Argentina and the dispersal of resistant biotypes was reported (Heap and Duke 2018). The advent of imidazolinone-tolerant rice resulted in the evolution of resistant weedy rice (Kraehmer *et al.* 2016). Herbicide contamination of soil and water negatively impacted soil health through the interference of important microbial and enzymatic activities in the soil (Hussain *et al.* 2009). Overdose of herbicide could disrupt the earthworm ecology in the soil, N-fixation and mineralization (Chauhan *et al.* 2017). Further, as a result of climate change, herbicide dependent weed control is facing several issues. There is evidence of declined efficacy of herbicides due to higher CO_2 concentration. The CO_2 induced morphological and anatomical changes in plants resulted in dilution effect and thereby less efficacy of herbicides (Ziska *et al.* 2004; Ziska and Goins 2006). Frequent shower increases leaching and subsequent groundwater contamination (Ramesh *et al.* 2017).

The herbicide research domain is spread across multi-dimensional fields such as herbicide efficacy, herbicide residue, herbicide-tolerant (HT) crops, toxicology, environmental sciences *etc*. The weed research is more oriented towards herbicide research and more funding is routed in this direction (Wyse 1992, Harker and O'Donovan 2013, Rao and Chauhan 2015). Nevertheless, this changing scenario necessitated scientists across the globe to address emerging issues related to herbicides because weed management has to stay and need to be strengthened in the agricultural system. Therefore, the challenge before the scientists is to develop cutting edge technologies for weed management through scrutiny of existing issues of herbicide dependent agricultural production systems to deal with the growing concerns about environmental pollution and safe food production.

In this context, the present study was conducted to undertake a scientometric assessment of herbicide research in the world during the period from 2011 to 2020. Efforts were made to find out scientific productivity, author contribution and collaboration, major countries and organizations involved, important research themes and emerging research priorities in the herbicide research domain. This would help provide an overview of recent advancements in the herbicide research domain and aid in understanding the required research focus and way forward.

MATERIALS AND METHODS

The present study used metadata obtained from ISI Web of Science (accessed in March 2021). Web of Science database has comprehensive coverage of published literature (Ramanan *et al.* 2020) and several bibliometric studies relied on the Web of Science database (Zyoud *et al.* 2017). The search string used to select the publications were; ("herbicide" OR "weedicide") AND ("crop OR plant"). This string was used in advanced search options available in the Web of Science in three fields TOPIC, TITLE and ABSTRACT. Then combined using appropriate Boolean operators which resulted in a total of 9980 studies. Three exclusion criteria were used; year=2011-2020, Language=English and Document type=article. Bibliometric data on author names, title, publication year, citation, journal name and references of all the retrieved publications were collected.

The h-index of authors would indicate the research performance or productivity for the period considered (Huang 2012) and the h-index was obtained from Web of Science through individual search after sorting the top authors from the downloaded bibliometric data. The Web of Science inbuilt "Analyze result" option is used for the first step analysis. Thereafter, a full record of citation report metadata was downloaded in the text format. This data was used for network analysis with the help of VOSviewer software. It is a free and open software used for constructing and visualizing bibliometric networks. VOSviewer enables the visualization of bibliometric data in an easily interpretable manner (van Eck and Waltman 2014).

Network analysis was carried out to understand the co-citation of authors and journals, co-occurrence of the author keywords and co-authorship of countries and organizations involved in herbicide research. Fractional counting option were chosen to get proper visualization of the results. This analysis would help to identify existing collaboration and emerging thrust areas in the research domain considered. Since in this study we have only considered articles published in journals indexed in web of science (as mentioned in the title, it is a web of science-based scientometric work). Hence, many of the Indian journals including Indian Journal of Weed Science (IJWS), which are yet to be indexed in WoS, were not a part of this analysis.

RESULTS AND DISCUSSION

Temporal trends in research publications

The number of published articles on "herbicide research" witnessed an increasing trend during the period from 2011 to 2020 (**Figure 1**). By 2020, a cumulative number of 9980 research articles were published with an average citation per article of 9.94. The Web of Science (WoS) indicated an h-index equal to 84 for this whole volume of publications. Similarly, citations also indicated an increasing trend over the years and the total of citations recorded 99,224 in 2020, of which 73,992 were without self-citations. Year-wise record indicated that both citations and number of published articles were highest in 2020 (23,318 and 1392, respectively) with an average citation per article equal to 16.75. This increasing trend of herbicide research could be due to the various issues that emerged out of continued and over usage of herbicides for weed management and increased consciousness about ecologically balanced methods for weed control (Rüegg *et al.* 2007, Rao and Ladha 2011).

The percentage share of articles belonging to each research field out of the total articles published on herbicide research indicated that among the top 10 research fields wherein herbicide research related articles appeared during 2011-2020, the agriculture field showed the highest per cent share (43%) followed by plant science (31%) and environmental sciences ecology (20%) (**Figure 2**). The least share of articles among the top 10 fields was noticed in toxicology (3%). The herbicides are important to agriculture and the demand for the same is increasing over the years particularly in developing countries due to the labour shortage for manual weeding. As demand for herbicide increases in agriculture, undoubtedly research and development would continue to be an important domain of research (Hossain 2016).

Major counties involved in herbicide research

The bibliometric analysis revealed that 71 countries published at least 10 articles on herbicide research during 2011-2020. Of the 71 countries, the top 10 countries involved most in herbicide research were identified and ranked based on the number of publications and total citations (**Table 1**). USA ranked first with 3056 published articles, followed by China and Brazil with 1067 and 1013 articles, respectively. In citations, the first ranked country was the USA (33282 citations) followed by the China and Australia with 11240 and 8688 citations, respectively. Brazil was 6th in terms of citations while it was in 3rd in the number of published articles. Australia was 4th in terms of the number of published articles but its citation was 3rd highest (8688) with an average citation per article equal to 14.60. In the USA, glyphosate use takes the major share of total herbicide application and the early adoption of herbicide-

Table 1. First 10 countries with highest number of publications and citations

Publications	Rank	Country	No. of publications
	1	USA	3056
	2	Peoples R China	1067
	3	Brazil	1013
	4	Australia	595
	5	Spain	510
	6	Canada	477
	7	India	468
	8	Germany	462
	9	Italy	358
	10	France	345
Citations	Rank	Country	Total citations
	1	USA	33282
	2	Peoples R China	11240
	3	Australia	8688
	4	Spain	8258
	5	Germany	7264
	6	Brazil	6124
	7	France	5585
	8	Canada	5201
	9	Italy	3986
	10	England	3962

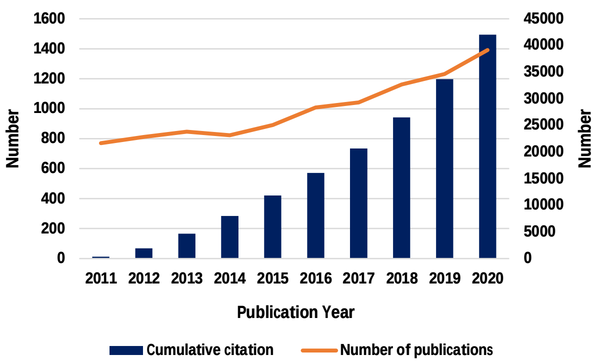

Figure 1. Year-wise number of publications and cumulative citation

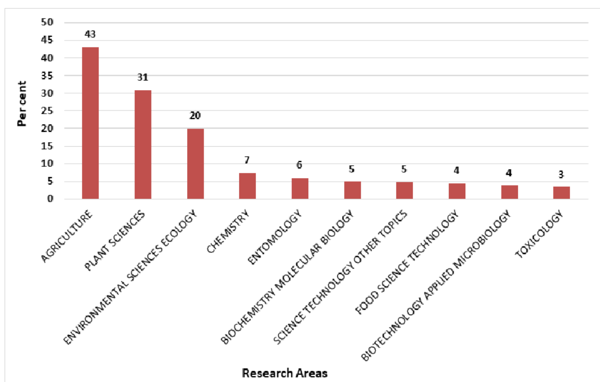

Figure 2. The per cent share of publications across major research areas

tolerant crops in the country could have led to wider use and increased research and development in herbicide research (Benbrook 2016).

The co-authorship network analysis of countries was done considering the minimum number of articles as 10 and the minimum number of citations as 20 to map the most important countries involved in the herbicide research domain. Out of 138 countries, 71 countries met the threshold for which the total strength of the co-authorship links with other countries was calculated. The countries with the greatest link strength were selected amongst which USA showed the highest link strength (687) and hence it was connected to many countries but closely to China and Canada (**Figure 3)**. The second and third highest link strength was found for China and Canada, respectively. The 4th highest link strength (279) was of Australia and it has a good cluster of networks with counties like England, Japan, New Zealand *etc*. Thus, the countries with better collaborations produced higher quality as well as volume of publications. India can perhaps take hint from this and attempt to collaborate more with countries engaged in advanced research on herbicides.

Most active organizations involved in herbicide research

There were 101 organizations with a minimum of 30 published herbicide research articles indexed in the WoS database. The USDA ARS ranked first amongst the top 10 organizations involved in the herbicide research with highest total publications (410) and citations (5469) (**Table 2**). The second and third ranking institutions were the University of Florida and the University of Western Australia with 197 and 178 published articles, respectively. Whereas in the case of citation ranking, the second rank was of The University of Western Australia (3506 citations) followed by the National Institute of Agricultural Research (NIAR) (2430 citations). One of the interesting findings is that, although, NIAR, France and Spanish National Research Council (CSIC) were

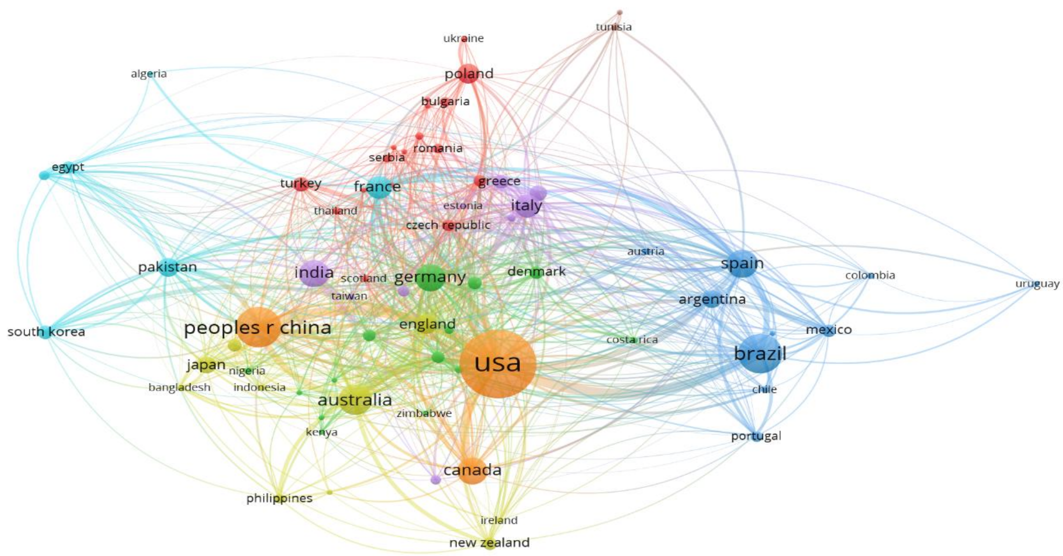

Figure 3. Co-authorship network of top countries involved in herbicide research

Table 2. First ten organizations with highest number of publications and citations

Publication			Citation		
Rank	Organization	No. of publication	Rank	Organization	Total citation
1	USDA ARS	410	1	USDA ARS	5469
2	University of Florida	197	2	The University of Western Australia	3506
3	The University of Western Australia	178	3	National Institute of Agricultural Research (INRA)	2430
4	University of Arkansas	177	4	Spanish National Research Council (CSIC)	2184
5	Mississippi State University	141	5	University of Arkansas	1910
6	University of California, Davis	140	6	The University of Queensland, Australia	1653
7	Agriculture and Agri-Food Canada	135	7	Iowa State University	1590
8	Federal University of Viçosa	134	8	Nanjing Agricultural University	1564
9	The University of Queensland, Australia	127	9	University of Illinois, Chicago	1551
10	University of Tennessee	126	10	Agriculture and Agri-Food Canada	1466

positioned at 3rd and 4th in the citations-based ranking, both of these organizations did not appear in the top 10 organizations based on the number of published articles. This could be due to the better quality of published articles from these organizations. There is a significant share of scientific man-years of USDA-ARS weed scientists out of total scientific man-years devoted to weed science in the country (Abernathy and Bridges 1994).

The co-authorship network of the most active organizations involved in herbicide research is depicted in **Figure 4**. The minimum number of published articles considered for an organization for this network mapping was 30 and the minimum citations were 10. Hence, 102 organizations among 6239 organizations met this threshold and network mapping have been done for these selected organizations. For each of the 102 organizations, the total strength of the co-authorship links with other organizations was calculated. The organizations with the greatest total link strength were selected. The USDA ARS (red) indicated the highest link strength (258) and hence, it has a large number of co-authorship networks with many other organizations. The USDA ARS has a close network with the University of California Davis, University of Illinois and University of Florida. This further suggests that better collaborations among organizations play crucial role in improving their research output.

Key authors contributing to herbicide research

The perusal of ranking of 10 key authors who published articles on herbicide research indicated that J.K. Norsworthy, University of Arkansas, USA was the author having the highest number of publications (108) during the period from 2011 to 2020 (**Table 3**). He is having a total citation of 1057 with an average citation per article equal to 9.79. As per the Web of Science database, he started research publication in 1998 and his h-index is 33 at present. The second-ranked author is P.H. Sikkema, University of Guelph, Canada with 73 articles and an average citation per article of 7.3. However, S. B. Powels, University of Western Australia is having the highest average

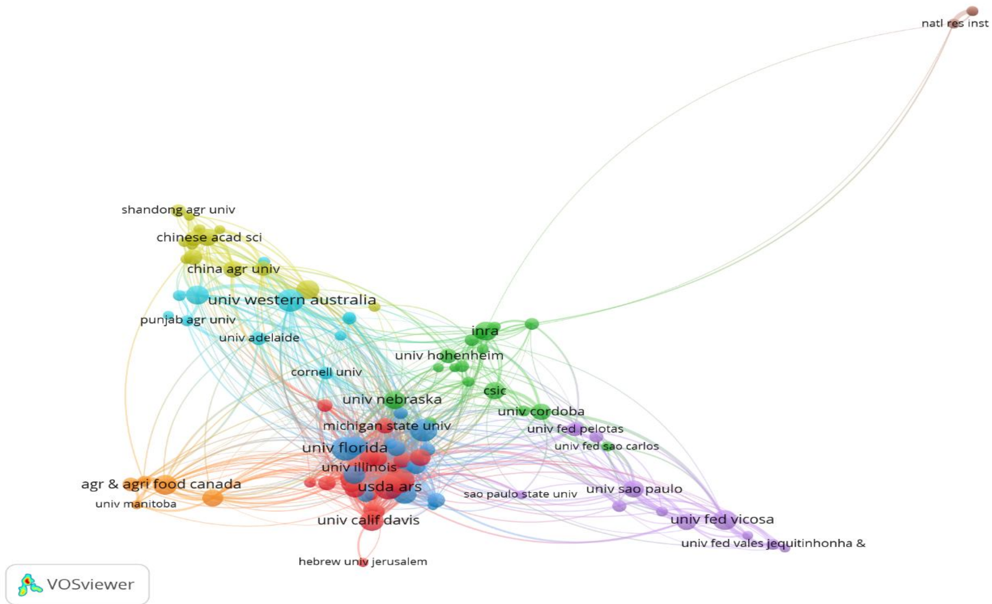

Figure 4. Co-authorship network of top organizations involved in herbicide research

Table 3. Ranking of 10 key authors based on number of publications

Rank	Author	Total publication	Total Citation	Average citation per paper	Country	Affiliation	h-index	Starting year of publication
1	Norsworthy, J. K.	108	1057	9.79	USA	University of Arkansas System	33	1998
2	Sikkema, PH	73	533	7.30	Canada	University of Guelph	21	1987
3	Powles, S. B	69	1609	23.32	Australia	University of Western Australia	62	1978
4	De prado, R.	61	796	13.05	Spain	Universidad de Cordoba	27	1982
5	Soltani, N.	52	336	6.46	Canada	University of Guelph	18	2003
6	Jhala, A. J.	51	459	9.00	USA	University of Nebraska Lincoln	18	2008
7	Young, B.G.	50	510	10.20	USA	Purdue University	27	1985
8	Scott, R. C.	46	715	15.54	USA	University of Arkansas System	29	2008
9	Jordan, D. L.	44	402	9.14	USA	North Carolina State University	3	2009
10	Preston, C.	43	606	14.09	Australia	University of Adelaide	41	1978

citation per paper (23.32) and h-index (62), among all the top 10 authors.

The authors' co-citation network analysis has selected 100 authors out of 13067 authors who meet the citation threshold of 50. For each of the 100 authors, the total strength of co-citations links with other authors was calculated and authors with the greatest link strength were selected. The network map has grouped the authors into 4 different clusters. The first cluster (green) was the biggest. I. Heap and S. O. Duke were the leading authors with respective citation figures of 1367 and 1314, and link strength of 1306 and 1000, respectively (**Figure 5**).

Lead journals publishing herbicide research

The ranking of the top 10 journals in which herbicide research articles were published during 2011-2020 was done based on the number of publications as well as total citations received. With respect number of publications, Weed Technology, published by the Weed Science Society of America (WSSA), was found on the top (648) followed by Weed Science (390) and Planta Daninha (339) (**Table 4**). Weed Technology publishes original research articles in the form of peer-reviewed articles focused on understanding weed management. In terms of total citations, Pest Management Science ranked first (4982) followed by Weed Science (4769) and Weed Technology (4507). Pest Management Science is an international journal focused on research in crop protection and pest control published for the Society of Chemical Industry by Wiley & Sons Ltd.

The Co-citation network analysis of journals considered the minimum number of citations of a journal source as 500. A total of 113 journals met the threshold out of 54,170 journals. For each of the 113 journals, the total co-citation link strength was calculated and journals with the greatest link strength were selected. The map depicted 4 major clusters, of which, the red one is having the highest co-citation networks in which the Pest Management Science was the leading journal with citation figure equal to

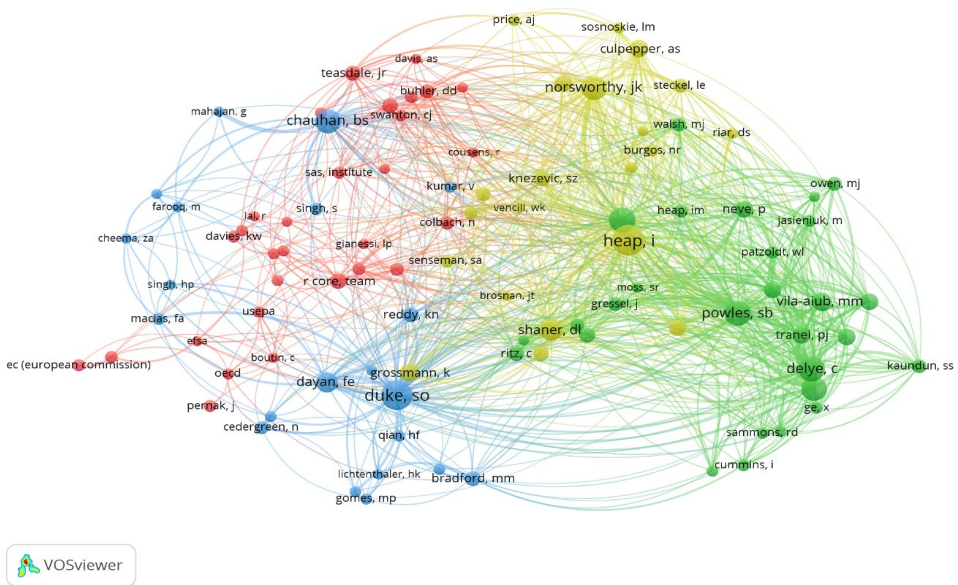

Figure 5. Co-citation network of authors of published articles based on herbicide research

Table 4. The first ten journals with highest number of publications and their citations

Number of publication			Total citation		
Rank	Journal	Number of publication	Rank	Journal	Total citation
1	Weed Technology	648	1	Pest Management Science	4982
2	Weed Science	390	2	Weed Science	4769
3	Planta Daninha	339	3	Weed Technology	4507
4	Pest Management Science	275	4	Science of The Total Environment	3178
5	Crop Protection	193	5	Journal of Agricultural and Food Chemistry	3161
6	Journal of Agricultural and Food Chemistry	175	6	Plos One	2900
7	Science of The Total Environment	164	7	Chemosphere	2387
8	Plos One	160	8	Crop Protection	2030
9	Weed Research	157	9	Weed Research	1961
10	Pesticide Biochemistry and Physiology	134	10	Pesticide Biochemistry and Physiology	1875

8,597 (**Figure 6**). Weed Science had the highest link strength (14664) and citations (19,063) followed by Weed Technology and Pest Management Science with total link strength equals 10,782 and 7, 586, respectively.

Most cited articles in herbicide research

The most important research articles in the herbicide research domain published during 2011-2020 were ranked based on total citations received. The article entitled "Trends in glyphosate herbicide use in the United States and globally" (Benbrook 2016), published in Environmental Sciences Europe journal, ranked first with a total citation of 487 (**Table 5**) with an average citation per year equal to 81.17. This paper discussed in detail herbicide use for agricultural and non-agricultural purposes in the US and the world. It suggested a rise in global glyphosate use (56%) after the introduction of genetically engineered herbicide-tolerant crops like "Roundup-Ready" crops (Benbrook 2016). This paper got wide acceptance due to the importance of the study carried out by the author. Though herbicide application data were sparse, the author managed to collect time-series data on the application of glyphosate in the USA and globally. He also advocated quantifying the human health impact due to the rising use of glyphosate as the way forward. The second-ranked article is titled "A combinatorial TIR1/AFB-Aux/IAA co-receptor system for differential sensing of auxin" (Calderon Villalobos *et al.* 2012) published in Nature Chemical Biology. It has a total citation of 308 and 30.8 as an average citation per year.

Focused areas in herbicide research

Bibliometric data on author keywords were downloaded and assessed to understand the priorities in the herbicide research domain in recent times. The frequency of occurrence of the author keywords in the 9,980 articles retrieved from the Web of Science indicated that the word "herbicide or weedicide" had the maximum number of occurrences (1298) followed by "herbicide resistance" (537), "glyphosate" (529), "weeds" (357) and "weed

Table 5. Ranking of 10 most cited articles in herbicide research

Rank	Title	Author	Year of publication	Source journal	Total Citations	Average citation per year
1	Trends in glyphosate herbicide use in the United States and globally	Benbrook, Charles M.	2016	ENVIRONMENTAL SCIENCES EUROPE	487	81.17
2	A combinatorial TIR1/AFB-Aux/IAA co-receptor system for differential sensing of auxin	Calderon Villalobos, Luz Irina A.; Lee, Sarah; De Oliveira, Cesar; Ivetac, Anthony; Brandt, Wolfgang; Armitage, Lynne; Sheard, Laura B.; Tan, Xu; Parry, Geraint; Mao, Haibin; Zheng, Ning; Napier, Richard; Kepinski, Stefan; Estelle, Mark	2012	NATURE CHEMICAL BIOLOGY	308	30.8
3	A Meta-Analysis of the Impacts of Genetically Modified Crops	Kluemper, Wilhelm; Qaim, Matin	2014	PLOS ONE	293	36.63
4	Why have no new herbicide modes of action appeared in recent years?	Duke, Stephen O.	2012	PEST MANAGEMENT SCIENCE	265	26.5
5	Targeted base editing in rice and tomato using a CRISPR-Cas9 cytidine deaminase fusion	Shimatani, Zenpei; Kashojiya, Sachiko; Takayama, Mariko; Terada, Rie; Arazoe, Takayuki; Ishii, Hisaki; Teramura, Hiroshi; Yamamoto, Tsuyoshi; Komatsu, Hiroki; Miura, Kenji; Ezura, Hiroshi; Nishida, Keiji; Ariizumi, Tohru; Kondo, Akihiko	2017	NATURE BIOTECHNOLOGY	249	49.8
6	Herbicide cross resistance in weeds	Beckie, Hugh J.; Tardif, Francois J.	2012	CROP PROTECTION	243	24.3
7	Environmental fate of glyphosate and aminomethylphosphonic acid in surface waters and soil of agricultural basins	Aparicio, Virginia C.; De Geronimo, Eduardo; Marino, Damian; Primost, Jezabel; Carriquiriborde, Pedro; Costa, Jose L.	2013	CHEMOSPHERE	207	23
8	Milkweed loss in agricultural fields because of herbicide use: effect on the monarch butterfly population	Pleasants, John M.; Oberhauser, Karen S.	2013	INSECT CONSERVATION AND DIVERSITY	207	23
9	Unravelling the genetic bases of non-target-site-based resistance (NTSR) to herbicides: a major challenge for weed science in the forthcoming decade	Delye, Christophe	2013	PEST MANAGEMENT SCIENCE	195	21.67
10	Metabolism-Based Herbicide Resistance and Cross-Resistance in Crop Weeds: A Threat to Herbicide Sustainability and Global Crop Production	Yu, Qin; Powles, Stephen	2014	PLANT PHYSIOLOGY	185	23.13

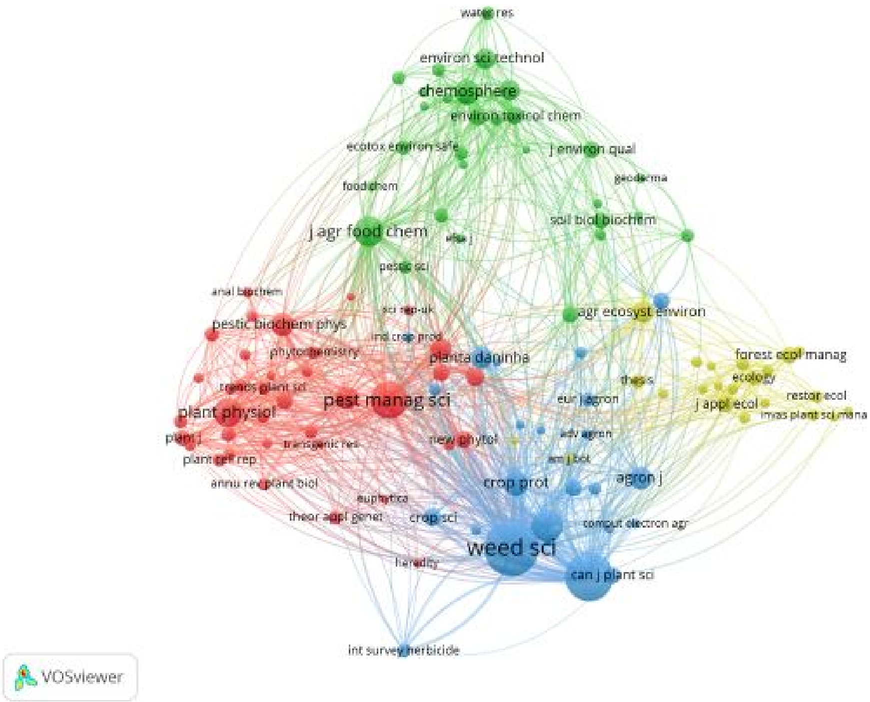

Figure 6. Co-citation network of leading journals publishing articles on herbicide research

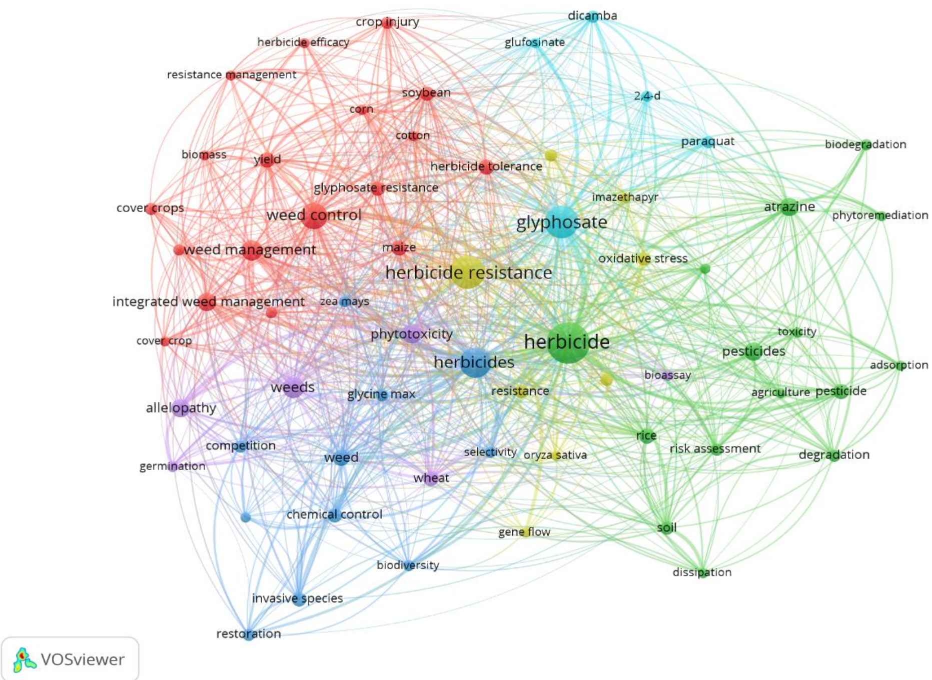

Figure 7. Co-occurrence network of the most frequently used author keywords

control" (329). Barring the keyword herbicide because, it is as obvious to appear with more frequency considering the search string used for the study, herbicide resistance was the dominating keyword. Other important keywords appeared in the descending order of frequency were "phytotoxicity", "photosynthesis", and "allelopathy". Further, a co-occurrence network of the most frequently used author keywords was constructed (**Figure 7**). The analysis indicated a total of 63 important keywords met the threshold of 50 as the minimum occurrence of a keyword. For each of the selected words, a total link strength of co-occurrence with other keywords was calculated and keywords with the greatest link strength were mapped. Four prominent clusters were found in the network wherein as an obvious fact "herbicide" was the keyword with the highest link strength (426). The keyword "weed control" was observed as the leading word in the red colored cluster with the highest number of keyword networks (17) and those keywords include "glyphosate resistance, herbicide tolerance, crop injury, herbicide efficacy" *etc*. Another important cluster was the one in which "herbicide resistance" was the leading keyword with a link strength of 256 and other words connected in this cluster were gene flow, oxidative stress, and imazethapyr. Many recent studies opined in the similar line identified through this keywords analysis. Special focus needs to be given to fundamental research on evolved glyphosate resistance because of the global over reliance on this herbicide (Duke and Powles 2008). Herbicide resistance studies could be given more emphasis to minimize the resistance of weeds to herbicides because it is one of the limiting factors to food security in global agriculture (Busi *et al.* 2013). There is a great concern about glyphosate weed resistance among researchers as per keyword analysis of literature (de Castilhos Ghisi *et al.* 2020).

Conclusion

In summary, this study provides a comprehensive bibliometric review of global herbicides research. The various analysis undertaken, help to explore different dimensions from a scientometric perspective. Ranking of countries, organizations, journals, and articles help to know the leading entities in each category that are involved in herbicide research, publications and their contribution in terms of volume and citations. Different network analyses provided an understanding of the collaborations and cooperation prevailing in herbicides research across the globe. Overall, the study highlighted the present status of research in the herbicide research domain and hints at future thrust areas of research like herbicide resistance which has been appeared as the most focused field of research in author keywords analysis.

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OPINION ARTICLE

The opportunities and challenges for harvest weed seed control (HWSC) in India: An opinion

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ABSTRACT

Weeds which are escaped during the control measures are one of the source of soil weed seedbank. At the time of crop harvest, several weed species retain a considerable quantity of their seed. These weed seeds are evenly spread across the crop field through various weed seed dispersal mechanisms. By knowing the weed seed retention character of every weed species, their effective weed control can be achieved by the collection and/or destruction of weed seeds during crop harvest using harvest weed seed control (HWSC) methods. Narrow windrow burning, chaff tramlining, chaff carts, chaff lining, the Harrington seed destructor (HSD) and the bale direct system are common HWSC procedures. The crop harvest is a primary contributor to the transmission of weed seeds over the crop fields and with HWSC, we can now skip this process and prevent weed seed spread. This strategy is useful to target weed species that retain a large part of their seed after maturity and was found highly effective in controlling the spread of herbicide resistant weed seeds. HWSC aims to prevent the mature weeds seed from entering the seedbank. Through HWSC, we can prevent the enrichment of soil weed seedbanks and deplete existing soil weed seedbanks in long run. In India, the scope for HWSC is high in organic farming, direct-seeded rice, zero-till wheat, herbicide tolerant rice and high intensive irrigated agriculture while its scope is much limited in rainfed agriculture. However, the efforts on using HWSC are yet to begin in India and should be initiated.

Keywords: Direct-seeded rice, Harvest Weed Seed Control, HWSC, Weed seedbank, Zero tillage

INTRODUCTION

The weed seedbank is an integral part of agricultural systems since it is the major contributor of weeds in croplands and act as a weed biodiversity reserve (Gohil *et al.* 2020). It dictates the kind and intensity of weed menace in subsequent crops, while also reflecting the impact of previous management efforts on weed population dynamics (Legere *et al.* 2011). Weed seed reservoirs in soil seedbanks aid in the persistence of weeds (Gallandt 2006). In most agricultural fields, the soil weed seedbank contains millions of weed seeds per hectare which is the source of recurring weed infestations (Andreasen *et al.* 2018). The usual source of seedbank replenishment is weed seed rain, or the reproduction and spread of seeds by weedy plants. The seedbank composition is influenced by a variety of elements, such as management strategies, weed characteristics (competitiveness, duration, reproduction, stress tolerance) and edaphic environments (Arora and Tomar 2012). Similarly, weed seed production is influenced by a variety of factors, including available plant nutrients and water, as well as competition from other plants (Rao *et al.* 2017). The early-season survivors contribute more to the weed seedbank than late-emerging individuals (Steckel and Sprague 2004). Because late-emerging weed seedlings are harmed by crop competition, particularly for light. Reduced light supply is known to have little effect on seed viability (Baumann *et al.* 2001), and seed production in late-emerging weeds may contribute enough to seedbank persistence (Mayen *et al.* 2008). Late-season weed control was found effective in reducing weed seed rain and seedbank densities (Brewer and Oliver 2007).

Despite the farmer's best attempts to control weeds, the problem endures. The majority of farmer's non-chemical weed management strategies are aimed

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at preventing weed seedlings from interfering with the crop plant at early growth but not on weeds reproduction (Ramesh *et al.* 2022). In case of ineffective weed control, weeds survive and shatter seeds leading to enrichment of soil weed seedbank. Late-season weed escapes are a major contributor to seedbank persistence (Bagavathiannan and Norsworthy 2012). The late-season weed seed development has received a lot of attention with increasing herbicide-resistant weeds and changing weed management paradigm (Norsworthy *et al.* 2012).

The emerging problem of herbicide resistance (HR)

Herbicide resistant (HR) weeds are a major hindrance to agricultural sustainability. In agriculture, weed resistance to popular herbicides is becoming rampant (Duary 2008). Continuing to rely solely on herbicides for managing the weeds will not only expedite the spread of resistance but will also remove the few existing herbicides that are effective against these weeds (Patterson *et al.* 2021). Given the lack of new herbicides modes of action in the near future, precautions must be made to safeguard the efficacy of existing herbicides. To control herbicide-resistant or escaped plants, alternative non-chemical weed control approaches are required as seed produced by resistant weeds, prevailing at crop harvest, are evenly spread across the farm through various weed seed dispersal mechanisms at the time of harvest. HWSC is one such method gaining importance recently in many countries like Australia, USA and have been found to reduce the soil seedbank and minimise the likelihood of herbicide resistance evolution (Walsh and Newman 2007, Walsh and Powles 2007, Walsh *et al.* 2013, Walsh *et al.* 2017). Multiple HR outbreaks were extremely rare to occur and were nearly always avoided by implementing annual, efficient HWSC (Somerville *et al.* 2018). Combining HWSC with effective herbicides offers the potential to minimise future development of herbicide resistance besides decreasing weed populations.

Harvest weed seed control (HWSC)

HWSC is a term that refers to the collection and/or destruction of weed seeds during harvest. HWSC is a novel preventive wave of weed management. HWSC is being increasingly practised in Australia and other parts of the world. The percentage of weed seed retained on the plants at the time of crop harvest ranged from 80 to 90% in the majority of weed species (Schwartz-Lazaro *et al.* 2021a,b). Modeling studies (Shergill *et al.* 2020) report greater than 80% seed retention is needed for HWSC to be viable.

Furthermore, larger plants generated more seeds, and seed retention was significant at harvest regardless of plant size or emergence time. These weed seeds then reach the reaper and are rewarded for their survival by being uniformly disseminated around the field and becoming a weed problem in the following years (Walsh *et al.* 2013). By knowing the weed seed retention character of every weed species, we can plan effective weed control practices against specific weeds by adopting HWSC. Harvest is a primary contributor to the transmission of weed seeds over a crop field; however, with HWSC, we can now skip this process and prevent weed seed spread. This strategy is used to target weed species that have a flaw, such as retaining a large part of their seed after maturity. HWSC is highly effective in controlling the spread of herbicide resistant weed seeds besides other weeds and has matured into an integrated technique for managing herbicide-resistant weeds (Somerville *et al.* 2018). The adoption of HWSC methods prevents the enrichment of soil weed seedbanks and depletes existing soil weed seedbanks in long run (Beam *et al.* 2021).

Soil weed seedbanks are considered a better indicator of the medium and long-term impact of weed management practice (Hawes *et al.* 2010). Reducing the amount of weed seed in the soil, is important for farmers to reduce weed pressure in the long run. The goal of an effective weed management strategy should limit the late-season weed seed production and enrichment of soil weed seedbanks (Walker and Oliver 2008). The soil seedbank is often slower to respond to the seasonal weed management measures due to constant weed seed intake from numerous seasons of escaping weeds (Schwartz *et al.* 2016). At harvest, the seeds present in the weed plants are either shattered or get pulled through the harvester and then returned to the soil seedbank. As a result, weed seeds are dispersed on the soil surface, spreading further and building the soil seedbank (Walsh and Powles 2007). To reduce the number of weed seeds replenishing the soil seedbank, HWSC strategies have been developed, which comprise both cultural and mechanical management practices.

HWSC allows the farmer to gather and kill all the non-shed weed seeds at harvest and this techniques is mostly used in Australia (Walsh *et al.* 2013, Walsh and Powles 2007, Walsh *et al.* 2017). Many HWSC methods were developed specifically to target the seed production of surviving weeds to limit seedbank contribution (Walsh *et al.* 2013, Walsh and Powles 2007, Walsh and Newman 2007). Pre-harvest, at-harvest, and post-harvest measures can also be employed to reduce weed seed shattering.

Narrow windrow burning, the Harrington Seed Destructor (HSD), bale direct systems, chaff carts, and other methods of chaff targeting during harvest are examples of HWSC. These techniques have been demonstrated to destroy 75 to 99% of weed seeds present at harvest (Walsh *et al.* 2013). The practice of some of these methods for several years may lead to considerable weed reductions in subsequent years, while others may only lead to moderate reductions. The different HWSC strategies (Shergill *et al.* 2020) are listed below.

Chaff carts

In this method, chaff are collected and transferred to a cart attached to a grain harvester that delivers the weed seeds into a bulk collection bin (Schwartz *et al.* 2016). The collected weed seeds are either burned along with chaff in the field or removed from the field. However, this method has the disadvantage of attaching the chaff cart behind the lengthy harvester, making manoeuvrability in narrow fields more difficult.

Narrow windrow burning

This technique is the most effective and relatively simple HWSC tactic. A low cost conveyor with a base of 16 to 18 inches wide installed on the back of the combine collects all of the chaff into a small row. These rows should be fired as soon as possible after formation. Firing the entire field does not kill the weed seeds as effectively as firing the chaff in the windrows (Schwartz *et al.* 2016). The abundance of chaff creates significantly more heat and increase the duration of the burning, resulting in less residue loss than traditional burning. Furthermore, this technique does not slow down the harvesting process. Narrow windrow burning is a relatively low-cost, non-chemical weed control approach.

Harrington seed destructor (HSD)

The HSD is a trailer mounted cage mill with chaff transfer systems developed by Ray Harrington, in 2005. An initial study employing the HSD has shown to destroy 95% of weed seed in wheat (Walsh *et al.* 2013). HSD and Redekop (The Redekop Seed Control Unit is an impact mill that incorporates a blade system in the centre of the mill with the goal to increase suction into the mill and airflow through it) work based on the mechanism of crushing weed seeds at the time of harvest utilizing mechanical energy resulting in the reduction of enrichment of soil weed seedbank. HSD was initially manufactured as a trailer unit to be dragged behind the harvester. However, currently, both HSD and Redekop are integrated within grain harvesters. These technologies are highly successful in Australia (Walsh *et al.* 2017) and gaining a foothold in the USA (Shergill *et al.* 2020). These technologies have not been introduced in India yet. Also, the efficacy of these devices needs to be tested in more bulky and complex corn or sorghum straw. Based on the potential, these technologies can greatly impact weed management. However, the present price of the HSD will most likely limit its immediate adoption in USA, Australia (Schwartz *et al.* 2016).

Bale direct systems

A combine harvester is directly attached to the large baler that makes bales from the chaff/straw exiting the combine harvester. The bales capture the weed seeds and can be used as feed for farm animals. The major limitation of this method includes limited demand for bales in the market and high risk in spreading the resistant weed seeds to other fields through the distribution of the bales.

Scope of HWSC in India

The adaption of zero-till seed cum fertilizer drill sowing of wheat in India is increasing over the years especially in rice-wheat cropping system of the Indo-Gangetic Plain (IGP). Till 2014 the area of no-till wheat sowing was nearly 5 Mha in IGP and 1.5 Mha alone in India (Kukal *et al.* 2014, Das *et al.* 2017). The central and state governments are promoting this technology in several states through various schemes by providing machineries/seed drills at a subsidized rate. Thus, the area under zero-till seed cum-fertilizer sowing is expected to boom in the coming years. In long run, this method of wheat cultivation favours weeds flora shift, herbicide use and weed resistant development (Singh *et al.* 2015). In wheat, the transition from conventional to zero till tillage has led to a change in weed flora. The use of herbicides to reduce grassy weeds and the lack of any control measures for broad-leaved weeds in wheat appear to be the main reasons for the shift in weed flora over time (Singh *et al.* 2002). In zero-tillage method, the number of perennial and broad-leaved weeds were found increased (Singh *et al.* 2015, Brar and Walia 2009). The dominant weed species in zero-till wheat sowing are *Cirsium arvense* and *Convolvulus arvensis* (Catizone *et al.* 1990). *Rumex dentatus* has developed resistance to metsulfuron-methyl (Chhokar *et al.* 2013), and the problem of *Rumex dentatus* and *Malva parviflora* in wheat is becoming more prevalent in no-till environments (Singh *et al.* 2015). The threat of these weeds may grow in the future as the area under no-till circumstances expands and resistance evolves. Certain weed species in the rice-wheat cropping system have already evolved resistance to a few herbicides in India (Kaur *et al.* 2022). The adaption of HWSC may avoid the problem of herbicide resistant development under zero-till wheat system. The recruitment of seeds from soil weed seedbank is avoided in zero-till system. The new seed addition to the soil seedbank is prevented by HWSC. Thus, the adoption of HWCS control in zero-till wheat will be a win-win solution.

Similarly, the area under direct-seeded rice (DSR) is increasing in India due to growing labour and irrigation water shortage (Rao *et al.* 2007, Vijayakumar *et al.* 2018, 2019). DSR save water and labour significantly compared to conventional transplanting (Pooja *et al.* 2021). Availability of broad spectrum and wider window herbicides are one of the major reasons for successful adoption of DSR in India (Jinger *et al.* 2016). The government is also promoting DSR since it reduces methane emission, lower production cost, save water and labour (Das *et al.* 2017).

In India, the use of herbicides to control weeds in croplands increasing. The rice-wheat system accounts for the consumption of 60% of the herbicide used in field crops in India. Weeds in the system, *viz. Echinochloa* spp, *Phalaris minor* developed resistance to various herbicides due to dependent on a single herbicide for a long time (Jinger *et al.* 2016). The first case of evolved resistance to bispyribac-sodium in *Cyperus difformis* L. was recently reported in India (Choudhary *et al.* 2021). India released herbicide (imazethapyr) tolerant basmati rice varieties (*Pusa Basmati 1979* and *Pusa Basmati 1985*) for commercial cultivation. The area under DSR is anticipated to increase with the release of herbicide tolerant rice varieties. Also the use of herbicides especially imazethapyr will increase in rice. Many researchers documented weed flora shift in rice cultivation due to change in cultivation method from transplanting to direct seeding (Rao *et al.* 2007, Saravanane *et al.* 2021). Higher use of herbicide without its rotation may favours herbicide resistant development and weed flora shift. The practice of HWSC in herbicide tolerant rice varieties will prevent the development of herbicide resistant weeds. Similarly, HWSC will prevent the weed flora shift and weed pressure in DSR in long run. Thus, the scope for HWSC is more in DSR, zero-till wheat, herbicide tolerant rice cultivation.

The concept of the critical period of weed control (CPWC) focuses on the early stage of the crop but not the later stage (Saravanane *et al.* 2020). It also does not focus on minimizing the weed pressure in the long run. The best weed control method should minimize weed pressure in long run. Unlike developed countries, the yield loss due to weeds in India is relatively higher (>20%) (Oerke *et al.* 1994, Bhan *et al.* 199, Gharde *et al.* 2018). In India weeds are controlled mostly through manual weeding and weed control measures are taken only during the early stage of the crop *i.e.* 20-40 days after sowing. In the later stage, the crop weed competition will be in favour of crops. However, due to the late removal of weed, the germinated weeds already might have removed a significant amount of growth resources (Ramesh *et al.* 2022). In addition, many weeds escape during manual weed control practices and grow along with crop plants. These escaped weeds are not generally controlled till the harvesting of the crop. This negligence causes an unnoticeable increase in soil weed seedbank and yield loss.

Manual harvesting of escaped weeds in rice and wheat before harvesting of the crop possess the problem of damage to crop plants since the crop plants covered the entire field and secondly human penetration may cause shattering loss of grain in crop plants. To overcome these problems, farmers can try to adopt escaped weed seed control at the time of flowering of crop. Mimicry weeds of rice and wheat crops escape weed control measures during the early stage of the crop (Rao and Moody 1988), while it is easy to distinguish in the cropland after the flowering stage (Barrett 1983). These weeds are the dominant weeds in the system for more than six decades. Escaped weed contribution to soil weed seedbank enrichment is largely responsible for this. These weeds also hold the majority of the seeds at the time of harvest.

Organic farming: Weed control in organic farming is a highly labour intensive and costly affair. The number of weed species, or diversity, often increases in organic farming since it does not use herbicide (Hyvönen *et al.* 2003). Moreover, the eradication of perennial weeds like *Cirsium arvense* is very difficult in organic farming (Graglia *et al.* 2006). With the increasing demand for organic products, it is anticipated that more area under organic cultivation will be brought in the coming years. However, the increasing labour shortage demands an alternate method of weed control in organic cultivation which demand less labour and reduce weed pressure in long run. The scope of HWSC in organic farming is very high since it reduces the weed pressure and labour requirement for weed control in long run. HWSC will not be effective unless weed control measures are taken to control off-season weeds. Since weeds are prolific breeders and seeders, farmers should control weeds around the year ideally before their seed set during the off-season to obtain desirable results from HWSC. However, at present the research on HWSC in different crops under organic cultivation is yet to be initiated, and it is need of the hour to promote such research.

The benefit of HWSC will be realized fully only when weeds are controlled during the off-season or round the year. In India, 2/3 of the agricultural land is rainfed, and mono-cropping is more prevalent in these areas (Venkateswarlu 2011). Least care (limited irrigation and manure application, no or one weeding) has been taken in these areas to cultivate the crop. Land fallow during the summer season is a common phenomenon. Thus, adopting HWSC control is not feasible in these areas. Alternatively, in irrigated areas where round the year agriculture is followed, the scope for HWSC is more. In IGP, due to assured irrigation water availability farmers are taking three crops in a year. Also, the use of herbicides for weed control is more here and it is increasing every year. Combining herbicide weed control with HWSC has shown effective results in reducing the weed seedbank and weed pressure in long run (Patterson *et al.* 2021). IGP region has the highest adaption of farm mechanization (Vijayakumar *et al.* 2021) and hence the benefits of HWSC adoption may be more in IGP, and research needs to be started in this area to assess its feasibility.

Required research

HWSC is not a "*magic bullet*" as it needs forethought and expertise, and it is not a standalone solution, but rather a component of weed management approaches (exp. herbicides, hygiene of farm implements, and bund/banks). It functions because of the interaction of numerous practices and possible synergies. The percentage of seeds retention for the predominant weed species is necessary to establish the possibility for using HWSC in each crop. After determining which species may be targeted at harvest, more research can be conducted to discover where the weed seeds end up. What is uncertain is what percentage of the grain, chaff, and straw that enters the combine harvester end up in each of the three fractions. Because of the differences in seed size compared to crop plants, the weed seeds should fall into the chaff portion. A few research finding has shown that HWSC prevents weed resistant development and weed flora shift. Thus, it is need of the hour to test this technology in India under various cropping systems to confirm it.

Integrated Weed Management (IWM) is the common method of weed management suggested in India. However, HWSC is presently not a part of IWM in India. HWSC strategies are adopted as a part of IWM in USA and Australia (Shergill *et al.* 2020). In India too, the HWSC strategies should be tested with existing IWM practices in various location and cropping system to find out the effectiveness and feasibility this noval technology under Indian condition.

Study on impact of HWSC on parasitic weeds are not available. Similarly, very few studies were conducted on mimicry weeds. Therefore, conducting HWSC trial in parasitic and mimicry weeds holds important. It is possible to establish which of the weeds species would most like, or need, to target with HWSC based on the results of reseach trial. The development of low cost tools and machineries for HWSC and its validation in India is yet to begin.

The study on negative impact of HWSC on environment like damage to native soil microbiome; emission of GHG, smoke, loss of carbon and nutrients due to biomass burning; soil compaction due to movement of heavy vehicles; higher cost of HWSC is also highly important (Patterson *et al.* 2021). The long term adaption of HWSC in agricultural fields may promote the extinction of weed species and cause biodiversity loss, which needs to be studied.

Conclusion

Harvesting weed seeds at the time of crop harvest is one of the finest preventive management tactics commonly known as HWSC, has potentiality for usage in Indian agro-ecosystems and hence research efforts need to be initiated and intensified. For the successful development and implementation of HWSC, it is critical to learn more about weed seed retention during crop harvest in different agro-ecological zones of India. HWSC is a cultural/mechanical weed management strategy that should be used in conjunction with other nonchemical weed control methods.

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RESEARCH ARTICLE

Weed dynamics and crops productivity as influenced by diverse cropping systems in eastern India

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ABSTRACT

The study of weed dynamics in diverse cropping systems helps to formulate the strategies for effective management of weeds. Hence, this study was conducted to assess the effect of diverse cropping systems on weed dynamics and crops productivity in eastern India. The minimum total weed density (4.85 no./m^2) and biomass (2.43 g/m^2) during rainy season crops was recorded in fodder sorghum-mustard-blackgram systems. In winter crops, the lowest total weed density was observed in soybean-maize system (5.79 no./m^2), while the lowest weed biomass (2.26 g/m^2) with finger millet-rapeseed (*toria*) system. In summer, soybean-maize, pearl millet-chickpea and sorghum-chickpea were equally effective for reducing weed density and biomass. Weed seedbank analysis revealed maximum grass weed seed density at 0-15 cm depth in foxtail millet-lentil, while minimum with fodder sorghum-mustard-blackgram system. The highest weed seed density of broad-leaved weeds was noted at 0-15 cm depth in maize-pigeonpea and the lowest with conventionally tilled direct-seeded rice (CTDSR)-mustard-blackgram system. It was concluded that diverse cropping systems significantly suppress weed density and biomass in all the seasons.

Key words: Cropping systems, Weed flora, Weed management, Weed seedbank, Zero-tillage

INTRODUCTION

Rice-wheat cropping system (RWCS) is one of the most important agricultural production systems in the world, which cover large extent of area and feeds a vast population (Pan *et al.* 2019). This production system contributes ~40% of rice and wheat in India (Kumar *et al.* 2021). In Indo-Gangetic Plains (IGP), *viz*. India, Bangladesh, Nepal, and Pakistan, rice-wheat system occupies ~13.5 million ha of cultivable land. Productivity of RWCS is decreasing due to decline in factor productivity and increased the problem of various biotic and abiotic stresses (Singh *et al.* 2012). Among biotic stress, weeds are major threat to crop productivity, input-use efficiency, and profitability of any cropping systems.

Soil weed seedbank is the major source of weeds that determines above-ground weed flora composition and density in agricultural fields. Maximum weed seed reserves have been reported in top 0–5 cm soil depth and decreases with increasing soil depth (Mishra and Singh 2012). Continuous cultivation of rice-wheat sequence favoured grassy weeds dominance (Malik *et al*. 2014, Bhatt *et al*. 2016). Adoption of various tillage practices, crop rotations and choice of crop influences type and degree of weed infestation by altering the weed seedbank and species composition (Kumar *et al*. 2013). Retention and incorporation of previous crop residues can play a vital role on weed seed germination by altering the weed seed environment (Nichols *et al.* 2015). Thus, adoption of new crops or changes in RWCS of IGP reduced weed growth as in rice-wheat-greengram sequence (Singh *et al.* 2008) due to creation of an unstable environment for weeds that prevent recurrence of specific annual weed species. Crop rotation strategies may not eradicate troublesome weed species, but they can limit their growth and reproduction (Scherner *et al*. 2018). Hence, this study was conducted to evaluate the role of diverse cropping systems on management of weeds, weed seed dynamics and crops productivity in eastern India.

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MATERIALS AND METHODS

A study was carried out for five consecutive years from 2016-2020 at the ICAR-Research Complex for Eastern Region, Patna, India, at 25°30'N,85°15'E,52 m above mean sea levels. The annual precipitation was 1168 mm, of which 88% rainfall is received between July and September. Mean annual evaporation was 1573 mm. Soil of experimental site was loamy in texture (50.4, 35.0 and 14.6% sand, silt and clay, respectively) with Typic Haplustept, Fluvisol having pH of 7.5, electrical conductivity of 0.12 dS/m, soil organic carbon content of 6.0 g/kg, $KMnO_4$ oxidizable N of 64.6 mg/kg, Olsen phosphorus of 23.9 mg/kg, NH_4OAc exchangeable potassium of 78.3 mg/kg, and DTPA-extractable zinc of 0.66 mg/kg (0-15 cm soil).

A randomized block design replicated thrice was used. Ten diverse cropping sequences were tested, *viz.* farmers practice (FP) of transplanted rice (TPR)-conventional till (CT) wheat-CT greengram; conventional till-direct-seeded rice (CTDSR)-zero till (ZT) wheat-ZT greengram; CT soybean-ZT maize, CTDSR-ZT mustard-ZT blackgram; CT foxtail millet-ZT lentil; CT pearl millet-ZT chickpea; CT finger millet- ZT rapeseed (*toria*); CT sorghum (grain)-ZT chickpea; CT maize-ZT pigeon-pea and CT sorghum (fodder)-ZT mustard-ZT blackgram. All the rainy season crops were grown in CT, while all winter and summer season crops were grown under ZT, except in farmers' practice. Size of individual experimental plot was 8.0×5.0 m. All the component crops were grown as per the standard crop calendar (**Table 1**). All the rainy season crops were planted during third week of June and harvested by second week of October except for maize and fodder sorghum. During the winter, wheat, oilseed, and pulse crops were sown during 3rd week of October and harvested in March and April. Summer crops (greengram/blackgram) were sown and harvested during first week of April and June, respectively. The observations on weed composition, weed density and biomass were recorded (at 4-5 leaf stage) using quadrats (0.5×0.5 m) placed randomly at four places in each plot.

Weed seedbank studies were undertaken at the end of 5h year rotation by 'seedling emergence' method as described by MacLaren *et al.* (2021). Although this method is time consuming, under-estimate the absolute weed seedbank size, but it provides more accurate estimation of the species composition than seed extraction method. Sampling of weed seedbank was done during June 2020 after harvest of greengram. Soil samples were taken using a 4.0 cm diameter metal core from two depths, 0–15 and 15-30 cm of five places in each plot. All samples of a given depth were bulked to make a composite soil sample per plot. Bulked soil samples were partially air-dried, and clods were broken by the hand. Soil debris and large root fragments were separated from soil samples. Three-kilogram soil sample for each depth per plot was spread on 40.4×30.3×9.5 cm plastic trays with~2 cm soil layer

Table 1. Crops, varieties, seed rate, fertilization and weed management practices used in crops during different seasons

Crops	Varieties	Seeding rate (kg/ha)	Spacing (cm)	Fertilization (kg NPK/ha)	Weed management practices followed during cropping
Rainy season					
Transplanted rice	*Swarna Shreya*	20	20×15	120-60-40	Pretilachlor PE at 2-3 DAT *fb* 1 HW
Direct-seeded rice	*Swarna Shreya*	30	20×5	120-60-40	Pendimethalin PE 2-3 DAS *fb* bispyribac-Na at 25-35 DAS and 1 HW at 50-55 DAS
Soybean	*Pusa 9712*	80	45×15	20-80-40	Pendimethalin PE at 2-3 DAS *fb* 1 HW at 30-35 DAS
Foxtail millet	*Rajendra Kauni*	10	25×10	60-40-25	Atrazine PE at 2-3 DAS *fb* 1 HW at 40-45 DAS
Pearl millet	*Proagro 9001*	5	45×15	80-40-40	Atrazine PE at 2-3 DAS *fb* 1 HW at 40-45 DAS
Finger millet	*RAU 8*	5	20× 10	60-40-25	Atrazine PE 2-3 DAS *fb* 1 HW at 40-45 DAS
Sorghum grain	*CSH 25*	10	45×15	80-40-40	Atrazine PE 2-3 DAS *fb* 1 HW at 50-55 DAS
QPM maize	*Shaktiman 5*	20	60×20	100-60-40	Atrazine PE 2-3 DAS *fb* 1 HW at 35-40 DAS
Sorghum fodder	*CSH 13*	30	25×5	80-40-40	-
Winter season					
Wheat	*HD 2967*	125	22.5×5	150-60-40	Pendimethalin PE at 2-3 DAS *fb* total and 2,4-D at 35-40 DAS
Pigeonpea	*Pusa 9*	50	30×15	20-50-0	Pendimethalin PE at 2-3 DAS *fb* HW at 40-45 DAS
Lentil	*HUL 57*	35	30×10	20-50-0	Pendimethalin PE at 2-3 DAS *fb* HW at 35-40 DAS
Chickpea	*Pusa 256*	80	30×10	20-50-0	Pendimethalin PE at 2-3 DAS *fb* HW at 40-45 DAS
Rapeseed (*toria*)	*TS 38*	5	30×10	60-40-40	Pendimethalin PE at 2-3 DAS *fb* HW at 30-25 DAS
Mustard	*Proagro 5222*	5	30×10	80-40-40	Pendimethalin PE at 2-3 DAS *fb* HW at 35-40 DAS
Maize	*S2-945*	20	50×20	120-75-50	Atrazine PE 2-3 DAS *fb* HW at 35-40 DAS
Summer season					
Greengram	Samrat	25	30×10	20-50-0	Pendimethalin PE at 2-3 DAS *fb* 1 hand weeding at 35-40 DAS
Blackgram	Uttara	25	25×10	20-50-0	Pendimethalin PE at 2-3 DAS *fb* 1 hand weeding at 35-40 DAS

QPM: Quality protein maize; PE: Pre-emergence, HW: hand/manual weeding; DAT: days after transplanting; DAS: days after sowing thickness. Subsequently, these trays were placed in a greenhouse and watered to keep the soil at field capacity. Emerged weed seedlings were identified, counted, and removed until the emergence was nil.

Crop yield of different cropping sequences was converted into rice equivalent yield (REY) by following formula,

$$\text{REY (t/ha)} = \frac{\text{Grain yield of the winter/summer crop} \times \text{MSP of winter/summer crops}}{\text{Price of rice}}$$

Where, MSP is the minimum support price as fixed by the Government of India (GOI).

System rice equivalent yield (SREY) was calculated by adding REY of different crops of a system. All data on weed density and biomass were analysed with 'Statistix 8.1' for analysis of variance (ANOVA). Data were square-root transformed before analysis to reduce heterogeneity of variance.

RESULTS AND DISCUSSION

Weed density and biomass during rainy (*Kharif*) season

Data on weed density and biomass recorded during rainy season (**Table 2)** indicated that minimum total weed density was associated with fodder sorghum-mustard-blackgram (4.85 no./m^2), while the maximum weed density was with soybean-maize system. Minimum density of *Trianthema portulacastrum* (3.92 and 10.27 no./m^2) was recorded in fodder sorghum-mustard-blackgram and pearl millet-chickpea, respectively. While, maximum density of *T. portulacastrum* (58.9 no./m^2) was observed in soybean-maize followed by CTDSR-wheat-greengram (43.32 no./m^2). Similarly, the lowest density of *Cyperus rotundus* and *Brachiaria ramosa* was recorded with fodder sorghum-mustard-blackgram and CTDSR-wheat-greengram systems. The lowest total weed biomass was observed in fodder sorghum-mustard-blackgram (2.43 g/m^2), while the maximum was in soybean-maize (11.57 g/m^2). Maximum biomass of *T. portulacastrum*, *C. rotundus*, *B. ramosa* and *C. dactylon* was recorded in soybean-maize, pearl millet-chickpea, soybean-maize, and fodder sorghum-mustard-blackgram (10.29, 6.84, 2.26 ad 1.52 g/m^2) systems, respectively. However, the minimum biomass of *T. portulacastrum*, *C. rotundus* and *B. ramosa* was observed in fodder sorghum-mustard-blackgram system. Diverse cropping systems reduced weed density and biomass probably due to greater soil moisture that promoted germination and reduced resistance of soil to seedling emergence. Pan *et al.* (2019) reported that adoption of finger millet + blackgram and finger millet + horsegram system effectively reduced the weed growth and biomass accumulation.

Table 2. Effect of tillage practice and crop rotation on weed density and dry biomass during rainy season

Cropping systems	Weed density (no./m^2)					Weed dry biomass (g/m^2)				
	TP	CR	BR	CD	Total	TP	CR	BR	CD	Total
TPR-CT wheat -CT greengram	18.4 (338*)	0.71 (0)	3.67 (13)	0.71 (0)	18.74 (351)	3.32 (10.5)	0.71 (0)	1.14 (0.8)	0.71 (0)	3.43 (11.3)
CTDSR-ZT wheat -ZT greengram	43.3 (1877)	5.52 (30)	10.93 (119)	0.71 (0)	45.01 (2026)	8.13 (65.6)	2.86 (77.0)	1.97 (3.4)	0.71 (0)	8.79 (76.7)
CT Soybean-ZT maize	58.9 (3471)	8.91 (79)	5.43 (29)	0.71 (0)	59.83 (3574)	10.29 (105.4)	4.89 (23.4)	2.26 (4.6)	0.71 (0)	11.57 (133.4)
DSR-ZT mustard-ZT blackgram	38.8 (1506)	2.34 (5)	4.52 (20)	0.71 (0)	39.13 (1531)	6.07 (36.4)	2.39 (5.2)	1.30 (1.2)	0.71 (0)	6.58 (42.8)
CT Foxtail millet-ZT lentil	31.4 (986)	7.10 (50)	0.71 (0)	0.71 (0)	32.19 (1036)	5.34 (28.0)	4.40 (18.9)	0.71 (0)	0.71 (0)	6.88 (46.9)
CT Pearl millet-ZT chickpea	10. (105)	9.46 (89)	0.71 (0)	0.71 (0)	13.95 (194)	1.70 (2.4)	6.84 (46.3)	0.71 (0)	0.71 (0)	7.01 (48.7)
CT Finger millet-ZT rapeseed (*toria*)	16.89 (285)	5.70 (32)	4.74 (22)	0.71 (0)	18.42 (339)	2.92 (8.0)	3.03 (8.7)	0.71 (0)	0.71 (0)	4.15 (16.7)
CT Sorghum (Grain)-ZT chickpea	24.39 (595)	3.94 (15)	0.71 (0)	0.71 (0)	24.71 (610)	5.75 (32.6)	2.76 (7.1)	0.71 (0)	0.71 (0)	6.34 (39.7)
CT Maize -ZT pigeonpea (ZT)-fallow	25.44 (647)	1.87 (3)	1.58 (2)	0.71 (0)	25.54 (652)	5.84 (33.6)	1.30 (1.2)	1.14 (0.8)	0.71 (0)	6.01 (33.6)
CT Sorghum (fodder)-ZT mustard-ZT blackgram	3.39 (11)	0.71 (0)	0.71 (0)	3.53 (12)	4.85 (23)	2.02 (3.6)	0.71 (0)	0.71 (0)	1.52 (1.8)	2.43 (54.4)
LSD (p=0.05)	1.27	0.23	0.15	0.05	1.28	0.23	0.15	0.03	0.02	0.25

*Data were subjected to square root transformation ($\sqrt{x+0.5}$), values in parentheses represent original values; TPR: transplanted puddle rice; CTDSR: conventional till-direct-seeded rice; CT: conventional-till; ZT: zero-till; DSR: direct-seeded rice; TP: *Trianthema portulacastrum*; CR: *Cyperus rotundus*; BR: *Brachiaria ramosa*; CD: *Cynodon dactylon*

Density and dry matter of weeds during winter (*Rabi*) season

Major weed flora was identified in winter season includes *Solanum nigrum*, *Chenopodium album*, *C. rotundus*, *C. dactylon*, *Ipomoea aquatica*, *Trifolium fragiferum* and *Launaea pinnatifida*. Maximum total weed density was observed in foxtail millet-lentil system (10.91 no./m^2), however, minimum weed density was associated with soybean-maize (5.79 no./m^2) rotation (**Table 3**). The lowest density of *S. nigrum* was associated with sorghum - chickpea, while the highest with foxtail millet-lentil. This might be due to greater weed seed reserves in the soil of those respective cropping systems in comparison to other cropping sequences (Mishra *et al.*2019). Similarly, the maximum suppression of *C. album* was observed in all other cropping system except TPR-wheat-greengram, CTDSR-wheat-greengram and foxtail millet-lentil systems. Significantly the highest reduction in density of *C. rotundus* was recorded by TPR-wheat-mugbean and foxtail millet-lentil systems in comparison to other systems. Density of *I. aquatica* and *T. fragiferum* were significantly lower in all other cropping system except foxtail millet-lentil and soybean-maize systems, respectively. Significant reduction of *L. pinnatifida* was observed with all cropping system except soybean-maize. A recent meta-analysis on 15 studies covering crop treatment in maize-soybean rotations showed that cover crop helps significantly in reducing weed biomass without changing weed density. Moreover, to achieve 75% reduction in weed biomass, it requires at least 5 mg/ha of cover crop (Sharma *et al.* 2021).

Diverse cropping systems significantly reduced total weed biomass except foxtail millet-lentil, pearl millet-chickpea and fodder sorghum-mustard-blackgram systems. Similarly, diverse cropping systems had significant effect on biomass of *S. nigrum* except TPR-wheat-greengram, foxtail millet-lentil and CTDSR-wheat-greengram. Minimum biomass of *S. nigrum* was recorded in maize-pigeonpea followed by sorghum-chickpea, while maximum biomass of *S. nigrum* was with foxtail millet-lentil followed by CTDSR-wheat-mung. Maximum biomass of *C. album* was observed with TPR-wheat-greengram. TPR-wheat-greengram, foxtail millet-lentil, finger millet-*toria* and soybean-maize significantly reduced biomass of *C. rotundus* compared to other systems. Similarly, biomass of *I. aquatic*, *T. fragiferum* and *L. pinnatifida* was significantly reduced by all cropping system except foxtail millet-lentil, soybean-maize, and pearl millet-chickpea systems. Earlier studies have reported that adapting different crop rotations help in lowering the density of a particular weed/weed density (Zeller *et al.* (2021).

Table 3. Effect of tillage practice and crop rotation on weed density and biomass during winter season

Cropping systems	Weed density ((no./m^2)								Weed dry biomass (g/m^2)							
	SN	CA	CR	IA	TF	LP	Others	Total	SN	CA	CR	IA	TF	LP	Others	Total
TPR-CT wheat -CT	7.43	3.54	0.88	0.71	0.71	1.10	1.44	8.57	2.09	1.14	0.75	0.71	0.71	0.82	0.91	2.42
greengram	(59.0*)	(13.0)	(0)	(0)	(0)	(1.00)	(3.0)	(75.0)	(3.90)	(0.80)	(0.07)	(0)	(0)	(0.20)	(0.40)	(5.37)
CTDSR-ZT wheat -ZT	7.16	1.39	2.83	0.71	0.71	1.94	1.52	8.58	2.28	0.87	1.18	0.71	0.71	1.04	0.90	2.71
greengram	(53.0)	(2.0)	(10.0)	(0)	(0)	(6.0)	(2.0)	(73.0)	(4.83)	(0.27)	(1.07)	(0)	(0)	(0.80)	(0.34)	(7.31)
CT Soybean-ZT maize	2.54	0.71	2.53	0.71	2.26	0.71	2.71	5.79	1.71	0.71	1.12	0.71	1.49	0.71	1.58	3.11
	(13.0)	(0)	(8.0)	(0)	(6.0)	(0)	(8.0)	(35.0)	(4.43)	(0)	(0.93)	(0)	(2.03)	(0)	(2.33)	(9.73)
DSR-ZT mustard-ZT	1.25	0.71	6.23	0.71	0.71	0.71	2.06	6.73	0.91	0.71	2.32	0.71	0.71	0.71	1.11	2.60
blackgram	(2.0)	(0)	(40.0)	(0)	(0)	(0)	(4.0)	(46.0)	(0.40)	(0)	(5.53)	(0)	(0)	(0)	(0.81)	(6.74)
CT Foxtail millet-ZT	8.92	2.34	1.84	1.77	0.71	0.71	4.88	10.91	3.23	0.91	0.97	1.21	0.71	0.71	1.74	3.89
lentil	(83.0)	(5.0)	(4.0)	(3.0)	(0)	(0)	(25.0)	(120.0)	(10.73)	(0.35)	(0.47)	(1.10)	(0)	(0)	(2.60)	(15.25)
CT Pearl millet-ZT	2.05	0.71	8.06	0.71	0.71	2.48	1.72	9.14	0.91	0.71	4.04	0.71	0.71	1.27	0.99	4.38
chickpea	(7.0)	(0)	(70.0)	(0)	(0)	(8.0)	(4.0)	(88.0)	(0.40)	(0)	(17.50)	(0)	(0)	(1.40)	(0.62)	(19.92)
CT Finger millet-ZT	1.70	0.71	4.86	0.71	0.71	0.88	2.98	6.39	0.94	0.71	1.83	0.71	0.71	0.73	1.29	2.26
rapeseed (*toria*)	(4.0)	(0)	(24.0)	(0)	(0)	(0)	(4.0)	(43.0)	(0.50)	(0)	(2.87)	(0)	(0)	(0.03)	(1.45)	(4.84)
CT Sorghum (grain)-ZT	1.10	0.71	7.78	0.71	0.88	0.71	0.88	7.87	0.87	0.71	3.51	0.71	0.72	0.71	0.71	3.55
chickpea	(1.0)	(0)	(62.0)	(0)	(0)	(0)	(0)	(64.0)	(0.30)	(0)	(12.10)	(0)	(0.01)	(0)	(0)	(12.42)
CT Maize -ZT pigeonpea	1.18	0.71	5.64	0.71	0.71	1.70	1.39	6.28	0.82	0.71	2.98	0.71	0.71	1.13	0.84	3.25
(ZT)-fallow	(1.0)	(0)	(32.0)	(0)	(0)	(4.0)	(2.0)	(39.0)	(0.20)	(0)	(8.60)	(0)	(0)	(0.77)	(0.23)	(10.16)
CT Sorghum (fodder)-ZT	2.86	0.71	6.16	0.71	0.71	2.54	1.32	8.03	2.03	0.71	2.56	0.71	0.71	1.43	0.94	4.01
mustard-ZT blackgram	(14.0)	(0)	(39.0)	(0)	(0)	(10.0)	(2.0)	(64.0)	(5.13)	(0)	(7.69)	(0)	(0)	(2.30)	(0.50)	(15.63)
LSD (p=0.05)	3.36	0.72	2.77	0.55	0.78	1.76	2.32	2.70	1.45	0.11	1.49	0.25	0.38	0.68	0.70	1.42

*Data were subjected to square root transformation ($\sqrt{x+0.5}$), values in parentheses represent original values; TPR: transplanted puddle rice; CTDSR: conventional till-direct seeded rice; CT: conventional-till; ZT: zero-till; DSR: direct-seeded rice; SN: *Solanum nigrum;* CA: *Chenopodium album*; CR: *Cyperus rotundus*; CD: *Cynodon dactylon*; IA: *Ipomoea aquatica*; TF: *Trifolium fragiferum*; LP: *Launia pinnatifida*

Weed density and biomass during summer

During summer, the lowest total weed density was recorded with soybean-maize system, which was followed by pearl millet-chickpea and sorghum-chickpea, while the maximum density was noticed with TPR-wheat-greengram followed by CTDSR-wheat-greengram and foxtail millet-lentil (13.16, 12.88 and 12.34 no./m^2, respectively) systems **(Table 4).** Significantly higher suppression of *C. rotundus* in summer was recorded under sorghum-chickpea followed by pearl millet-chickpea, soybean-maize and TPR-wheat-greengram as compared with other cropping system. The lowest density of *T. portulacastrum* was observed in different cropping systems except TPR-wheat-greengram, CTDSR-wheat-mung and foxtail millet-lentil. Similarly, cropping system significantly reduced density of *S. nigrum* except TPR-wheat-greengram, CTDSR-wheat-greengram and CTDSR-mustard-blackgram systems. Brankov *et al.* (2021) reported that maize-wheat system can reduce weed density in winter season wheat. MacLaren *et al.* (2021) also reported that crop rotation with reduced tillage lowered weed infestation, whereas crop interaction by ZT interaction was unable to reduce weed density.

Soybean-maize, pearl millet-chickpea, finger millet- rapeseed (*toria*) and sorghum-chickpea systems significantly reduced total weed biomass in summer crops (**Table 4**). All cropping systems reduced biomass of *C. rotundus* except CTDSR-mustard-blackgram and fodder sorghum-mustard-blackgram. Similarly, diverse cropping systems had significant effect on biomass of *S. nigrum* except TPR-wheat-greengram and DSR-mustard-blackgram. Maximum biomass of *S. nigrum* was associated with TPR-wheat-greengram and DSR-mustard-blackgram (3.24 and 3.1 g/m^2, respectively) in comparison to other treatments. Higher biomass of *T. portulacastrum* was noticed under TPR-wheat-greengram followed by foxtail millet-lentil and CTDSR-wheat-mung (4.59, 3.27 and 3.14 g/m^2, respectively). All diverse cropping systems significantly reduced other weeds biomass except CTDSR-wheat-greengram and maize-pigeonpea. Diverse cropping systems significantly reduced the biomass of *C. album* except TPR-wheat-greengram, which had recorded the highest biomass. TPR-wheat-mung, foxtail millet-lentil, finger millet-rapeseed (*toria*) and soybean-maize significantly reduced biomass of *C. rotundus* compared to others cropping systems. Similarly, biomass of *I. aquatic*, *T. fragiferum* and *L. pinnatifida* significantly reduced by diverse cropping systems except foxtail millet-lentil, soybean-maize, and pearl millet-chickpea, respectively, which was maximum biomass. Anderson (2004) reported that weed density could be reduced by utilizing balanced life-cycle intervals in

Table 4. Effect of tillage practice and crop rotation on weed density and dry biomass during summer season

Cropping systems	Weed density (no./m^2)					Weed dry biomass (g/m^2)				
	CR	SN	TP	Others	Total	CR	SN	TP	Others	Total
TPR-CT wheat -CT greengram	1.25 (2.0*)	5.89 (41.0)	10.92 (125.0)	2.34 (6.0)	13.16 (174.0)	0.78 (0.12)	3.24 (12.45)	4.59 (22.59)	1.09 (0.78)	5.00 (26.15)
CTDSR-ZT wheat -ZT greengram	4.78 (26.0)	3.89 (20.0)	10.10 (103.0)	4.22 (18.0)	12.88 (166.0)	2.23 (4.88)	2.38 (7.17)	3.14 (10.04)	2.62 (6.65)	4.39 (20.81)
CT Soybean-ZT maize	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
DSR-ZT mustard-ZT blackgram	8.68 (78.0)	4.17 (22.0)	0.71 (0)	4.27 (19.0)	10.85 (118.0)	4.45 (19.85)	3.14 (13.32)	0.71 (0)	1.69 (3.12)	5.05 (28.67)
CT Foxtail millet-ZT lentil	5.25 (40.0)	1.99 (4.0)	9.79 (101.0)	2.67 (7.0)	12.34 (152.0)	3.06 (12.77)	1.50 (1.95)	3.27 (10.96)	2.05 (4.63)	4.32 (18.74)
CT Pearl millet-ZT chickpea	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
CT Finger millet-ZT rapeseed (*toria*)	4.44 (21.0)	0.71 (0)	0.71 (0)	3.72 (17.0)	6.13 (37.0)	2.25 (5.42)	0.71 (0)	0.71 (0)	2.01 (4.00)	2.76 (8.12)
CT Sorghum (grain)-ZT chickpea	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
CT Maize -ZT pigeonpea (ZT)-fallow	5.48 (36.0)	2.29 (6.0)	0.71 (0)	3.83 (16.0)	7.22 (58.0)	3.31 (14.31)	1.90 (3.86)	0.71 (0)	2.38 (6.67)	4.25 (24.17)
CT Sorghum (fodder)-ZT mustard-ZT blackgram	6.39 (41.0)	2.35 (5.0)	0.71 (0)	3.93 (17.0)	7.92 (62.0)	3.81 (14.30)	1.17 (0.98)	0.71 (0)	1.90 (3.38)	3.76 (15.19)
LSD (p=0.05)	3.51	2.44	2.50	2.14	2.19	2.19	1.80	1.26	1.42	2.10

*Data were subjected to square root transformation ($\sqrt{x+0.5}$), values in parentheses represent original values; TPR: transplanted puddle rice; CTDSR: conventional till-direct seeded rice; CT: conventional-till; ZT: zero-till; DSR: direct-seeded rice; TP: *Trianthema portulacastrum;* CR: *Cyperus rotundus*; SN: *Solanum nigrum* crop rotation. Different weed management strategies decreased the weed density and biomass, resulting in lower weed-crop competition, which ultimately improved crop productivity.

Crop yield and system productivity

Among different rainy and winter crops, the maximum rice equivalent yield was produced by maize and pigeonpea, respectively, whereas during summer season greengram in TPR-ZT wheat-ZT greengram produced the highest rice equivalent yield (**Table 5**). Total system equivalent yield differed among the cropping systems. The maximum system yield was recorded with maize-pigeonpea (22.34 t/ ha) cropping system with none of the cropping system was statistically similar to it and it was followed by fodder sorghum-mustard-blackgram, rice-mustard-blackgram and CTDSR-wheat-greengram.

Economics

Economic returns obtained from diverse cropping systems revealed the maximum net returns and benefit: cost ratio (BCR) was noted for maize cob- pigeonpeapea (₹ 262902/ha and 3.75), while the lowest with finger millet-toria (₹ 35882/ha and 1.61) (**Table 5**). Expenditure incurred on cereal-based production sequences was higher and could be attributed to excessive tillage operation, and high use of fertilizers, irrigation, and human labours (Kumar *et al.* 2021). Comparatively the lower B: C ratio in cereal-based production system was due to lower returns and higher expenditure involved per unit production.

Weed seedbank dynamic in diverse cropping systems

Altogether 14 weed species including grassy and BLW were identified from weed density assessment during rainy season, 11 weed species were identified during winter crop season and 8 weed species were observed during summer **(Table 6).** Maximum weed seed density of grassy weeds at 0-15 cm depth was observed in foxtail millet-lentil (147.37 seedlings/m^2) followed by CTDSR-mustard-blackgram and maize-pigeonpea (133.66 and 126.08 seedling/m^2, respectively). While minimum weed seed density of grassy weeds (80.9 seedlings /m^2) was noticed in fodder sorghum-mustard-blackgram followed byTPR-wheat-mung and DSR-wheat-mung. While maximum weed seed density of grassy weeds (175.78 seedling/m^2) was observed with maize-pigeonpea (ZT) and minimum in TPR-wheat-greengram (56.04 seedling/m^2) at 15-30 cm of soil depth. Adoption of different tillage techniques may suppress or encourage emergence of weeds, as germination of few weeds is influenced by previously germinated weeds, because of inter-specific competition (Nandan *et al.* 2020). Exposure to light breaks dormancy and eventually increases germination in many species. Generally small seeded species are found to be more sensitive to light than large seeded ones. Eliminating light penetration during tillage can help in reduction of emergence of buried light sensitive species (Singh *et al.* 2012). Maximum weed seed density of broad-leaved weeds (BLW) at 0-15 cm depth (174.29 seedling/m^2) was found in maize-pigeonpea followed by sorghum-chickpea (161.95 seedlings/ m^2). However, minimum density of BLW at 0-15 cm depth was obtained in DSR-mustard-blackgram (70.24 seedling/m^2) followed foxtail millet-lentil (79.86 seedling/m^2). At depth of 15-30 cm, the highest weed seed density of BLW was noticed with fodder sorghum-mustard-urd (161.73 seedling/m^2) followed by maize-pigeonpea (143.38 seedling/ m^2). While the lowest weed seed density of BLW was observed in CTDSR-wheat-mung (44.94 seedling/m^2). This might be due to tillage changes vertical distribution of weed seeds in soil profile and soil physical properties, and affects emergence and seed survival of weed through changes in soil conditions and determines weed seedling emergence and species composition (Mishra *et al.* 2019).

Table 5. Crop yields and economics and system productivity under diverse cropping systems

Cropping systems	Crop yield (t/ha)			Rice equivalent yield (t/ha)			System rice equivalent yield (t/ha)	System net returns (x10^3 `/ha)	Benefit: cost ratio
	Kharif	*Rabi*	Summer	*Kharif*	*Rabi*	Summer			
TPR-CT wheat -CT greengram	4.98	5.16	1.21	4.85	5.78	4.35	14.98	104.93	1.70
CTDSR-ZT wheat -ZT greengram	5.31	5.48	1.01	5.35	6.13	3.63	15.11	123.01	1.91
CT Soybean-ZT maize	1.86	10.51	-	3.66	9.66	-	13.32	129.73	2.29
DSR-ZT mustard-ZT blackgram	5.26	2.83	1.10	5.26	7.30	3.83	16.39	135.90	2.04
CT Foxtail millet-ZT lentil	1.56	2.06	-	1.91	5.65	-	7.56	73.56	2.20
CT Pearl millet-ZT chickpea	4.39	2.42	-	4.04	6.87	-	10.91	121.39	2.62
CT Finger millet-ZT rapeseed (*toria*)	1.64	1.51	-	2.01	3.80	-	5.81	35.88	1.61
CT Sorghum (grain)-ZT chickpea	4.11	2.53	-	4.51	7.18	-	11.69	136.51	2.76
CT Maize -ZT pigeonpea (ZT)-fallow	10.31#	2.81	-	12.46	9.88	-	22.34	262.90	3.75
CT Sorghum (fodder)-ZT mustard-ZT blackgram	75.32	2.43	1.21	9.72	6.27	2.54	18.53	182.00	2.66
LSD (p=0.05)				0.47	0.57	0.23	1.17	11.36	0.20

TPR: transplanted puddle rice; CTDSR: conventional till-direct seeded rice; CT: conventional-till; ZT: zero-till; DSR, direct seeded rice

Table 6. Impact of various tillage practice and cropping systems on grasses and broad-leaved weeds seedbank

Cropping systems	Weed seed density (emerged weed seedlings/m^2)			
	Grasses		Broad-leaved weeds	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
TPR-CT wheat -CT greengram	95.6 (9270)	56.0 (3146)	100.9 (10281)	59.4 (3539)
CTDSR-ZT wheat -ZT greengram	96.2 (9271)	60.4 (3876)	81.1 (6629)	44.9 (2079)
CT Soybean-ZT maize	122.6 (15337)	150.1 (22697)	89.5 (9607)	135.1 (18371)
DSR-ZT mustard-ZT blackgram	133.7 (18764)	92.6 (10112)	70.2 (5000)	57.8 (3371)
CT Foxtail millet-ZT lentil	147.4 (21798)	111.6 (12472)	79.9 (6405)	68.9 (4888)
CT Pearl millet-ZT chickpea	103.8 (11742)	84.2 (7247)	80.9 (7472)	96.3 (10618)
CT Finger millet-ZT rapeseed (*toria*)	110.2 (12528)	82.6 (6854)	94.4 (9551)	101.0 (10281)
CT Sorghum (grain)-ZT chickpea	114.6 (13146)	76.7 (5899)	161.9 (29101)	127.5 (17023)
CT Maize -ZT pigeonpea (ZT)-fallow	126.1 (15955)	175.8 (31798)	174.3 (34326)	143.4 (22023)
CT Sorghum (fodder)-ZT mustard-ZT blackgram	80.9 (6573)	117.2 (13989)	92.8 (8708)	161.7 (30393)
LSD (p=0.05)	36.71	40.24	65.66	55.77

TPR: transplanted puddle rice; CTDSR: conventional till-direct seeded rice; CT: conventional-till; ZT: zero-till; DSR: direct-seeded rice

The present study revealed that various diverse cropping systems reduce weed density and manage specific weed flora. Therefore, the best strategy for developing a resilient and sustainable production system is adopting diversified farming as an ecological weed management option. However, farmers are continuing to be reluctant to adopt a diversified cropping system because of requirement of varying skills and higher initial investment.

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RESEARCH ARTICLE

Impact of nutrient management in rice-maize-greengram cropping system and integrated weed management treatments on summer greengram productivity

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ABSTRACT

Nutrient and weed management in crops and especially cropping system play an important role to enhance productivity and sustainability in different cropping systems. A field experiment was conducted for two consecutive years to evaluate the effect of nutrient management in preceding crops and integrated weed management practices in summer greengram on weeds growth and greengram productivity. The nutrients were applied in previous rice and maize crops and greengram was grown under residual soil fertility. The inorganic nitrogenous (N) fertilizer (25% of recommended dose) was substituted with bulky organic manures [farm yard manure (FYM) and vermicompost] and concentrated organic manures [Brassica seed meal (BSM) and neem cake]. The weed management treatments comprised of: herbicide use alone [post-emergence application (PoE) of imazethapyr 100 g/ha at 25 days after sowing (DAS)] and integrated weed management approach [pre-emergence application (PE) of pendimethalin 750 g/ha at 2 DAS followed by (*fb*) hoeing at 25 DAS]. The addition of concentrated organic manures (BSM and neem cake) effectively reduced the germination and overall growth of the weeds probably due to released allelochemicals. The N supplementation using neem cake and BSM decreased the weed biomass and reduced the nutrient uptake by weeds, and enhanced the nutrient uptake of greengram crop which ultimately enhanced the greengram growth and seed yield. This effect was more pronounced in the second year of study due to repeated application of organic manures. In comparison to use of herbicide alone (imazethapyr), the integrated weed management (pendimethalin PE *fb* hoeing) reduced the weed density and biomass accumulation by ~50 and 80%, respectively. The integrated weed management also enhanced the greengram seed yield by 12 and 9% compared to herbicide usage alone during 2015 and 2016, respectively.

Keywords: Brassica seed meal; Neem cake; Integrated weed management, Herbicide; Nutrient management, Rice-maize- greengram cropping system

INTRODUCTION

Rice-maize is one of the predominant cropping systems adopted in Indian subcontinent (Timsina *et al*. 2010). The productivity of this system and farmer's income are gradually declining due to enhancement in input cost. Repeated cultivation of high-input-driven crops resulted in the declination of factor productivity and soil health parameters. Inclusion of legume like greengram in this crop rotation could be a good choice to avoid such problems as greengram improves the soil fertility by fixing atmospheric nitrogen with root nodules and incorporation of greengram crop residue in succeeding rice crop was found more sustainable and profitable than traditional practice. Greengram is also a popular pulse preferred by the vegetarians of the country. It occupies around 304.8 thousand hectares with an annual production of about 134.5 thousand tons and productivity of 441 kg/ha in India (DES 2020).

The nutrients management is important for sustaining cropping system productivity but non-judicious use of synthetic fertilizers resulted in deterioration of soil health and other ecological parameters (Pingali 2012, Doran and Parkin 1994) which are amongst the key constrains for food production and security. The improvement of soil health parameters are needed for enhancing crop

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productivity. Integration of various sources of nutrients, especially organic, plays a major role in correcting soil health parameters and enhancing the system productivity (Das *et al.* 2014; Saha *et al.* 2018). The use of bulky organic manures like farmyard manure (FYM) and vermicompost as integrated approach in rice–maize system has been widely studied (Kumara *et al.* 2015), but use of concentrated organic manures, *viz.* Brassica seed meal (BSM) and neem cake as nutrient source and their weed suppressing ability in rice–maize–greengram cropping system has not been explored that much yet.

Weeds are the major biotic constraints competing for nutrient, water, light and space, causing substantial crop yield loss (Ghosh *et al.* 2016). The agronomic management practices, more specifically nutrient management, play a major role in weed diversity and its degree of yield loss (Ghosh *et al* 2017a, 2020a&b, Kumar *et al.* 2018). The herbicides-based weed management strategy widely accepted by the farmers due to ease of application. But sole dependency on herbicides may cause development of herbicide-resistant weeds along with contamination of herbicides in food chain and causing environmental hazards (Arias-Estévez *et al.* 2008, Magne *et al.* 2006). The integration of chemical and mechanical weed management strategies provide better weed control than chemical method alone (Ghosh *et al.* 2017b). Therefore, this study was undertaken to quantify the residual effect of nutrient (organic manures) and weed management practices on weed growth, nutrient uptake and yield of greengram in rice–maize–greengram cropping system.

MATERIALS AND METHODS

This study was conducted during summer 2015 and 2016 at farmers' field of Uttar Chandamari village, Muratipur, Nadia, West Bengal, India (88°27' E longitude and 22°59' N latitude). The climate of experimental site was humid and subtropical, with an average annual rainfall of 1400 mm and most of which precipitated from June to September. During the study period, the rainfall; mean maximum and minimum temperature and relative humidity; and sunshine hours were 149 mm; 39.8 and 18.9°C; 92 and 34% and 7.76 hr in 2015; and 213 mm; 41.7 and 21.8°C; 93 and 37% and 7.52 hr in 2016, respectively. The soil of the experimental site was Gangetic alluvium (*Entisol*), clay loam in texture with pH of 6.27, electrical conductivity (dSm^{-1}) of 0.19, and medium in organic carbon (0.52%), low in available N (215 kg N/ha), high in available P (36.3 kg/ha), and medium in available K (173 kg/ha).

The study was conducted in a factorial randomized block design having two factors: nutrient and weed management. The nutrient management practices include: inorganic fertilizers alone (100% nitrogen, phosphorus and potassium); integration of inorganic fertilizers (75% nitrogen) with bulky organic manures (FYM and vermicompost) and concentrated organic manures (BSM and neem cake) for 25% of recommended nitrogen in rice and maize; whereas recommended P and K were applied through inorganic fertilizers. The fertilizer and manures were applied in previous rice and maize crops and greengram was grown under residual soil fertility. The weed management practices were: weedy (unweeded), herbicide [imazethapyr 100 g/ha at 25 days after sowing (DAS) as post-emergence application (PoE)] and integrated [pendimethalin 750 g/ha as pre-emergence application (PE) at 2 DAS followed by (*fb*) hoeing at 25 DAS]. The recommended dose of fertilizer for rice and maize crops was 60-30-30 and 200-60-60 kg N-P-K /ha. The nutrients were applied using urea (46% N), single superphosphate (16% P), and muriate of potash (60% K). The N content in organic manures were 1.54 to 1.59, 0.59 to 0.66, 4.80 to 4.90 and 5.13 to 5.30% in vermicompost, FYM, BSM and neem cake, respectively. Knapsack sprayer (16 liters' capacity) with flat fan nozzles was used for herbicide application and the spray volume was 500 l/ha.

The greengram (cv. *PDM-139*) was sown on 25th and 23rd March of 2015 and 2016, respectively with row to row and plant to plant spacing of 30 and 5-7 cm, respectively. Seeding rate of greengram was 25 kg/ha. The plot size of each treatment was 7.2 × 3.0 m and was separated from adjacent plots by 1.0 m. For uniform germination irrigation was applied after sowing and subsequent one irrigation was given at flowering stage of the crop. The plant biometric observations and destructive sampling was taken from second and third rows either side of each plot and for yield determination middle eighteen rows were harvested manually on 2nd June and 31st May of 2015 and 2016, respectively. The preceding rainy *(Kharif)* season rice crop cv. *Satabdi* (IET 4786) was manually transplanted in puddled soil with 20 cm row-to-row and 15 cm plant-to-plant spacing and winter *(Rabi)* maize cv. '*P-3396'* was sown with 60 and 30 cm row to row and plant to plant spacing, respectively.

Biometric measurements and nutrient analysis

Data on weed density and biomass accumulation at 25 and 50 DAS was taken from two quadrats (60 cm × 60 cm) of each plot. Weeds were cut at ground level, counted and cleaned with water followed by sun and hot-air oven-dried at 65 °C for 72hr and weighed. Five greengram plants were selected from each plot and data on height along with branches per plant were taken. For greengram plant biomass, plants were cut at ground level from 50 cm row length of 2nd or 3rd rows of either side of plot then sun and hot-air oven-dried at 65°C for 72hr and weighed for determination of plant dry biomass accumulation. Punching core of known area was used for greengram leaf area index (LAI) calculation. The dry weight of greengram of known area was recorded and the area-weight relationship was calculated. The leaf area of each treatment was worked out using this relationship. The LAI was calculated as per the formula given by Watson (1953). The seed and stover yield of greengram was determined from net plot area (5.4 m × 2.0 m). The harvested seeds were threshed and weighted at 14% moisture level.

$$\text{LAI} = \frac{\text{Area of total number of leaves (cm}^2\text{)}}{\text{The ground area from where leaf samples were collected (cm}^2\text{)}}$$

The weed and greengram plant samples from each treatment were collected at 50 DAS and harvest, respectively, then oven-dried, and ground for analyzing total N, P and K. The sum of total N, P and K was reflected as nutrient uptake. Total N was estimated by the micro-Kjeldahl method and P and K were determined as per the method of Jackson (1973).

Statistical analysis

The actual weed density (X) data were transformed [$\sqrt{(X + 0.5)}$] due to high variance before statistical analysis. Data were subjected to analysis of variance, and the analysis was done using GenStat software.

RESULTS AND DISCUSSION

Weed growth

During the experimentation the weed flora in greengram crop were *Echinochloa colona* (L.) Link., *Oplismenus composites* (L.) P. Beauv., *Cyperus rotundus* L., *Caesulia axillaris* Roxb., *Phyllanthus virgatus* G. Forst., *Alternanthera philoxeroides* (Mart.) Griseb. and *Physalis minima* L. The weed density at early growth stages of greengram (25 DAS) varied significantly in 2015 with different nutrient sources applied in previous crops, but it was non-significant in 2016 (**Table 1**). The weed density at later crop growth stage (50 DAS) varied statistically in second year and it was non-significant in first year. Supplementation of nutrient through concentrated organic manures (BSM and neem cake) in the earlier rice and maize crops significantly reduced weed density at 25 DAS in 2015 and at 50 DAS in 2016 in comparison to inorganic fertilizer application alone or nutrient supplementation with bulky organic manures (vermicompost and FYM). The biomass accumulation by weeds differed statistically with sources of nutrient, except at 25 DAS in the first year. As compared to FYM, nutrient supplementation through BSM applied to previous crops decreased weed dry biomass in greengram by 27% at 25 DAS in the second year. Weed biomass accumulation at later growth stage of greengram was decreased with the application of different organic manures in 2015, and by BSM and neem cake in 2016. The addition of BSM and neem cake over years had a cumulative effect in suppressing the weed growth in the second year of study, compared to the bulky organic manures and inorganic fertilizer. The performance of BSM and neem cake in reducing the weed biomass was mainly due to the residual effect in restricting the growth of weeds due to the allelochemicals present in mustard and neem cake which had allelopathic effect on weed seed germination and growth (Abdulla and Kumar 2014, Marley *et al.* 2004).

In both the years, weed management treatments significantly reduced the weed density and biomass at different crop growth stages. The application of pendimethalin as PE lessened the weed density at 25 DAS by 70.4 and 61.2% in 2015 and 2016, respectively. As compared to the single herbicide application (imazethapyr PoE), integrated weed management practice with PE herbicide *fb* hoeing reduced the weed density at 50 DAS by 48 and 51% in 2015 and 2016, respectively; while corresponding reduction in weed biomass accumulation was 74 and 85% during two years. It could be due to the additional effect of hoeing in controlling those weeds that were not usually controlled by pendimethalin PE (Jinger *et al.* 2016). The weed density and biomass were reduced significantly in the second year of experimentation as compared to first year due to the puddling performed prior to rice transplanting.

Crop growth and yield

The plant growth parameters of greengram, *viz.* height, biomass, number of branches and leaf area index were measured at 40 DAS. The greengram plant height varied with the nutrient sources in both the years and dry matter accumulation only in second year of experimentation, whereas, number of branches/plant and leaf area index did not differ with the addition of organic manures in preceding rice and maize crops (**Table 2**). During first year of experimentation, highest plant height at 40 DAS (49.6 cm) was recorded in the plots receiving BSM as nutrient source. Addition of concentrated organic manures (BSM and neem cake) produced the tallest greengram plant in second year. The maximum biomass of greengram at 40 DAS was found with the use of neem cake as nutrient source in previous crops, which ultimately enhanced the plant growth and produced utmost greengram seed yield at harvest. The organic manures treatments improved residual effect compared to the sole inorganic fertilizer treatment. This may be due to the fact that the organic manure is a nutrient-rich, microbiologically-active amendment, releasing plant nutrients slowly but steadily to the crops in sequence, ultimately ensuing its superior performance in the succeeding crops (Xu *et al.* 2003, Srivastava *et al.* 2007).

Pendimethalin PE *fb* hoeing produced more robust greengram crop over sole PoE herbicide. The integrated weed management had not any added advantage over herbicide use alone in respect of number of branches/plant and leaf area index of greengram, yet it produced 12 and 9% higher greengram seed yield over sole imazethapyr PoE in 2015 and 2016, respectively. The integration of pendimethalin PE with hoeing at 25 DAS resulted in increased seed and stover yield of greengram by ~11 and 7% respectively, compared to imazethapyr PoE alone.

Table 1. Effect of different nutrient sources (residual) and weed management practices on weed growth in summer greengram

Treatment	Weed density (no./m²)				Weed biomass (g/m²)			
	25 DAS		50 DAS		25 DAS		50 DAS	
	2015	2016	2015	2016	2015	2016	2015	2016
Nutrient management								
100% RD_{NPK}	21.4 (459)	16.6 (274)	17.3 (298)	10.9 (118)	53.4	31.4	160.0	65.0
100% RD_{PK} +75% RD_N + 25% N (Vermicompost)	22.3 (499)	15.9 (254)	17.0 (288)	11.6 (134)	51.7	31.9	112.7	69.8
100% RD_{PK} +75% RD_N + 25% N (FYM)	22.5 (505)	16.7 (279)	17.6 (308)	11.3 (128)	56.2	36.5	128.8	63.5
100% RD_{PK} +75% RD_N + 25% N (BSM)	18.9 (358)	14.7 (215)	16.9 (284)	9.8 (96)	50.8	26.5	119.4	53.7
100% RD_{PK} +75% RD_N + 25% N (Neem cake)	20.0 (401)	15.1 (227)	16.2 (263)	9.8 (95)	51.8	30.1	110.1	49.3
LSD (p=0.05)	2.17	NS	NS	1.37	NS	7.35	12.60	10.35
Weed management								
Imazethapyr 100 g/ha PoE	24.7 (609)	17.4 (302)	16.2 (263)	10.1 (101)	63.0	38.0	89.8	45.3
Pendimethalin 750 g/ha PE *fb* hoeing	13.5 (182)	11.5 (132)	8.4 (70)	4.9 (23)	28.5	17.1	23.7	6.9
Un-weeded	25.0 (622)	18.5 (342)	26.3 (693)	17.1 (291)	66.7	38.8	265.1	128.5
LSD (p=0.05)	1.68	1.74	1.60	1.06	8.75	5.69	9.76	8.02

RD: Recommended dose through fertilizer; N: Nitrogen; P: Phosphorus; K: Potassium; FYM: Farm yard manure; BSM: Braseca seed meal; NS: Non significant; DAS: Days after sowing; PoE: Post-emergence application; PE: Pre-emergence; Values given in the parentheses were subjected to square root transformation before statistical analysis.

Table 2. Effect of different nutrient sources (residual) and weed management practices on plant growth at 40 DAS and seed yield of summer greengram

Treatment	Plant height (cm)		Dry weight (g/m²)		No. of branches/ plant		Leaf area index		Seed yield (kg/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Nutrient management										
100% RD_{NPK}	41.7	44.6	162	155	7.37	7.37	2.12	2.46	737	756
100% RD_{PK} +75% RD_N + 25% N (Vermicompost)	42.4	42.0	157	167	7.12	7.12	2.11	2.45	727	767
100% RD_{PK} +75% RD_N + 25% N (FYM)	43.8	44.7	164	177	7.38	7.38	2.14	2.35	735	804
100% RD_{PK} +75% RD_N + 25% N (BSM)	49.6	47.0	180	185	7.58	7.58	2.21	2.34	750	790
100% RD_{PK} +75% RD_N + 25% N (Neem cake)	43.8	47.3	172	169	7.66	7.66	2.20	2.38	752	813
LSD (p=0.05)	3.68	3.53	NS	25.4	NS	NS	NS	NS	NS	48.7
Weed management										
Imazethapyr 100 g/ha PoE	41.3	43.4	166	171	7.80	7.80	2.26	2.51	753	812
Pendimethalin 750 g/ha PE *fb* hoeing	43.6	44.4	188	189	7.82	7.82	2.29	2.55	845	884
Un-weeded	47.9	47.5	147	152	6.65	6.65	1.92	2.13	623	662
LSD (p=0.05)	2.85	2.73	19.0	19.7	0.49	0.49	0.29	0.33	38.6	37.8

RD: Recommended dose through fertilizer; N: Nitrogen; P: Phosphorus; K: Potassium; FYM: Farm yard manure; BSM: Braseca seed meal; *fb*: Followed by; NS: Non significant; DAS: Days after sowing; PoE: Post-emergence application; PE: Pre-emergence

Nutrient uptake by weed and crop

The nutrient supply through organic sources had significant impact on nutrient uptake by greengram seed and stover in 2016 and 2015, respectively; whereas nutrient harvest index was influenced in both the years of study (**Table 3**). The application of FYM and neem cake in previous crops enhanced the nutrient uptake of greengram seed and nutrient supplementation using vermicompost maximized the nutrient uptake of greengram stover. The higher nutrient harvest index was found with the plots receiving BSM and neem cake in 2015 and 2016, respectively for nutrient supplementation in previous rice and maize crops.

Herbicide usage and integrated weed management practices significantly reduced weed growth and eventually restricted the nutrient uptake by weeds and enhanced the nutrient uptake by greengram seed and stover. These observations are in conformity with the findings of Kataria *et al.* (2016) who also reported that integrated weed management practices like pendimethalin PE followed by imazethapyr + imazamox PoE at 30 DAS effectively reduced nutrient uptake by weeds in greengram crop.

Economics

The economics of greengram was varied with the variation in the residual impact of different nutrient management practices applied to the preceding crops as well as with the direct impact of different weed management practices used in greengram (**Table 4**). The total treatment cost in greengram has varied with the variation in the cost for

Table 3. Effect of different nutrient sources (residual) and weed management practices on nutrient uptake by weeds at 50 DAS and crop at harvest

Treatment	Nutrient uptake						Nutrient harvest index	
	Weeds (kg/ha)		Seed (kg/ha)		Stover (kg/ha)			
	2015	2016	2015	2016	2015	2016	2015	2016
Nutrient management								
100% RD_{NPK}	37.00	15.13	13.96	15.73	58.39	67.31	19.25	18.91
100% RD_{PK} +75% RD_N + 25% N (Vermicompost)	26.29	16.68	14.44	16.20	60.71	66.97	19.19	19.48
100% RD_{PK} +75% RD_N + 25% N (FYM)	29.82	14.90	14.80	17.12	55.42	67.79	20.97	20.13
100% RD_{PK} +75% RD_N + 25% N (BSM)	27.33	12.13	14.87	16.47	53.49	70.37	21.68	18.86
100% RD_{PK} +75% RD_N + 25% N (Neem cake)	25.20	11.04	14.94	17.02	58.20	64.96	20.65	20.73
LSD (p=0.05)	2.99	2.38	NS	1.01	4.08	NS	1.02	1.17
Weed management								
Imazethapyr 100 g/ha PoE	19.73	9.72	14.68	16.94	59.36	67.69	19.91	20.08
Pendimethalin 750 g/ha PE *fb* hoeing	5.49	1.53	16.85	18.72	62.75	73.15	21.24	20.41
Un-weeded	62.16	30.67	12.28	13.86	49.62	61.61	19.90	18.38
LSD (p=0.05)	2.32	1.85	0.74	0.78	3.16	3.69	0.79	0.91

RD: Recommended dose through fertilizer; N: Nitrogen; P: Phosphorus; K: Potassium; FYM: Farm yard manure; BSM: Braseca seed meal; *fb*: Followed by; NS: Non significant; DAS: Days after sowing; PoE: Post-emergence application; PE: Pre-emergence

Table 4. Economics for greengram production/hectare (based on mean data of two years)

Treatment combinations	Cultivation cost ($x10^3$ ₹)	Gross return ($x10^3$ ₹)	Net return ($x10^3$ ₹)	Benefit- cost ratio	Economic efficiency (₹/day/ha)
*NM_1×WM_1	32.48	35.21	2.72	1.08	39
×WM_2	34.72	43.62	8.90	1.26	129
×WM_3	39.49	47.05	7.56	1.19	110
NM_2×WM_1	32.48	36.14	3.65	1.11	53
×WM_2	34.72	43.80	9.08	1.26	132
×WM_3	39.49	46.19	6.69	1.17	97
NM_3×WM_1	32.48	36.23	3.74	1.12	54
×WM_2	34.72	44.19	9.47	1.27	137
×WM_3	39.49	49.06	9.56	1.24	139
NM_4×WM_1	32.48	36.27	3.79	1.12	55
×WM_2	34.72	42.60	7.88	1.23	114
×WM_3	39.49	50.86	11.37	1.29	165
NM_5×WM_1	32.48	37.27	4.79	1.15	69
×WM_2	34.72	45.21	10.49	1.30	152
×WM_3	39.49	48.90	9.41	1.24	136

*Residual; NM_1: 100% RD_{NPK}; NM_2: 100% RD_{PK} +75% RD_N + 25% N (vermicompost); NM_3: 100% RD_{PK} +75% RD_N + 25% N (FYM); NM_4: 100% RD_{PK} +75% RD_N + 25% N (BSM); NM_5: 100% RD_{PK} +75% RD_N + 25% N (neem cake); WM_1: Weedy; WM_2: Imazethapyr 100 g/ha at 25 DAS; WM_3: Pendimethalin 750 g/ha at 2 DAS followed by mechanical weeding at 25 DAS; FYM: Farm yard manure; BSM: Braseca seed meal; DAS: Days after sowing weed management practices only. With respect to sole herbicide use approach, the integrated approach required higher treatment cost. Due to the maximum production ability, the treatment superiority relating to gross return, net return, benefit-cost ratio as well as economic efficiency was realized in the plot previously treated with BSM under integrated approach in greengram.

Conclusions

Nutrient management in crops of a cropping system influences the growth and productivity of the component crops. The supplementation of organic nutrients (BSM and neem cake) has progressive residual impact on nutrient availability and growth of subsequent greengram crop and suppressed weed seed germination and growth. Integration of mechanical weeding (hoeing) with pendimethalin PE reduced the weed growth and enhanced the yield of greengram crop.

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RESEARCH ARTICLE

Phalaris minor Retz. infestation in wheat crop as influenced by different rice straw management practices usage in Punjab, India

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ABSTRACT

Phalaris minor Retz. is a competitive weed in wheat crop causing significant yield losses. In the rice-wheat cropping system, rice residue burning spoils the carbon cycle, pollutes the environment and deteriorates the soil health. An extensive survey was conducted during *Rabi* 2018-19 to analyse the *P. minor* infestation and wheat crop productivity under different rice straw management practices used by farmers in their fields and compared them with conventional straw burning practice. A total of 54% of respondents reported low infestation of *P. minor* in the fields sown with "*Happy-Seeder*" while 26% and 44% respondents observed low infestation of *P. minor* in fields where rice straw incorporation was done with harrow and mould board plough, respectively. The low infestation of *P. minor* in rice residue removed fields (no burning) was reported by 38% respondents. Overall, 8% respondents reported severe infestation of *P. minor* in rice straw managed fields while 30% respondents reported severe infestation of *P. minor* in wheat fields with conventional straw burning practice. *Phalaris minor* infestation was lower in fields with rice residue retention or incorporation. Therefore, rice residue management should be an important integrated weed management component especially for managing multiple-resistant *P. minor*.

Keywords: Happy-Seeder, *Phalaris minor*, Rice straw management, Rice residue burning, Residue incorporation, Transfer of technology, Wheat

INTRODUCTION

Rice-wheat is one of the major cropping systems in the Punjab state. Rice crop is being grown on an area of about 30 lakh hectares in Punjab with a production of 126 lakh tons of rice along with 220 lakh tons of straw. The large-scale adoption of coarse long duration high yielding rice varieties and combine harvesting have increased the incidence of in-situ rice residue burning in Indo-Gangetic Plains (Chaudhary *et al.* 2019). Farmers consider burning of rice straw as the easiest way to get rid of left-over rice straw in their fields. About 70-75% of the total rice straw produced in the state is being burnt in the fields in a short window of 15-20 days (Singh *et al.* 2018). The burning of rice straw has serious environmental, human and animal health implications and results in loss of organic matter and nutrients which adversely affects soil health. About 40% of N, 30-35% of P, 80-85% of K, and 40-50% of S taken up by rice plant remains in rice straw at maturity, and it is estimated that 80-90% of N and S and 15-20% of P and K present in rice straw are lost to air during burning (Jain *et al.* 2014).

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The issue of burning is not limited to state or region only but it has harmful impact across the globe. The smoke that arises from these burning contains toxic substance, including $PM_{2.5}$, CO_2, CH_4, CO, NO_x, SO_x and black carbon which are beyond international and national standard limits. To manage rice straw left in the field after combine harvesting, Punjab Agricultural University (PAU), Ludhiana has developed various site-and situation-specific straw management techniques (Mahal *et al.* 2019). It was estimated that a total of 11.4 MT of rice straw may be put into ex-situ uses and 8.3 MT of rice straw is still left for in-situ utilization. It can effectively be managed within the same field by sowing wheat with "Happy-Seeder" machine after harvesting of rice with combine harvester fitted with PAU-Super Straw Management System. The rice straw can be incorporated with mould board plough after chopping with straw chopper or mulcher or it can be collected and removed either mechanically or manually from the harvested rice fields.

Yield losses of wheat due to weeds are estimated around 25-50% and in very severe cases, the losses may go up to 80% (Malik and Singh 1995). Chemical weed control with isoproturon and 2,4-D and monoculture of rice-wheat cropping system resulted in the dominance of grass weeds particularly, *P. minor* Retz. in late 1970s. *Phalaris minor* infestation occurs in several winter crops, but it is a severe weed in wheat due to their similar morphology and growing requirements. In wheat, initial period of 4-6 weeks after sowing is most critical regarding weed competition, and large scale weed control failures in farmers' fields have been being reported. These failures were attributed mainly to delayed sowing, evolution of herbicide resistance, adverse climatic factors (low temperature, rainfall and reduced sunlight) during herbicide spray and inaccurate spray technology usage. Moreover, evolution of multiple herbicide resistance in *P. minor* has resulted from the repeated use of herbicides with a similar mode of action which could threaten the sustainability of the rice-wheat cropping system in North-West India.

Rice straw management methods have variable effect on weeds and other crop pests (Kaur *et al.* 2021). The emergence of first flush of *P. minor* is reduced to about 50% in zero-till wheat, irrespective of the soil texture and aeration (Singh *et al.* 1999, Franke *et al.* 2007). Weed dynamics are significantly affected by residue retention on surface or residue incorporation. The residue helps to reduce weed seed emergence by avoiding exposure to light and through mechanical impedance to the weed seedlings (Chhokar *et al*. 2007) or altering soil conditions (Teasdale and Mohler 2000) or by exhibiting allelopathic effects which inhibit weed seed germination (Weston 1996). The emergence of *P. minor* was lowered by 25-50% under residue retained wheat crop fields than residue removed fields under the rice-wheat cropping system (Franke *et al.* 2007). Thus, the covering or mulching the soil surface using crop residues can reduce weed problems by preventing weed seed germination and by suppressing the growth of emerging weed seedlings. Trainings and demonstrations are being undertaken to educate the farmers about benefits of maintaining mulch at soil surface on weed control especially, *P. minor*. A survey was undertaken to analyse the effect of different crop residue management technologies on weed infestation and crop productivity at farmers' fields by conducting a survey after popularising the rice residue management technology. The hypothesis of the survey study was to analyse the impact of rice residue management methods on crop, weeds and cost of cultivation at the farmers field-scale level.

MATERIALS AND METHODS

An appeal to the farmers of Punjab, India was made to avoid burning rice residues/stubbles during the months of October-November of 2017 and 2018. Extension efforts were undertaken to promote efficient agro-technologies for the crop residue recycling in rice machine harvested areas as an alternative to rice straw burning. An awareness was created with the combination of extension activities and innovative technologies to solve the problem of residue burning to a greater extent. The extension activities like distribution of extension literature, *Kisan Goshti* (farmers meeting), and conducting field days, farmers scientists' interface, training programs and campaigns on the use of "Happy-Seeder" machine for rice seeding and crop residue management techniques were undertaken by various *Krishi Vigyan Kendras* (Agricultural Science Centers) in which farmers were educated about the facts, issues and government policies about crop residue management (Mahal *et al.* 2019). The central/ state government has given huge subsidy on newly developed machineries for residue management. The farmers were advised to follow either farm machinery banks or custom hiring system approach (as farm machinery is costly) for effective and cost-friendly residue management. The technological knowledge was given to the farmers on proper handling and economic use of farm implements (Happy-Seeder, chopper, straw collector and baler) recommended by Punjab Agricultural University (PAU) for the rice residue incorporation in soil. These technologies have substantially aided farmers to manage rice residue in-situ. Happy-Seeder machines were used for sowing of wheat in combine harvested rice fields without any straw burning or removal of rice straw. The loose straw was uniformly distributed in the field prior to wheat sowing with Happy-Seeder. The chopper or mulcher or roto-drill or rotavator or cultivators or disc harrows were used by certain farmers for incorporating the rice residues in the 0-15cm soil depth. Mould-board ploughs were also used for residue incorporation and soil inversion by certain farmers. Incorporation of rice straw with rotavator or disc harrow resulted in rice straw incorporation in upper 3–5-inches soil layer only while incorporation with mould board plough resulted in inversion of soil layer and rice straw is incorporated in deeper layer (up to 8-13-inches deep). Residue removal included collection and removal of straw from the harvested rice fields mechanically using stubble shaver or rake or baler or it was removed manually by a few farmers. Residue incorporation or removal was followed by sowing of wheat crop with zero till drill or conventional seed drill.

After the completion of wheat season, an extensive survey was conducted in 22 districts of

Punjab during *Rabi* 2018-19 to analyse the pattern of usage of different rice straw management technologies by farmers in farmers' fields and to assess impact of straw management practices on the cost incurred, herbicide and irrigation water usage in wheat and wheat grain yield. The questionnaire consisted of both qualitative and quantitative questions about crop agronomy, weeds, crop yield, costs involved and their experience. In each of the district, a total of 90 farmers were identified for survey. The survey involved interviewing one-third of total farmers who have burnt the rice straw before seedbed preparation of winter wheat crop and two-third of total farmers who have managed the rice straw with any one of the methods including: sowing of wheat with Happy-Seeder machine in standing rice stubbles, incorporation of rice straw with disc harrow or with mould-board plough and removal of rice straw from fields. The total sample size was 1980 farmers, out of which sample size of 1322 farmers were those who managed the rice straw. Another sample of 658 farmers, adopting the conventional rice straw burning, was also surveyed for comparison.

RESULTS AND DISCUSSION

The crop residue management practices require hard work, time and expenditure. The elaborative extension campaign on crop residue management technologies organized during 2017-18 and 2018-19 across the Punjab state, India has helped farmers to realize or understand that burning crop residue is a disincentive for them. Farmers understood the ill effects of rice straw burning. The efforts made by PAU in popularization of short duration rice varieties cultivation in Punjab, rice straw management machinery and ex-situ use of rice straw through demonstrations, lectures, field days, Radio/TV talks, popular articles, *etc*. has resulted in scientific management of about half of the rice straw in Punjab.

The survey has revealed that the rice residue management has reduced air pollution and caused additional benefits such as water saving, weed suppression, higher yield, buffering of temperature, and quick and better wheat germination. It was observed that 60% of farmers managed rice straw by Happy-Seeder sowing (**Table 1**). Out of all straw management techniques, total cost of expenditure was the lowest for wheat sowing using Happy-Seeder in rice stubbles (₹ 4,518/- per hectare) as Happy-Seeder machine can be operated directly in combine harvested rice field and hence saved field preparation tillage cost. The wheat sowing was done using the soil moisture retained after last irrigation to rice. Thus, there was a saving of pre-sowing irrigation when compared with traditional method. The chopped straw acts as mulch and saves irrigation water in addition to weeds growth control.

Farmers opined that rice residue incorporation practice, apart from adding to soil health and controlling environment pollution from rice residue burning, results in advancement in sowing time of potato by seven days (approximately) which subsequently results in timely uprooting of potato as well as timely sowing of next crop. In addition to the timely sowing of potato by incorporating the rice straw into the soil, it also helps in improving the fertility status of the soil. Out of 37% farmers, 32% farmers preferred incorporation by rotavator and disc plough while mould board plough was used by 5% farmers (**Table 1**). The expenditure incurred was maximum when straw incorporation was done with mould board. Incorporation of rice straw has led to an increase in the soil organic carbon in the plough layer. Farmers observed that residue incorporation increased the water holding capacity, so it also aids in saving of water by reducing the number of irrigations. Earthworm population was also observed to increase in residue retained soils. Earlier studies also corroborated this finding that rice residue addition back to soil resulted in increased soil organic carbon (Ogbodo 2009, Mahal *et al.* 2019) and improved the biological life (Tian *et al.* 1993), thus creating a suitable environment for the crops to grow. In conventional straw burning method, ₹ 7,975/- per hectare was incurred by farmers as farmers use stubble cutter and spreader for cutting rice stubbles and spreading it over the field before burning the straw.

Wheat sowing was completed by 75% of total farmers up to first fortnight of November irrespective of rice straw management techniques (**Table 2**). Nearly 45% farmers sowed their wheat crop during fourth week of October to first week of November in both rice straw managed fields and in conventional sowing method (with rice residue burning). *Phalaris minor* emergence and its growth was affected by sowing date, and biomass accumulation by *P. minor* was found to be greater in November sowing (960 kg/ha) as compared to October or December (450 kg/ha) sowing of wheat under Punjab conditions (Kolar and Mehra 1992). In this study, sowing time of wheat was not affected by adoption of different rice straw management techniques and therefore sowing time was not a variable factor affecting *P. minor* density. The farmers reported average number of irrigations applied to wheat crop and wheat productivity was statistically similar in all the methods of rice straw management (**Table 1**).

Table 1. The impact of rice straw management method adopted by Punjab farmers on the cost incurred on straw management, number of herbicide sprays and irrigation usage in wheat and wheat grain yield

Rice straw management method	No. of farmers	Area (ha)	Cost incurred on rice straw management (`/ha)	Average number of herbicide sprays in wheat	Average number of irrigations given to wheat	Wheat grain yield (t/ha)
Happy-Seeder usage for wheat seeding	789(60)	3588(50)	4,518	0.86 a	2.91 a	5.34 a
Incorporation of rice straw	425(32)	2468(35)	9,718	1.40 b	3.07 a	5.28 a
Mould board plough usage	66(5)	323(5)	12,905	0.78 a	3.28 a	5.28 a
Rice straw removal	42(3)	249(4)	9,225	1.18 ab	3.17 a	5.32 a
Total: In rice straw managed fields	1322(100)	7157(100)	-	-	-	-
Conventional wheat sowing (after rice straw burning)	658	-	7,975	1.46 b	3.22 a	5.29 a

*Mean values in each column not connected by the same letter are significantly different according to Fisher's protected least significant difference (LSD) test (p=0.05); Figures in the parentheses indicate % to their respective totals of sample size.

Phalaris minor infestation was low to moderate (up to 50 plants/m^2) in 96% of cases when wheat sowing was done with Happy-Seeder (**Table 3**). The density of *P. minor* was 0-10 plants (low) and 11-50 plants/m^2 (moderate) in 26% and 58% cases, respectively when rice straw was incorporated with rotavator/disc plough. On the other hand, *P. minor* density was low and moderate in 44% and 45% cases when rice residue was incorporated with mould board plough. Further, only 4% of respondents recorded severe infestation of *P. minor* in Happy-Seeder sown fields, while 11-16% respondents observed severe infestation of *P. minor* in fields with rice straw incorporation. Presence of crop residues on soil surface creates micro-environments that are either inhibitive (Brar and Walia 2008, Sharma and Singh 2010, Mobil *et al.* 2020) or favorable (Franke *et al.* 2007) to weed emergence, seed predation and decomposition. The *P. minor* emergence was observed to be in patches in the farmers' fields, where residue mulching was not uniform in the field. Retention of residue load of 5.0 and 7.5 t/ha can reduce the weed infestation by 27.2 and 40.2%, respectively (Kaur *et al.* 2021). In residue removed field, 52% and 10% respondents reported moderate and severe density of *P. minor*, respectively. Only 12% respondents reported low weed density in fields where rice straw burning was done.

The rice residue load at farmers' fields varied from 4-9 t/ha with average of 4-6.5 t/ha residue load for short duration varieties and about 7-9 t/ha of residue load from medium to long duration rice varieties. The surveyed farmers reported that rice residue of 6 t/ha or more resulted in complete coverage of soil surface and ultimately less infestation of *P. minor* was observed as compared to less residue load (4-5 t/ha). Increasing the crop residue load as surface mulch in wheat can increase the suppression of weeds. It has been observed that increased soil moisture content in the top soil layer due to the presence of crop residues on soil surface can stimulate weed germination and consequently the emergence, particularly under a partially covered soil (Sharma and Singh 2010). On the contrary, burning of rice straw on soil surface enhanced weed seed germination of *Phalaris minor*, besides hampering the efficacy of soil active herbicides such as pendimethalin and isoproturon (Chhokar *et al.* 2009).

Weed management was done with the post-emergence herbicides, and farmers used either sequential or tank-mix applications. Farmers used clodinafop or sulfosulfuron or mesosulfuron plus iodosulfuron or metribuzin plus clodinafop to control *P. minor*. The usage of lower number of herbicides sprays was observed when wheat sowing was done by Happy-Seeder and when rice straw incorporation was done with mould board plough as compared to conventional sowing method (**Table 1**). The residue burning and residue incorporation with disc harrow has resulted in significantly a greater number of herbicides sprays for weed management. The cases of herbicide resistance evolution are more frequent with continuous usage of herbicide or herbicides belonging to the same group (Chaudhary *et al.* 2021).

Table 2. The variation in wheat sowing time by respondent farmers of rice straw managed fields vis-à-vis conventional method

Sowing time	Rice straw managed fields	Conventional sowing
4th week of October	190 (14)	86 (13)
1st week of November	392 (30)	213 (32)
2nd week of November	406 (31)	190 (30)
3rd week of November	242 (18)	114 (17)
4th week of November	92 (7)	55 (8)

Figures in the parentheses are percentages to their respective totals of sample size

Table 3. The infestation of *Phalaris minor* in wheat crop as affected by rice straw management method adopted by farmers

Rice straw management method	*P. minor* infestation		
	Low (0-10 plants/m^2)	Moderate (11-50 plants/m^2)	Severe (>51 plants/m^2)
Happy-Seeder usage for wheat seeding	421 (54)	334 (42)	34 (4)
Incorporation of rice straw	109 (26)	249 (58)	67 (16)
Mould board plough usage	29 (44)	30 (45)	7 (11)
Rice straw removal	16 (38)	22 (52)	4 (10)
Total: In rice straw managed fields	575 (44)	635 (48)	112 (8)
Conventional wheat sowing (after rice straw burning)	78 (12)	380 (58)	200 (30)

Figures in the parentheses are percentages to their respective totals of sample size

Hence, greater focus should be on integration of crop rotation, herbicide rotation, herbicide mixtures usage along with implementation of other agronomic practices like stale seed bed, zero tillage, early planting, competitive cultivars selection and increased crop seeding rate which will create the environment in favour of the crop over weeds.

It was concluded that rice residue management methods influence weed dynamics and wheat crop productivity. The residue retention at soil surface resulted in the lowest infestation of *P. minor* coupled with less cost of cultivation. The rice residue incorporation involved more cost of cultivation and resulted in less infestation of *P. minor* as compared to conventional method of rice residue burning.

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RESEARCH ARTICLE

Effect of nitrogen and weed management practices in maize and their residual effect on succeeding groundnut

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ABSTRACT

A field experiment was conducted to evaluate nitrogen and weed management practices in maize and their residual effect in groundnut during two consecutive rainy *(Kharif)* and winter *(Rabi)* seasons of 2019-20 and 2020-21 at Dryland Farm, S. V. Agricultural College, Tirupati, Andhra Pradesh, India. Among nitrogen (N) management practices, lower weed density and biomass were registered with control, whereas Green Seeker-directed N management (GSNM) recorded significantly higher kernel and stover yield in maize. Hand weeding twice at 15 and 30 days after sowing (DAS) significantly lowered the weed density and biomass and improved maize kernel and stover yield. This was closely followed by pre-emergence application (PE) of atrazine 1.0 kg/ha followed by (*fb*) post-emergence application (PoE) of topramezone 30 g/ha and atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE. Among all the treatment combinations, higher kernel and stover yield of maize was recorded with GSNM and hand weeding twice (15 and 30 DAS). Nitrogen management practices executed in preceding maize did not exert any significant influence on weed and growth parameters in succeeding groundnut. Lower weed density and biomass were recorded with hand weeding twice (15 and 30 DAS), which was at par with brown manuring, atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha or tembotrione 120 g/ha PoE.

Keywords: Groundnut, Maize, Nitrogen management, Productivity, Weed management

INTRODUCTION

India ranks seventh in terms of maize production with a record of 28.76 million tonnes (Mt) from an area of 9.5 million hectares (mha) with productivity of 3.01 t/ha. The state of Andhra Pradesh produced 2.12 Mt of maize from an area of 0.30 mha with a productivity of 7.06 t/ha (Anonymous 2020). As compared to major maize growing regions of the world, the low and unstable productivity in India is due to a number of factors. Of these, improper nutrient management and inadequate weed management appear to the major ones. Among different nutrients, nitrogen (N) plays a crucial role in crop production.

The real-time nitrogen management (RTNM) approach can help to increase N use efficiency by right scheduling of N application as per plant need, based on periodic monitoring of crop nitrogen status (Dobermann *et al*. 2004). As a useful tool for RTNM (Harrell *et al*. 2011), GreenSeeker™ optical sensor determines the fertilizer rate based on plant's normalized difference vegetation index (NDVI).

Yield losses occur to the extent of about 40% due to weed infestation in maize (Singh *et al.* 2015). Although manual hand weeding has been so far the best method of weed management, it is constrained by timely non-availability and higher wages of agricultural laborer. Use of pre- and post-emergence herbicides in right combination may be a cost-effective option to keep the weeds under control during the critical period of crop-weed competition (Kumar *et al.* 2017). Evolution of herbicide resistance in a large number of weed species is also a concern across the world. There should have been a judicious combination of chemical and non-chemical options in order to achieve a rational weed control. There is a need to redesign weed management strategies with the use of new generation herbicides, cover crops, brown manuring and spraying of botanicals.

At present, maize-groundnut cropping sequence is gaining importance under both rainfed and irrigated situations. Since maize is exhaustive and weed sensitive crop, system-based management approach is more appropriate for managing the weeds and nutrient needs. Further, the herbicide application

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in maize may have residual effect on succeeding crops. There is no such comprehensive information on these aspects. Thus, the present study was taken up with an objective to evaluate effective nitrogen and weed management practices for higher productivity in maize and quantify their residual effect in groundnut.

MATERIALS AND METHODS

A field experiment was conducted during two consecutive rainy *(Kharif)* and winter *(Rabi)* seasons of 2019-20 and 2020-21 at Dryland Farm, S. V. Agricultural College, Tirupati, located at 13.5°N latitude and 79.5°E longitude with an altitude of 182.9 m above mean sea level in the Southern Agro-climatic Zone of Andhra Pradesh, India. The soil was sandy loam in texture, neutral in soil reaction, low in organic carbon and available nitrogen, and medium in available phosphorus and potassium. Four nitrogen management practices, *viz*. control (no. N), recommended dose of nitrogen (RDN, 180 kg/ha), Green Seeker-directed N management (GSNM), and soil–test crop response (STCR)-based nitrogen management (SNM) in main plots, and nine weed management practices, *viz.* unweeded check, hand weeding twice at 15 and 30 days after sowing (DAS), atrazine 1.0 kg/ha as pre-emergence application (PE) followed by (*fb*) topramezone 30 g/ha as post-emergence application (PoE), atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE, two sprays of Parthenium water extract 15 l/ha at 15 and 30 DAS, two sprays of sunflower water extract 15 l/ha at 15 and 30 DAS, atrazine 1.0 kg/ha PE *fb* Parthenium water extract 15 l/ha (PoE), atrazine 1.0 kg/ha PE *fb* sunflower water extract 15 L/ha PoE, and brown manuring in sub-plots. A split-plot design with three replications was used.

As per treatments, N was applied in the form of urea. In RDN, split application was done at basal, knee-high and tasseling. In GSNM, one-third dose of total N was applied as basal and the remaining N was top dressed as per Green Seeker readings. Whenever the NDVI values fall below the threshold value of 0.8, N was immediately top dressed at 25 kg/ha to meet the N requirement, irrespective of the crop growth stages. The remaining dose of N was applied at 80 DAS coinciding with the silking stage (Prakasha *et al.* 2020). In SNM, an extra dose of 30% of RDN was applied due to low level of available N in the experimental soil. A uniform dose of 60 kg P_2O_5 and 50 kg K/ha was applied to all the plots. The atrazine PE and tembotrione and topramezone PoE herbicides were sprayed uniformly at 2 and 15 DAS, respectively. The filtered concentrated plant water extracts were sprayed at 15 and 30 DAS. In brown manuring treatment, *Sesbania* was grown in intermediate rows of maize and was knocked down with the application of 2,4 D (Na salt) 1.0 kg/ha at 35 DAS. Data on different parameters of maize were recorded and statistically analyzed following the analysis of variance (Panse and Sukhatme 1985). Maize hybrid '*DHM-117*' was raised with recommended package of practices except for the nitrogen and weed management. Groundnut variety '*Dharani*' was raised after harvest of maize in the undisturbed layout to study the residual effect of different nitrogen and weed management practices as imposed in maize

RESULTS AND DISCUSSION

Weed flora

In two-year field study, maize-groundnut cropping sequence was found infested with mixed weed flora belonging to sixteen taxonomic families, including four species of grasses, two species of sedges, and sixteen species of broad-leaved weeds. The predominant weed species in the experimental field were *Cyperus rotundus* L., *Digitaria sanguinalis* (L). Scop., *Dactyloctenium aegyptium* (L.) Willd., *Blainvillea acmella* L., *Lagascea mollis* Cav. and *Commelina benghalensis* L. Similar type of weed flora was reported by Swetha *et al.* (2015) and Ravi *et al.* (2017).

Effect on weeds

Lower density and biomass of grasses, sedges, broad-leaved, and total weeds were registered in control plots (no. N). RDN and GSNM recorded significantly lower densities of grasses, sedges, broad-leaved and total weeds than SNM (**Table 1**). Initial higher dose of N in SNM might have increased the weed biomass per unit area (Evans *et al.*, 2003). The results were in agreement with the findings of Kristensen *et al.* (2008) and Khan *et al.* (2012).

Among different weed management treatments, hand weeding twice (15 and 30 DAS) recorded significantly lower density and biomass of grasses, sedges, broad-leaved and total weeds over the rest of treatments at 20 DAS. Hand weeding twice (15 and 30 DAS) was found at par with atrazine 1.0 kg/ha PE *fb* topramezone 30 or 120 g/ha PoE in lowering down density and biomass of grasses, sedges, broad-leaved and total weeds at 40 DAS. This was mainly attributed to effective control of weeds with hand weeding twice or sequential application of pre- and post-emergence herbicides (Swetha *et al.* 2015).

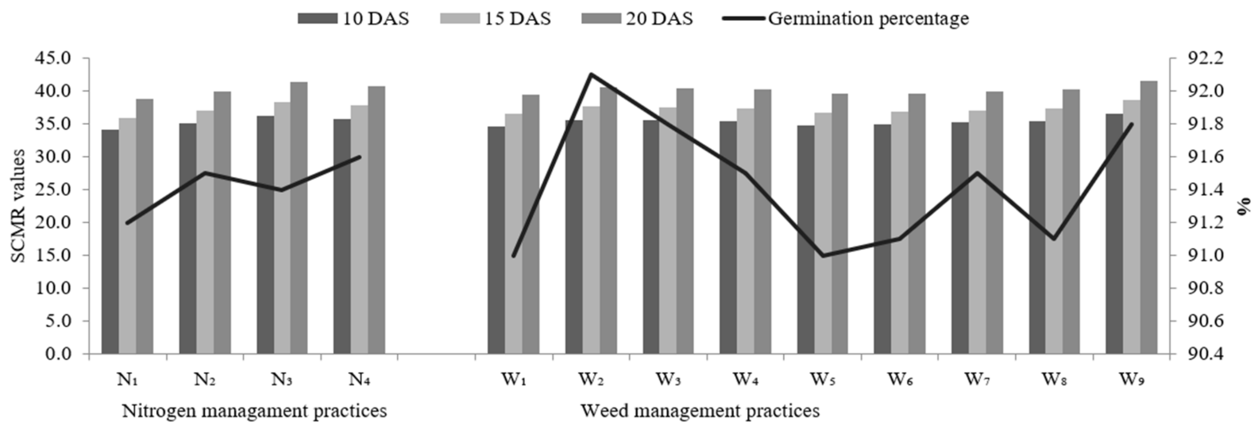

Figure 1. Germination percentage and SCMR values in groundnut as influenced by nitrogen and weed management practices imposed in preceding maize (pooled of two-year data)

Table 1. Effect of nitrogen and weed management treatments on total weed density and biomass in maize

Treatment	Total weed density (no./m^2)				Total weed biomass (g/m^2)			
	20 DAS		40 DAS		20 DAS		40 DAS	
	2019	2020	2019	2020	2019	2020	2019	2020
Nitrogen management								
Control	6.07 (42.9)	7.33 (62.7)	5.26 (33.7)	5.54 (37.5)	7.16 (67.7)	8.06 (86.3)	6.34 (52.9)	6.59 (57.1)
Recommended dose of fertilizer	7.71 (68.8)	9.29 (99.7)	7.35 (64.3)	7.73 (71.0)	8.20 (89.3)	9.44 (118.4)	7.93 (83.6)	8.45 (95.1)
Green seeker directed N application	7.83 (73.4)	9.43 (106.2)	7.66 (69.9)	8.07 (77.4)	8.55 (96.0)	9.66 (122.6)	8.20 (88.6)	8.80 (102.2)
Soil test-based fertilizer application	8.80 (97.2)	10.38 (134.4)	8.60 (85.6)	8.78 (89.0)	9.69 (122.7)	10.69 (148.9)	9.20 (110.9)	9.65 (121.9)
LSD (p=0.05)	0.73	0.89	0.52	0.56	0.74	0.99	0.61	0.67
Weed management								
Unweeded check	11.12 (132.8)	13.29 (188.9)	10.56 (119.7)	11.02 (130.3)	14.55 (214.5)	15.90 (255.1)	13.72 (192.0)	14.50 (214.6)
Hand weeding twice at 15 and 30 DAS	0.71 (0.0)	1.13 (1.0)	0.71 (0.0)	0.79 (0.1)	2.24 (4.6)	2.50 (5.9)	2.12 (4.1)	2.23 (4.6)
Atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE	6.24 (40.8)	7.44 (58.2)	6.33 (41.7)	6.60 (45.4)	2.46 (5.9)	2.75 (7.6)	2.33 (5.3)	2.46 (5.9)
Atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE	6.68 (45.5)	7.98 (65.1)	6.49 (44.0)	6.78 (47.9)	2.70 (7.0)	3.04 (9.0)	2.56 (6.2)	2.70 (7.0)
Application of Parthenium water extract 15 L/ha twice at 15 and 30 DAS	10.96 (127.7)	13.09 (181.5)	10.27 (108.4)	10.72 (117.9)	13.06 (173.5)	14.87 (224.8)	12.31 (155.5)	13.01 (173.8)
Application of sunflower water extract 15 L/ha twice at 15 and 30 DAS	10.93 (125.8)	13.06 (179.1)	10.33 (108.7)	10.73 (117.1)	12.66 (163.0)	14.42 (211.2)	11.94 (146.0)	12.63 (163.5)
Atrazine 1.0 kg/ha PE *fb* Parthenium water extract 15 L/ha PoE	6.77 (46.8)	8.09 (66.8)	6.45 (44.2)	6.72 (47.9)	11.05 (122.2)	12.57 (158.4)	10.39 (108.8)	10.99 (121.9)
Atrazine 1.0 kg/ha *fb* sunflower water extract 15 L/ha PoE	6.67 (45.2)	7.97 (64.8)	6.31 (42.3)	6.58 (45.8)	10.82 (117.2)	12.32 (152.0)	10.18 (104.4)	10.77 (117.0)
Brown manuring	8.30 (70.4)	9.94 (101.0)	7.53 (61.2)	7.85 (66.2)	6.05 (37.6)	6.79 (47.4)	5.72 (33.8)	6.10 (38.4)
LSD (p=0.05)	0.96	1.15	1.04	1.09	1.05	1.20	1.07	1.13
N at W								
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
W at N								
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Data in parentheses are original values, which were transformed to ($\sqrt{x+0.5}$) and analysed statistically

Brown manuring was the next best weed management treatment in reducing the weeds biomass. Application of atrazine 1.0 kg/ha PE *fb* sunflower water extract 15 l/ha PoE and atrazine 1.0 kg/ha PE *fb* Parthenium water extract 15 l/ha PoE were comparable with one another and were significantly lower than application of sunflower water extract 15 l/ha twice at 15 and 30 DAS and application of Parthenium water extract 15 l/ha twice at 15 and 30 DAS. Application of atrazine PE *fb* plant water extract PoE resulted in greater reduction in weed biomass than the plant water extracts applied alone.

Higher density and biomass of all categories of weeds were recorded with unweeded check due to heavy weed infestation right from sowing to crop harvest confirming Yakadri *et al.* (2015) and Rani *et al.* (2019). There was no significant effect of interaction during both the years of study.

Effect on crop

Maize: Among the nitrogen management practices, GSNM recorded significantly higher kernel and stover yield of maize as evidenced from year-wise well as pooled data. It might be due to precise nitrogen application in more number of splits compared to other treatments. Adequate supply of nitrogen at appropriate crop growth stages might have enhanced greater availability of nutrients in the soil which resulted in more absorption and higher uptake by the crop plants. This also facilitated better translocation and partitioning of assimilates from source to sink, amplifying yield parameters and thereby yield. This was in consonance with the findings of Prakasha *et al.* (2020) and Jyothsna (2020). Maize kernel and stover yields were improved due to hand weeding twice (15 and 30 DAS), which, however, remained at par with the application of atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE; atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE (**Table 2** and **3**). This might be due to reduced competition among the crop plants and weeds for the existing resources throughout the crop growth period, enabling the crop plants for better utilization of resources as reflected in terms of higher kernel yield. Lower yields were recorded with weedy check. The results corroborated with the findings of Rani *et al.* (2019) and Mahto *et al.* (2020).

There was a significant effect of interaction between nitrogen and management practices on kernel and stover yields of maize during both the years. The treatment combination of GSNM with hand weeding twice (15 and 30 DAS) recorded significantly higher kernel yield although it was at par with GSNM along with atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE; GSNM with atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE; SNM with hand weeding twice (15 and 30 DAS); SNM with atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE and SNM with atrazine 1.0 kg/ha (PE *fb* tembotrione 120 g/ha PoE. Significantly higher kernel yield in these treatment combinations might be due to maintenance of weed-free environment during critical period of crop-weed competition and sensor determined topdressing of nitrogen for maize with increased number of split applications, leading to increased availability of resources at different physiological growth stages and better translocation of photosynthates to sink. Nagalakshmi *et al.* (2006) and Deshmukh *et al.* (2009) also reported significant interaction between nitrogen and weed management practices. The lowest kernel and stover yields were observed with the non-application of N in unweeded plots, which were comparable even when combined with two sprays of Parthenium or sunflower water extract 15 l/ha (15 and 30 DAS), or the application of

Table 2. Effect of nitrogen and weed management treatments on maize kernel yield (t/ha)

Treatment	2019					2020					Pooled				
	C	RDF	GSD	STF	Mean	C	RDF	GSD	STF	Mean	C	RDF	GSD	STF	Mean
Atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE	3.24	6.16	7.78	7.32	6.12	3.00	5.99	7.65	7.15	5.95	3.12	6.07	7.71	7.24	6036
Atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE	2.98	5.82	7.71	7.23	5.94	2.74	5.65	7.45	7.06	5.72	2.86	5.74	7.58	7.15	5830
Application of Parthenium water extract 15 L/ha twice at 15 and 30 DAS	1.40	2.77	4.24	3.70	3.03	1.24	2.58	4.18	3.47	2.87	1.32	2.67	4.21	3.59	2949
Application of sunflower water extract 15 L/ha twice at 15 and 30 DAS	1.44	2.83	4.40	3.93	3.15	1.27	2.66	4.26	3.59	2.94	1.36	2.74	4.33	3.76	3048
Atrazine 1.0 kg/ha PE *fb* Parthenium water extract 15 L/ha PoE	1.57	3.07	4.49	3.93	3.26	1.39	2.90	4.32	3.76	3.09	1.48	2.98	4.41	3.85	3179
Atrazine 1.0 kg/ha *fb* sunflower water extract 15 L/ha PoE	1.64	3.22	4.53	3.97	3.34	1.47	3.05	4.36	3.83	3.18	1.56	3.13	4.45	3.90	3260
Brown manuring	2.73	4.74	6.06	5.73	4.82	2.56	4.57	5.90	5.57	4.65	2.65	4.66	5.98	5.65	4734
Unweeded check	1.04	2.13	3.77	3.50	2.61	0.97	1.88	3.43	3.25	2.38	1.00	2.01	3.60	3.37	2497
Hand weeding twice at 15 and 30 DAS	3.29	6.26	8.05	7.57	6.29	3.18	6.10	7.92	7.40	6.15	3.23	6.18	7.98	7.49	6221
Mean	2.15	4.11	5.67	5.21		1.98	3.93	5.50	5.01		2.06	4.02	5.58	5.11	
	SEm ±		LSD (p=0.05)			SEm ±		LSD (p=0.05)			SEm ±		LSD (p=0.05)		
N	0.11		0.39			0.12		0.40			0.11		0.39		
W	0.14		0.40			0.15		0.41			0.14		0.34		
N at W	0.28		0.79			0.30		0.83			0.27		0.81		
W at N	0.34		0.83			0.35		0.86			0.33		0.85		

C: Control; RDF: Recommended dose of fertilizer; GSD: Green seeker directed N application; STF: Soil test-based fertilizer application atrazine 1.0 kg/ha PE *fb* Parthenium/sunflower water extract 15 L/ha PoE.

Groundnut: Residual effect of both nitrogen and weed management practices as imposed in maize was found to be non-significant in influencing germination percentage, phytotoxicity and SPAD chlorphyll meter reading (SCMR) values. This might be due to the degradation of herbicides by several ways that resulted in less persistence of applied herbicides as also reported by Nazreen (2017) and Sathyapriya and Chinnusamy (2020).

Nitrogen management practices in maize did not exert any significant influence on weed dynamics, pod yield and haulm yield of groundnut. Irrespective of nitrogen management practices, total weed density and biomass in groundnut were lower with hand weeding twice (15 and 30 DAS), which was however, at par with brown manuring, application of atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha or tembotrione 120 g/ha PoE (**Table 4**). Higher pod and haulm yield of groundnut was recorded with brown manuring, which, however, remained at par with hand weeding

Table 3. Effect of nitrogen and weed management treatments on maize stover yield (kg/ha)

Treatment	2019					2020					Pooled				
	C	RDF	GSD	STF	Mean	C	RDF	GSD	STF	Mean	C	RDF	GSD	STF	Mean
Atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE	4.50	6.97	8.21	7.88	6.89	4.25	6.76	7.96	7.72	6.67	4.38	6.87	8.09	7.80	6.78
Atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE	4.37	6.50	8.18	7.79	6.71	4.12	6.32	7.93	7.63	6.50	4.25	6.41	8.05	7.71	6.60
Application of Parthenium water extract 15 L/ha twice at 15 and 30 DAS	2.67	3.94	5.47	4.76	4.21	2.42	3.79	5.35	4.57	4.03	2.54	3.86	5.41	4.67	4.12
Application of sunflower water extract 15 L/ha twice at 15 and 30 DAS	2.73	4.01	5.49	5.03	4.31	2.48	3.87	5.47	4.72	4.13	2.60	3.94	5.48	4.87	4.22
Atrazine 1.0 kg/ha PE *fb* Parthenium water extract 15 L/ha PoE	2.92	4.37	5.54	5.04	4.47	2.67	4.12	5.36	4.85	4.25	2.80	4.25	5.45	4.94	4.36
Atrazine 1.0 kg/ha *fb* sunflower water extract 15 L/ha PoE	2.98	4.54	5.55	5.06	4.53	2.76	4.29	5.30	5.00	4.34	2.87	4.41	5.43	5.03	4.43
Brown manuring	4.55	5.89	7.03	6.71	6.05	4.30	5.75	6.97	6.55	5.89	4.43	5.82	7.00	6.63	5.97
Unweeded check	2.02	3.25	4.84	4.64	3.69	1.90	3.22	4.76	4.41	3.57	1.96	3.23	4.80	4.53	3.63
Hand weeding twice at 15 and 30 DAS	4.50	7.05	8.37	8.15	7.02	4.25	6.80	8.29	7.99	6.83	4.38	6.93	8.33	8.07	6.92
Mean	3.47	5.17	6.52	6.12		3.24	4.99	6.38	5.94		3.36	5.08	6.45	6.03	
	SEm ±		LSD (p=0.05)			SEm ±		LSD (p=0.05)			SEm ±		LSD (p=0.05)		
N	0.11		0.37			0.11		0.38			0.11		0.35		
W	0.18		0.50			0.17		0.48			0.16		0.44		
N at W	0.32		0.90			0.33		0.91			0.30		0.88		
W at N	0.35		0.99			0.34		0.96			0.31		0.91		

C: Control; RDF: Recommended dose of fertilizer; GSD: Green seeker directed N application; STF: Soil test-based fertilizer application

Table 4. Effect of nitrogen and weed management practices executed in preceding maize on weed parameters and pod and haulm yield of succeeding groundnut

Treatment	Total Weed density (no./m^2)		Total Weed biomass (g/m^2)		Groundnut pod yield (t/ha)		Groundnut haulm yield (t/ha)	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Nitrogen management								
Control	8.6(76.6)	10.3(107.5)	7.3(55.3)	8.6(77.3)	2.45	2.28	3.44	3.36
Recommended dose of fertilizer	8.7(76.8)	10.3(107.8)	7.3(55.1)	8.6(77.1)	2.52	2.34	3.51	3.44
Green seeker directed N application	8.9(79.8)	10.5(111.7)	7.5(58.1)	8.9(81.1)	2.70	2.50	3.66	3.58
Soil test-based fertilizer application	9.0(82.8)	10.7(115.7)	7.7(61.3)	9.1(85.3)	2.62	2.42	3.55	3.50
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Weed management								
Unweeded check	10.1(101.4)	11.8(138.2)	8.9(78.9)	10.4(108.7)	2.21	2.04	3.29	3.09
Hand weeding twice at 15 and 30 DAS	7.2(50.9)	8.7(75.5)	5.5(30.3)	6.7(44.1)	2.93	2.74	3.80	3.73
Atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE	7.3(53.6)	8.9(78.9)	5.7(32.4)	6.9(47.0)	2.91	2.72	3.74	3.66
Atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE	7.5(55.3)	9.0(81.2)	5.9(33.9)	7.0(48.9)	2.86	2.66	3.68	3.65
Application of Parthenium water extract 15 L/ha twice at 15 & 30 DAS	10.0(100.2)	11.7(137.3)	8.9(78.1)	10.4(107.8)	2.26	2.07	3.33	3.30
Application of sunflower water extract 15 L/ha twice at 15 & 30 DAS	10.0(99.2)	11.7(136.0)	8.8(76.9)	10.3(106.2)	2.29	2.10	3.34	3.30
Atrazine 1.0 kg/ha PE *fb* Parthenium water extract 15 L/ha PoE	10.0(98.7)	11.7(135.5)	8.8(76.5)	10.3(105.6)	2.32	2.13	3.40	3.36
Atrazine 1.0 kg/ha *fb* sunflower water extract 15 L/ha PoE	10.0(98.7)	11.6(135.2)	8.8(78.1)	10.4(107.7)	2.37	2.18	3.42	3.38
Brown manuring	7.3(52.7)	8.8(77.8)	5.7(31.7)	6.8(46.0)	2.99	2.81	3.88	3.79
LSD (p=0.05)	0.82	0.83	0.77	0.87	0.27	0.23	0.23	0.25
Interaction								
N at W								
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
W at N								
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Data in parentheses are original values, which were transformed to ($\sqrt{X+0.5}$) and analysed statistically twice (15 and 30 DAS) and application of atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha or tembotrione 120 g/ha PoE. Better weed suppression coupled with higher residual nitrogen availability might have increased the yield attributes which in turn led to higher pod yield conforming earlier reports of Sathyapriya and Chinnusamy (2020).

Weedy check plots were comparable with the plots treated with two sprays of Parthenium/ sunflower water extract 15 l/ha (15 and 30 DAS) or application of atrazine 1.0 kg/ha PE *fb* Parthenium or sunflower water extract 15 l/ha in significantly registering higher weed density and biomass and lower yield levels in groundnut. Higher weed growth was due to prolific weed seed production in preceding crop, leading to severe crop-weed competition along with lower pod yield in groundnut (Rani *et al.* 2019).

Conclusion

It was concluded that Green Seeker-directed N management (GSNM) along with either hand weeding twice or application of atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha /tembotrione 120 g/ha PoE proved to be the most effective option in managing weeds and increasing the productivity of maize. When the groundnut is grown as a succeeding crop, it would be worthwhile to go for brown manuring, hand weeding twice or sequential application of pre- and post-emergence herbicides in preceding maize for an efficient weed management in maize-groundnut cropping system.

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RESEARCH ARTICLE

Efficacy of XR-848 benzyl ester + penoxsulam (ready-mix) in managing weeds in dry direct-seeded rice

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ABSTRACT

A field study was conducted during rainy *(Kharif)* seasons of 2016 and 2017 at Agricultural Research Station, Dhadesugur, University of Agricultural Sciences, Raichur, Karnataka, India to study the efficacy of XR-848 benzyl ester + penoxsulam (ready-mix) in managing weeds in dry direct-seeded rice. The dominant weeds in the field were: *Echinochloa colona, Panicum repens, Cynodon dactylon, Brachiaria mutica, Digitaria sanguinalis* and *Leptochloa chinensis* among grasses, *Eclipta alba, Commelina communis* and *Ludwigia parviflora* among broad-leaved weeds and the sedge, *Cyperus iria*. The post-emergence application (PoE) of XR-848 benzyl ester + penoxsulam (ready-mix) 48.8 g/ha significantly reduced weed biomass, recorded higher weed control efficiency and rice grain yield during 2016 and 2017 *Kharif* seasons. It was on par with XR-848 benzyl ester + penoxsulam (ready-mix) 40.6 g/ha PoE and hand weeding twice at 20 and 40 days after sowing.

Key words: Dry direct-seeded rice, Hand weeding, Herbicides, Weed control efficiency, Weed management.

INTRODUCTION

In India, rice (*Oryza sativa* L.) is cultivated over an area of 43.8 Mha with a production of 116.4 Mt which contributes to 40.86% of total food grain production of our country. The average rice productivity in India is 2.66 t/ha (GOI, 2020). In Karnataka, rice is cultivated in 0.99 Mha with a production of 4.53 Mt and a productivity of 4.56 t/ha (Pathak *et al.* 2020). Among several reasons for low rice productivity, the loss due to weeds competition is one of the most important reasons. Weeds are most severe and widespread biological constrains to crop production in India and weeds alone cause 33% of losses out of total losses due to pests (Verma *et al.* 2015). Irrespective of the method of rice establishment, weeds are a major impediment to rice production due to their ability to compete for resources. In general, weeds problem in transplanted paddy is lower than that of direct-seeded rice (Rao *et al.* 2007). But, in situations where continuous standing water cannot be maintained particularly during the first 45 days, weed infestation in transplanted rice may be as high as direct-seeded rice. Weeds can reduce the grain yield of dry direct-seeded rice (DSR) by 75.8%, wet-seeded rice (WSR) by 70.6% and transplanted rice (TPR) by 62.6% (Singh *et al.* 2004). Weeds by virtue of their high adaptability and faster growth dominate the crop habitat and reduce the rice yield potential. Hence, effective weed management in DSR is critical for attaining optimum rice productivity (Rao *et al*, 2015). Thus, the present study was undertaken to assess the efficacy of XR-848 benzyl ester 12.5 g/l + penoxsulam 20 g/l OD (w/v) (ready-mix) and compare it with other weed management treatments in managing weeds in dry direct-seeded rice.

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MATERIALS AND ETHODS

A field experiment was conducted during rainy *(Kharif)* seasons of 2016 and 2017 at Agricultural Research Station, Dhadesugur, Raichur, Karnataka. The soil of the experimental site was medium deep black and neutral in pH (8.04) with an EC of 0.47 dS/m. It was medium in organic carbon content (0.41%), low in nitrogen (189 kg/ha), medium in phosphorus (58.5 kg/ha) and potassium (287.5 kg/ha). There were seven treatments, *viz.* post-emergence application (PoE) of XR-848 benzyl ester 12.5 g/l + penoxsulam 20 g/l OD (w/v) [XR-848 benzyl ester + penoxsulam (ready-mix)] 32.5 g/ha, XR-848 benzyl ester + penoxsulam (ready-mix) 40.6 g/ha, XR-848 benzyl ester + penoxsulam (ready-mix) 48.8 g/ha PoE, XR-848 benzyl ester 2.5 % EC (w/v) [XR-848 benzyl ester] 31.25 g/ha PoE, penoxsulam 25.6 g/ha PoE, hand weeding twice at 20 and 40 days after sowing (DAS) and weedy check. The randomized complete block design (RCBD) was used with three replications having each plot of 6 x 4 m (24 m^2). All the herbicides were applied at 20 DAS using a knapsack sprayer fitted with a flat-fan nozzle at a spray volume of 500 l/ha. Rice seeds were sown on well prepared dry soil by tractor drawn seed-drill at a spacing of 20 cm (between the rows). Soon after irrigation was given in order to ensure proper germination of seeds. Recommended dose of fertilizers (150:75:75 kg N:P:K/ha) were applied uniformly in three equal splits. Irrigation comprised of alternate drying and wetting followed by intermittent irrigation at seven days interval up to 15 days before harvest. Other agronomic and plant protection measures during the crop growth were followed as per the recommendation. The efficacy of different treatments on weeds was evaluated at crop maturity.

Quadrat (0.25 m^2) was placed in each of the plots at random to determine the weed density. Weeds within this quadrat were counted and the efficacy of weed control treatments was calculated by comparing the weed density in treatment plot with the weedy check. Weeds were cut at the ground level, washed with tap water, oven dried at 70 ^{0}C for 48 hours and then weighed for biomass. The weed control efficiency was calculated using the formula as given by Tawaha *et al.* (2002). After harvest and threshing of crop, grain yield was recorded in net plot and converted to grain yield per hectare.

The data of each year was analyzed separately. Microcomputer Statistical Programme (MSTAT) was used for statistical analysis of data and means were separated using least significant difference (LSD) at p=0.05. The data on weeds were transformed by square root transformation by adding one before being subjected to ANOVA (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Effect on weeds, weed density and biomass

The grassy weeds predominant in the experimental field were *Echinochloa* colona, *Panicum repens*, *Cynodon dactylon*, *Brachiaria mutica*, *Digitaria sanguinalis* and *Leptochloa chinensis. The* post-emergence application of XR-848 benzyl ester + penoxsulam (ready-mix) 48.8 g/ha and hand weeding twice at 20 and 40 DAS recorded significantly lower grassy weeds at 30, 45 and 60 DAS, compared to other weed control treatments and weedy check during both the years of study. The reduction in weed density is attributed to effective suppression of grassy weeds with XR-848 benzyl ester + penoxsulam (ready-mix). The efficacy of early post-emergence and post-emergence application of penoxsulam on grassy weed density in rice was reported by Singh *et al.* (2007). The predominant broad-leaved weeds in the experimental field were: *Eclipta alba*, *Commelina communis* and *Ludwigia parviflora*. XR-848 benzyl ester + penoxsulam (ready-mix) 48.8 g/ha PoE and hand weeding twice at 20 and 40 DAS were found to be significantly superior in lowering the density of broad-leaved weeds and sedges (**Table 1**) and total weed biomass (**Table 2**). Further, weedy check recorded significantly higher density of broad-leaved weeds,

Table 1. Effect of weed control treatments on weed density (no./m^2) in dry direct-seeded rice

Treatment	Grasses						Broad-leaved weeds						Sedges					
	30 DAS		45 DAS		60 DAS		30 DAS		45 DAS		60 DAS		30 DAS		45 DAS		60 DAS	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
XR-848 benzyl ester + penoxsulam RM 32.5 g/ha PoE	2.70 (6.4)	2.88 (7.30)	3.32 (10.1)	3.35 (10.2)	3.50 (11.3)	3.53 (11.5)	1.95 (2.80)	2.07 (3.28)	2.23 (3.98)	2.25 (4.07)	2.34 (4.46)	2.35 (4.52)	1.40 (0.95)	1.41 (0.98)	1.69 (1.85)	1.70 (1.89)	1.76 (2.10)	1.76 (2.10)
XR-848 benzyl ester + penoxsulam RM 40.6 g/ha PoE	2.20 (3.9)	2.08 (3.33)	2.66 (6.06)	2.68 (6.18)	2.79 (6.79)	2.82 (6.93)	1.63 (1.66)	1.64 (1.69)	1.85 (2.42)	1.86 (2.47)	1.93 (2.74)	1.94 (2.77)	1.17 (0.38)	1.17 (0.38)	1.43 (1.05)	1.44 (1.07)	1.48 (1.20)	1.48 (1.20)
XR-848 benzyl ester + penoxsulam RM 48.8 g/ha PoE	2.00 (3.2)	1.70 (1.90)	2.56 (5.57)	2.58 (5.68)	2.69 (6.23)	2.71 (6.36)	1.50 (1.25)	1.46 (1.14)	1.80 (2.25)	1.82 (2.30)	1.87 (2.48)	1.90 (2.61)	1.12 (0.25)	1.12 (0.25)	1.42 (1.02)	1.43 (1.04)	1.45 (1.10)	1.48 (1.20)
XR-848 benzyl ester 31.25 g/ha PoE	3.60 (12.0)	3.62 (12.1)	3.99 (15.0)	4.03 (15.3)	4.21 (16.7)	4.25 (17.1)	2.36 (4.58)	2.37 (4.63)	2.69 (6.22)	2.71 (6.34)	2.83 (7.02)	2.85 (7.11)	1.61 (1.58)	1.61 (1.60)	1.94 (2.78)	1.96 (2.84)	2.02 (3.10)	2.05 (3.20)
Penoxsulam 25.6 g/ha PoE	3.40 (10.9)	3.47 (11.1)	3.90 (14.2)	3.93 (14.5)	4.11 (15.9)	4.15 (16.2)	2.29 (4.26)	2.30 (4.30)	2.62 (5.84)	2.64 (5.96)	2.75 (6.57)	2.77 (6.66)	1.50 (1.25)	1.50 (1.26)	1.91 (2.65)	1.92 (2.70)	2.00 (3.00)	2.00 (3.00)
Hand weeding twice at 20 and 40 DAS	1.00 (0.0)	1.00 (0.00)	1.41 (1.00)	1.42 (1.02)	1.46 (1.12)	1.47 (1.16)	1.00 (0.00)	1.00 (0.00)	1.24 (0.53)	1.24 (0.54)	1.27 (0.62)	1.27 (0.62)	1.00 (0.00)	1.00 (0.00)	1.11 (0.24)	1.11 (0.24)	1.14 (0.30)	1.14 (0.30)
Weedy check	5.40 (27.9)	5.64 (30.8)	7.41 (53.9)	7.48 (55.0)	8.91 (78.4)	8.99 (79.8)	3.49 (11.2)	3.83 (13.6)	5.47 (28.9)	5.51 (29.4)	6.51 (41.4)	6.57 (42.2)	2.69 (6.3)	2.70 (6.3)	3.54 (11.5)	3.56 (11.7)	4.11 (15.9)	4.15 (16.2)
LSD (p=0.05)	0.57	0.95	0.65	0.61	0.64	0.64	0.41	0.52	0.41	0.35	0.35	0.38	0.25	0.22	0.21	0.22	0.22	0.23

Note: Figures in outside the parentheses are square root transformed values ($\sqrt{x+1}$); RM: Ready-mix; DAS: Days after sowing

Table 2. Effect of weed control treatments on total weed biomass and weed control efficiency in dry direct-seeded rice

Treatment	Total weed biomass (g/m^2)						Weed control efficiency (%)					
	30 DAS		45 DAS		60 DAS		30 DAS		45 DAS		60 DAS	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
XR-848 benzyl ester + penoxsulam RM 32.5 g/ha PoE	4.15 (16.2)	4.30 (17.5)	5.11 (25.1)	5.39 (28.1)	5.75 (32.1)	5.93 (34.2)	77.3	78.7	77.8	78.4	78.9	80.5
XR-848 benzyl ester + penoxsulam RM 40.6 g/ha PoE	3.39 (10.5)	3.54 (11.5)	4.37 (18.1)	4.53 (19.5)	5.05 (24.5)	5.12 (25.2)	85.3	86.0	84.0	85.0	83.9	85.6
XR-848 benzyl ester + penoxsulam RM 48.8 g/ha PoE	3.19 (9.2)	3.35 (10.2)	4.00 (15.0)	4.18 (16.5)	4.81 (22.1)	4.89 (22.9)	87.1	87.6	86.7	87.3	85.5	86.9
XR-848 benzyl ester 31.25 g/ha PoE	4.67 (20.8)	4.80 (22.0)	5.52 (29.5)	5.93 (34.2)	6.29 (38.6)	6.60 (42.5)	70.9	73.2	73.9	73.7	74.7	75.7
Penoxsulam 25.6 g/ha PoE	4.59 (20.1)	4.72 (21.3)	5.32 (27.3)	5.74 (32.0)	6.23 (37.8)	6.41 (40.1)	71.9	74.1	75.9	75.4	75.2	77.1
Hand weeding twice at 20 and 40 DAS	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	2.63 (5.9)	2.94 (7.7)	100	100	100	100	96.1	95.6
Weedy check	8.51 (71.5)	9.12 (82.2)	10.69 (113.2)	11.45 (130.2)	12.38 (152.3)	13.27 (175.1)	0	0	0	0	0	0
LSD (p=0.05)	0.81	0.74	0.94	0.98	0.65	0.95	-	-	-	-	-	-

Note: Figures in outside the parentheses are square root transformed values (sq. root of x+1); RM: Ready-mix; DAS: Days after sowing

Table 3. Growth and yield parameters of dry direct-seeded rice as influenced by different weed control treatments

Treatment	Plant height (cm)		No. of productive tillers/m^2		Grain yield t/ha)	
	2016	2017	2016	2017	2016	2017
XR-848 benzyl ester + penoxsulam RM 32.5 g/ha PoE	103	105	202	204	5.42	5.57
XR-848 benzyl ester + penoxsulam RM 40.6 g/ha PoE	108	109	208	210	5.68	5.87
XR-848 benzyl ester + penoxsulam RM 48.8 g/ha PoE	110	110	210	212	5.84	5.93
XR-848 benzyl ester 31.25 g/ha PoE	101	101	190	191	5.04	5.15
Penoxsulam 25.6 g/ha PoE	101	102	191	200	5.08	5.12
Hand weeding twice at 20 and 40 DAS	113	113	212	215	6.14	6.21
Weedy check	92	94	174	175	3.80	3.82
LSD (p=0.05)	4.25	3. 32	6.25	5.42	0.34	0.29

sedges and total weed biomass. These results are in conformity with the findings of Yadav *et al.* (2007), Jabusch and Tjeerdema (2005), Jason *et al.* (2007), Mishra *et al.* (2007) and Nandal *et al.* (1999).

Effect on weed control efficiency (WCE)

Among different weed control treatments, higher weed control efficiency was recorded with XR-848 benzyl ester + penoxsulam (ready mix) 48.8 g/ha PoE and hand weeding twice at 20 and 40 DAS followed by XR-848 benzyl ester + penoxsulam (ready-mix) 40.6 g/ha PoE, XR-848 benzyl ester + penoxsulam (ready-mix) 32.5 g/ha PoE and penoxsulam 25.6 g/ha PoE (**Table 2**). The lowest weed control efficiency was noticed in weedy check due to significantly higher weed density and weed biomass accrued due to uncontrolled weed growth. These results were in conformity with the findings of Jabusch and Tjeerdema (2005) and Jason *et al.* (2007).

Effect on rice growth and grain yield

During both the years of study, hand weeding twice at 20 and 40 DAS recorded significantly higher rice grain yield (6.14 and 6.21 t/ha during 2016 and 2017, respectively) and which was at par with XR-848 benzyl ester + penoxsulam (ready-mix) 48.8 g/ha PoE (5.84 and 5.93 t/ha during 2016 and 2017, respectively) (**Table 3**). The higher rice yield with these treatments might be attributed to effective suppression of weeds and improved growth and yield attributes like higher plant height (110 and 109 cm in 2016 and 2017, respectively) and number of productive tillers/m^2 (210 and 212 in 2016 and 2017, respectively). The correlation studies indicated that, there was negative correlation between grain yield and total weed biomass at 30 DAS (r^2 = -0.970 and -0.965 during 2016 and 2017, respectively), 45 DAS (r^2 = -0.956 and -0.960 during 2016 and 2017, respectively) and at 60 DAS (r^2 = -0.947 and -0.946 during 2016 and 2017, respectively). Further, there was positive correlation between grain yield and number of productive tillers/m^2 (r^2 = 0.979 and 0.978 during 2016 and 2017, respectively) indicating decrement of grain yield with increase in weed biomass and enhancement of grain yield with increase in number of productive tillers/m^2 of rice plants. The regression equations also indicated that, quantum of rice grain yield decreased with each g/m^2 increase in weed biomass which was to the tune of

31.9 and 28.5 kg/ha at 30 DAS, 19.8 and 17.9 kg/ha at 45 DAS and 14.89 and 13.3 kg/ha at 60 DAS in 2016 and 2017, respectively. However, the regression equations revealed that with increase in tillers/m^2 would increase the grain yield of rice by 54.3 and 55.5 kg/ha in 2016 and 2017, respectively. These observations were in conformity with the findings of Yadhav *et al.* (2007), Ramesha *et al.* (2017).

Thus, post-emergence application of XR-848 benzyl ester 12.5 g/l + penoxsulam 20 g/l OD (w/v) (ready-mix) 48.8 g/ha was most effective treatment for the management of weeds and increasing yield in dry direct-seeded rice.

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RESEARCH ARTICLE

Effect of irrigation level and weed management practices on wheat growth, yield and economics

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ABSTRACT

An experiment was conducted at Sardarkrushinagar Dantiwada Agricultural University (SDAU), Sardarkrushinagar, Gujarat during two consecutive winter *(Rabi)* seasons of the years 2014-15 and 2015-16. The experiment consisted of twenty-one treatments with three levels of irrigation (0.6, 0.8, 1.0 IW:CPE ratio) as main plot treatments and seven weed management practices as sub-plot treatments. A split-plot design with three replications was used. The crop irrigated at 1.0 IW: CPE recorded significantly higher growth parameters, yield attributes, grain and straw yield. Among weed management practices, hand weeding twice and metsulfuron-methyl 4 g/ha at 28 DAS recorded significantly higher yield attributes, grain and straw yield. Interaction between irrigation levels and weed control practices revealed that wheat irrigated at 1.0 IW: CPE in combinations with two hands weeding or metsulfuron-methyl 4 g/ha and clodinafop + metsulfuron-methyl (ready-mix) 60 g/ha produced significantly higher grain yield than other treatments. The economic analysis revealed that irrigation at 1.0 IW:CPE ratio recorded significantly higher net returns of ₹ 66188/ha and B:C 2.11. Among weed management treatment, metsulfuron-methyl 4 g/ha) PoE attained maximum net income of ₹ 34036/ha with B: C 2.16 and next best was clodinafop + metsulfuron-methyl (ready-mix) 60 g/ha which fetched next highest net income (₹ 30843/ha) and B:C (2.01).

Keywords: Clodinafop-propargyl, Herbicides, Irrigation, Metsulfuron-methyl, Weed management, Wheat

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important staple food crops of India. The wheat is grown in India in 31.5 million ha and produced 107.6 million tons of wheat in 2019-2020 (GOI 2021), which is second highest in the world. The average productivity of wheat in India is 3.4 t/ha. The three main species of wheat, *viz*. *Triticum aestivum*, *Triticum durum* and *Triticum dicoccum* are cultivated in India, however, *Triticum aestivum* and *Triticum durum* are popularly grown in Gujarat. Water is one of the most important factors that are necessary for proper growth, balanced development and higher yields of all crops. Water deficiency affects plant growth and grain yield (Hussain *et al*. 2004). Irrigation management is one of the important managerial activities and effects the effective utilization of water by crop (Shirazi *et al.* 2014). In general, irrigation is being scheduled on the basis of the climatological approach (IW: CPE ratio) during the entire period of crop irrespective of the stage of growth. Proper scheduling of irrigation is necessary at both vegetative and reproductive phases to maintain the optimum moisture regime for better growth and development of the crop in the changing climatic scenario where abrupt variation in temperature takes place (Parihar and Tiwari 2003).

Besides irrigation, wheat crop is also negatively affected by biotic constraint such as weeds. Weeds not only compete with the crop plants for moisture and nutrients but also space and solar radiation. The wheat is mostly cultivated with irrigation in India in general and Gujarat in particular. The irrigated environment provides congenial conditions for weeds to proliferate and cause wheat yield reduction of 20 to 50% (Joshi 2002). Hence, managing weed is critical in attain higher productivity of crops with improved resources use efficiency, to meet the food and nutritional demand of increasing Indian population as well as increasing income of the farmers (Rao and Chauhan 2015). The hand weeding, normally practiced by farmers, is time-consuming and tedious and very costly due to the unavailability of labour in peak periods and high labour charges due to shifting of agricultural labours to industries for better and assured wages. Hence, the integrated weed management approach is advantageous because one technique rarely achieves complete and effective control of all weeds during crop season and even a relatively few surviving weeds can produce sufficient number of seeds to perpetuate the species (Walia *et*

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al. 1997). The recent studies on weed management showed that a single application of herbicide may not sufficient to control all weed flora present in field, but tank mix or sequential application of two or more herbicides may be needed to manage weeds effectively (Chand *et al.* 2004).

The water and weed management are critical to improve the wheat productivity, production and income of the farmers. Therefore, this study was conducted to understand the water-weed management relationship in field condition and identify suitable weed control methods and irrigation levels for optimal wheat production.

MATERIAL AND METHODS

The field experiment was laid out in Plot C-9 at the Agronomy Instructional Farm, Sardarkrushinagar Dantiwada Agricultural University (SDAU), Sardarkrushinagar, Gujarat during the winter *(Rabi)* seasons of the years 2014-15 and 2015-16. Geographically, Sardarkrushinagar is situated at 24°-19' North latitude and 72°-19' East longitude with an elevation of 154.52 m above the mean sea level. The climate of the region is sub-tropical with extreme cold winter, hot and dry windy summer. In general, monsoon is warm and moderately humid with an average annual rainfall of 638 mm received in about 26 rainy days. The winter season sets in the months of October and sets back in the month of February and remain fairly cold and dry. The minimum temperature of the year is observed in the month of December or January and considered as the coldest months of the year (**Figures 1** and **2**).

The experimental field has an even topography with a gentle slope having good drainage. The soil was loamy sand in texture, low in organic carbon (0.25%) and available nitrogen (158 kg/ha), medium in available phosphorus (37.5 kg/ha), and high in available potash (226 kg/ha). The experiment was conducted in split-plot design with 3 replications. Wheat variety *'GW 322'* was sown at 22.5 cm row spacing in the experiment. The experiment consisted of twenty one treatment combinations comprised three levels of irrigation (0.6,0.8,1.0 IW: CPE ratio) as main plot treatments and seven weed management practices: hand weeding twice at 20 and 40 days after sowing (DAS), pre-emergence application (PE), (on the next after seeding), of pendimethalin 1000 g/ha, post-emergence application (PoE), at 28 DAS, of metsulfuron-methyl 4.0 g/ha, clodinafop- propargyl 60 g/ha, sulfosulfuron 75% + metsulfuron-methyl 5% WG (ready-mix) 32 g/ha, clodinafop-propargyl 15% + metsulfuron-methyl 1% (ready-mix) 60 g/ha,

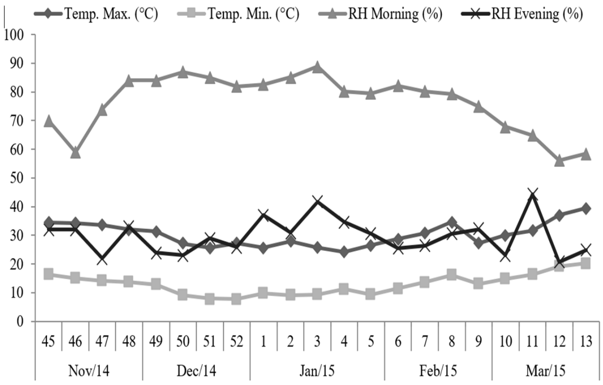

Figure 1. Mean weekly weather parameters recorded during crop growth period of 2014-15

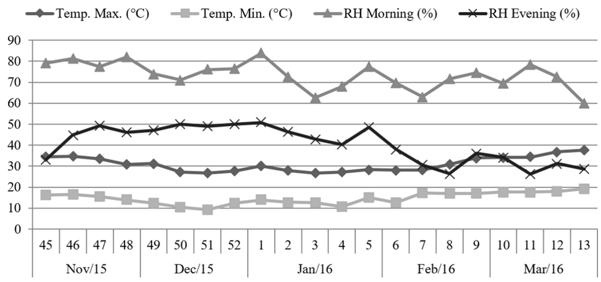

Figure 2. Mean weekly weather parameters recorded during crop growth period of 2015-16

weedy check as sub-plot treatments. The nitrogen 120 kg/ha was applied in 3 split (as urea). The phosphorus (P) (as single super phosphate) 60 kg P/ha and potash (K) (as muriate of potash) 30 kg/ha were applied as a basal dose for all the treatments. The sowing of wheat was done manually in dry moist soil, on 25th and 26th of November during the first and second year, respectively. Seeds were treated with fipronil 5% at 6 g/kg seed for termite and white grub control. Wheat was harvested during 21st March and 22nd March during the first and second year, respectively.

The cumulative pan evaporation values were calculated from daily pan evaporation measured with the help of USWB class 'A' open pan evaporimeter installed at the meteorological observatory, which was in the proximity of the experimental plot. The quantity of irrigation water applied in surface flooding was measured by a 7.5 cm head Parshall flume. A fixed depth of 50 mm irrigation water was applied to each treatment based on IW:CPE ratio of 0.6, 0.8 and 1.0. PE herbicide was sprayed next DAS (days after sowing) and PoE herbicides were sprayed on 28 DAS at spray volume of 500 l/ha. Spraying was done by manually operated knapsack sprayer. The weed biomass and crop data were collected as per standard procedures. The weed index was calculated by following the formula given by Gill and Kumar (1969). The weed control efficiency was calculated following the formula is given by (Mani *et al.* 1981).

The Benefit: Cost Ratio (B:C) is the ratio of gross realization to the total cost of cultivation that was calculated by using the following formula.

$$B:C = \frac{\text{Gross realization (₹/ha)}}{\text{The total cost of cultivation (₹/ha)}}$$

RESULTS AND DISCUSSION

Effect of irrigation levels

Growth attributes characters, *viz*. plant height, number of effective tiller/m^2, ear length and 1000-grains weight of wheat were significantly higher when irrigation scheduled at IW/CPE ratio of 1.0, over two irrigation schedules tried (**Table 1**). The highest grain (3.6 t/ha) and straw (4.8 t/ha) yields were recorded with the irrigations scheduled at the IW/CPE ratio of 1.0, which were significantly superior over rest of the irrigation schedules (**Table 1**). The remarkable increase in yields with higher levels of irrigation might be attributed to the favourable effect on yield attributes, *viz*. plant height, effective tillers, ear length, grain weight/ear, 1000-grains weight and grains/ear. Moreover, maintenance of adequate available soil moisture in the root zone would be conducive for proper uptake as well as utilization of nutrients, which has a variable impact on growth component and yield attributes for better yield. The positive linear response of wheat grain yield to irrigation has been reported by Bandyopadhyay and Mallick (2003), Parihar and Tiwari (2003), Singh *et al*. (2003) and Verma *et al*. (2011).

The economic evaluation of different levels of irrigation showed that gross and net returns increased with an increase in the level of irrigation (**Table 4**) with highest gross and net returns of ₹ 66188/ha and ₹ 34794/ha, respectively with 1.0 IW:CPE ratio. The B:C was also highest with the application of irrigation using 1.0 IW:CPE ratio.

Effect of weed management treatments

Among weed management practices, hand weeding twice at 20 and 40 DAS produced significantly higher effective tiller/m^2, ear length, grains/ear and grain weight/ear except plant height and 1000-grainsweight (**Table 1**) and it was on with metsulfuron-methyl 4 g/ha; clodinafop-propargyl 15% + metsulfuron-methyl 1% (ready-mix) 60 g/ha and sulfosulfuron 75% + metsulfuron-methyl 5% WG (ready-mix) 32 g/ha. The weed-free environment created by these treatments has minimized the weed-crop competition which led to better growth of the crop. The created weed-free environment also provided a better edaphic and nutritional environment in the wheat root zone. The results are in agreement with those reported by Bharat and Kachroo (2007), Chopra *et al*. (2008), Malik *et al*. (2008) and Bharat and Kachroo (2010).

The pooled data indicated that hand weeding twice at 20 and 40 DAS recorded significantly higher wheat grain (3.5 t/ha) and straw yield (4.7 t/ha) compared to other weed control practices except metsulfuron-methyl 4 g/ha. The increase in yields

Table 1. Wheat growth, yield attributes and yield as influenced by irrigation levels and weed management practices (pooled data of two year)

Treatment	Plant height (cm) at harvest	Effective tillers /m^2	Ear length (cm)	No. of grains/ ear	Grain weight per ear (g)	1000-grains weight (g)	Grain yield (t/ha)			Straw yield (t/ha)			Harvest Index (%)
							2014-15	2015-16	Pooled	2014-15	2015-16	Pooled	
Irrigation level													
I_1: 0.6 IW:CPE ratio	77.96	246.8	7.00	27.25	1.02	37.41	2.65	255	2.60	3.74	3.73	3.74	41.02
I_2: 0.8 IW:CPE ratio	83.27	263.2	7.81	28.67	1.08	37.74	2.97	2.29	2.94	4.11	3.98	4.04	41.97
I_3: 1.0 IW:CPE ratio	89.42	300.5	8.46	29.56	1.12	38.40	3.64	3.58	3.61	4.78	4.78	4.78	42.96
LSD (p=0.05)	5.01	17.2	0.49	1.021	0.04	0.46	0.27	0.35	0.18	0.46	1.49	0.28	NS
Weed management													
W_1: Hand weeding twice 20 and 40 DAS	84.52	310.0	8.09	29.58	1.12	38.14	3.55	3.47	3.51	4.73	4.64	4.68	42.77
W_2: Pendimethalin 1000 g/ha PE at next DAS	83.07	275.0	7.62	28.15	1.07	37.78	3.08	3.05	3.07	4.25	4.25	4.25	41.66
W_3: Metsulfuron-methyl 4 g/ha PoE at 28 DAS	84.47	306.5	8.00	29.34	1.11	38.02	3.48	3.41	3.44	4.65	4.59	4.62	42.66
W_4: Clodinafop-propargyl 60 g/ha applied at 28 DAS	82.43	203.1	7.50	27.30	1.02	37.64	2.44	2.32	2.38	3.43	3.39	3.41	41.14
W_5: Sulfosulfuron 75% + metsulfuron-methyl 5% WG 32 g/ha applied at 28 DAS	83.95	297.4	7.79	28.92	1.08	37.90	3.29	3.24	3.26	4.49	4.45	4.47	42.17
W_6: Clodinafop-propargyl 15% + metsulfuron-methyl 1% 60 g/ha applied at 28 DAS	84.20	300.3	7.89	29.06	1.10	37.93	3.36	3.29	3.33	4.55	4.47	4.51	42.37
W_7: Weedy check	82.21	199.1	7.41	27.10	1.01	37.54	240	2.29	2.34	3.37	3.34	3.35	41.10
LSD (p=0.05)	NS	15.2	0.44	1.07	0.04	NS	0.21	0.21	0.15	0.32	0.35	0.23	NS
Interaction													
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	0.26	NS	NS	NS	NS

DAS: Days after seeding; PE: Pre-emergence; PoE: Post-emergence

Table 2. Interaction effect of irrigation and weed management treatments (I × W) on wheat grain yield (pooled data of two year)

Irrigation levels (I)	Grain yield (t/ha)						
	Weed management treatments (W)						
	W_0	W_1	W_2	W_3	W_4	W_5	W_6
I_1	3.06	2.26	2.97	2.14	2.80	2.84	2.12
I_2	3.36	3.14	3.36	2.22	3.13	3.19	2.15
I_3	4.12	3.81	4.00	2.79	3.86	3.95	2.76
LSD (p=0.05)				0.26			

with these treatments may be attributed to the reduced in crop-weed competition due to broad-spectrum control of both broad and narrow leaf weeds and concomitant increase in nutrient availability to the crop plants resulting in a marked improvement in the crop yield attributes, *viz.* effective tillers, ear length, and grains weight/ear and yield. Those reported by Singh and Ali (2004), Malik *et al.* (2008), Bharat and Kachroo (2010), Bharat *et al.* (2012), Paighan *et al.* (2013), Singh (2013) and Padheriya *et al.* (2014). The lowest grain and straw yields were recorded with a weedy check treatment.

The weed biomass was significantly influenced by weed management treatments (**Table 3**). The highest weed biomass was recorded in weedy check, whereas hand weeding twice at 20 and 40 DAS recorded minimum (10.07 kg/ha). Among the herbicide, metsulfuron-methyl 4 g/ha measured lowest weed biomass (26.46 kg/ha) as per pooled data. The highest weed control efficiency (WCE) was obtained with hand weeding twice at 20 and 40 DAS whereas, in herbicides treatments, metsulfuron-methyl 4 g/ha applied at 28 DAS recorded maximum WCE (95.11%) followed by clodinafop-propargyl 15% + metsulfuron-methyl 1% (ready-mix) 60 g/ha and sulfosulfuron 75% + metsulfuron-methyl 5% WG (ready-mix) 32 g/ha. The weed index (WI) in different weed treatment, metsulfuron-methyl 4 g/ha applied at 28 DAS recorded lower value (2.00 %) as against 33.12% by weedy check. The clodinafop-propargyl 15% + metsulfuron-methyl 1% (ready-mix) 60 g/ha and sulfosulfuron 75% + metsulfuron-methyl 5% WG (ready-mix) 32 g/ha had recorded the second and third WI value than other treatments of this study.

Economics plays an important role in the adoption of effective weed management treatments by the farmers. Significantly higher net income (₹ 34036/ha) and B:C (2.16) were recorded by metsulfuron-methyl 4.0 g/ha followed by metsulfuron-methyl 4.0 g/ha and clodinafop-propargyl 15% + metsulfuron-methyl 1% (ready-mix) 60 g/ha with net income of ₹ 30843/ha and B:C of 2.01.

Table 3. Effect of weed management treatments on weed biomass, weed control efficiency and weed index in wheat

Weed management	Weed biomass (kg/ha) at harvest	Weed control efficiency (%)	Weed index (%)
Hand weeding twice 20 and 40 DAS	10.07	98.14	0.00
Pendimethalin 1000 g/ha PE	193.16	64.29	12.61
Metsulfuron-methyl 4 g/ha PoE at 28 DAS	26.46	95.11	2.00
Clodinafop-propargyl 60 g/ha at 28 DAS	421.44	22.09	32.05
Sulfosulfuron 75% + metsulfuron-methyl 5% WG 32 g/ha at 28 DAS	126.68	76.58	7.05
Clodinafop-propargyl 15% + metsulfuron-methyl 1% 60 g/ha at 28 DAS	100.92	81.34	5.31
Weedy check	540.94	0.00	33.12
LSD (p=0.05)	16.80	-	-

Table 4. The gross return, net returns and B:C ratio as influenced by irrigation levels and weed management treatments

Treatment	Cost of cultivation (x10^3 `/ha)	Gross returns (x10^3 `/ha)	Net returns (x10^3 `/ha)	B:C
Irrigation level				
0.6 IW:CPE ratio	29.19	47.91	18.72	1.64
0.8 IW:CPE ratio	30.29	53.95	23.65	1.78
1.0 IW:CPE ratio	31.39	66.19	34.79	2.11
LSD (p=0.05)	-	3.23	3.23	0.10
Weed management				
Hand weeding twice 20 and 40 DAS	34.28	64.42	30.14	1.87
Pendimethalin 1000 g/ha PE at next DAS	30.32	56.41	26.09	1.85
Metsulfuron-methyl 4 g/ha PoE at 28 DAS	29.12	63.15	34.04	2.16
Clodinafop-propargyl 60 g/ha applied at 28 DAS	29.84	43.89	14.05	1.47
Sulfosulfuron 75% + metsulfuron-methyl 5% WG 32 g/ha applied at 28 DAS	30.01	59.97	29.96	1.99
Clodinafop-propargyl 15% + metsulfuron-methyl 1% 60 g/ha applied at 28 DAS	30.22	61.06	30.84	2.01
Weedy check	28.28	43.20	14.92	1.52
LSD (p=0.05)	-	2.62	2.62	0.09

Selling price of grain and straw were ₹ 17.0/kg and ₹ 1.0/kg, respectively

Interactions

The treatment combination of 1.0 IW: CPE ratio with hand weeding twice recorded significantly higher grain yield of 4.12 t/ha (**Table 2**) and it was at par with the treatment combination of 1.0 IW: CPE ratio with metsulfuron-methyl 4.0 g/ha (grain yield of 4.0 t/ha) and 1.0 IW: CPE ratio with clodinafop-propargyl 15% + metsulfuron-methyl 1% (ready-mix) 60 g/ha (grain yield of 4.0 t/ha). This might be due to an increase in yield attributes. Hence the crop should be irrigated at 1.0 IW:CPE ratio and weed control be done using hand weeding twice at 20 and 40 DAS. These findings are in agreement with the results reported by Singh and Singh (2004) and Nadeem *et al.* (2007).

Conclusion

It was concluded that for getting higher wheat grain and straw yield, the crop should be irrigated at 1.0 IW: CPE ratio and should be kept free from weed competition by using hands weeding twice at 20 and 40 DAS or with the application of metsulfuron-methyl 4 g/ha or clodinafop-propargyl 15% + metsulfuron-methyl 1% 60 g/ha (ready-mix) at 28 DAS.

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RESEARCH ARTICLE

Effect of tillage and weed control measures on the yield and economic efficiency of maize under rainfed conditions of semi-arid region

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ABSTRACT

A field experiment was conducted for two years (2015 and 2016) to study the impact of tillage and weed management practices on weed control, grain yield and the economic efficiency of maize (*Zea mays* L.) in the semi-arid region of central India. The study was conducted in split-plot design with two tillage practices: conventional tillage (CT) and zero tillage (ZT), randomly allotted to main plots and four weed control treatments, *viz.* pre-emergence application (PE) of atrazine 1.0 kg/ha; post-emergence application (PoE) of 2, 4-D 0.75 kg/ha; hand weeding twice at 20 and 40 days after sowing (DAS) and weedy check, into subplots and replicated thrice. CT recorded significantly lowest weed density and biomass and highest maize grain yield (3.01 t/ha), net returns (₹ 29.77×10^3/ha) and maize production efficiency (28.07 kg/ha/day). Amongst weed control treatments the hand weeding twice at 20 and 40 DAS resulted in the lowest weed density and biomass and highest maize grain yield (3.17 t/ha) and production efficiency (29.64 kg/ha/day). However, atrazine 1.0 kg/ha PE has resulted in to the highest net returns (₹ 30.30×10^3/ha) and maize economic efficiency (₹ 283/ha/day). Thus, CT with hand weedings twice at 20 and 40 DAS and atrazine 1.0 kg/ha PE at 2 DAS proved better to improve weed control efficiency and attain higher maize grain yield, and economic efficiency.

Keywords: Economics, Maize, Production efficiency, Weed management, Zero tillage

INTRODUCTION

Maize (*Zea mays* L.) is one of the third most important cereal crop next to rice and wheat in global agriculture. Recently maize growing area is gradually increasing due to increasing demand from the poultry or livestock sector (37%) and other purposes coupled with the assured market price. Globally, maize is cultivated on an area of 193.7 mha with average productivity of 5.75 t/ha (FAOSTAT 2020, Halli *et al.* 2021). India has an area of 9.2 mha maize area with production of 27.8 Mt and average productivity of 2.97 t/ha (DACNET 2020). About 83% of the maize area is under rainfed conditions (*Kharif*) and experiences various biotic and abiotic stresses. Among biotic stresses, weed infestation is the major limitation causing an economic loss of approximately 25.3 to 60% in maize in addition to indirect losses such as competition for growth resources, harboring other crop pests, and interfering management practices (Gharde *et al.* 2018). However, crop management practices like tillage, planting methods, irrigation, and weed control practices were found to reasonably manage the weeds and iimprove the crop yield (Halli *et al.* 2021a,b).

Tillage is one of the important and primary operations being practiced in maize and provides favorable conditions for better crop growth and development. Tillage also improves soil physical, chemical, biological properties, and suppresses the weed growth which enables the crop to grow and yield well (Gathala *et al.* 2011). To increase the crop yield and soil health maintenance, adaptation of optimum tillage practices are necessary (Gangwar *et al.* 2006). It was also inferred from many studies that zero tillage (ZT) in combination with a surface crop residue improved the soil water balance by improving the water availability and other physical properties of the soil (Sommer *et al.* 2012). Though conservation agricultural (CA) practices are cost-effective and environmentally friendly, weeds are one of the key challenges. Therefore, evaluation of tillage practices from the point of weed management is necessary for maize to produce a higher grain yield.

During critical growth stages competition between crop-weed could reduced maize yield by over 30% (Ahmed *et al.* 2014). In India, manual hand weeding is an age-old method of weed control in

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most the cultivated crops. More than 50% of labor time is devoted to weeding and is mainly done by the family women and children (Tesfay *et al*. 2014). In this context, the present study was carried out to quantify the effect of tillage and herbicide treatments on weed control efficiency, grain yield, and the economics of maize.

MATERIALS AND METHODS

Experimental location, weather, and soil

The field trial was conducted during *Kharif* season of 2015 and 2016 at Central Research Farm, ICAR- Indian Grassland and Fodder Research Institute, Jhansi. The location is geographically situated at an altitude of 270 m above mean sea level on 25°27' N latitude and 78°33' E longitude. The region falls under Agro-climatic zone VIII Central Plateau and Hills region (Bundelkhand Agro-climatic Zone 6 of the Uttar Pradesh). The weather parameters recorded at the study site during the crop growth period indicated that mean weekly maximum temperature ranged from 31.7-37.3°C with an average of 34.7°C during 2015 and it ranged from 30.3-35.0°C with an average of 33.1°C during 2016. Likewise, the mean weekly minimum temperature for the corresponding period varied from 16.9-25.3°C (2015) and 16.3-26.5°C (2016). The total rainfall received during the cropping period was 466.0 mm in 2015 and 510.2 mm in 2016. The average evaporation rate recorded was 6.4 mm in 2015 and 5.5 mm in 2016 as measured by the USWB-class A pan.

The soil type of the experimental site was clay loam with the bulk density (1.26 Mg/m), particle density (2.37 Mg/m), pH (7.15), electrical conductivity (0.34 dS/m), organic carbon (0.52%), available nitrogen (230.98 kg/ha), available phosphorus (15.15 kg/ ha), and available potassium (137.83 kg/ha).

Experimental details and crop husbandry

The experiment was laid out in split-plot design, two tillage practices, *viz*. CT; conventional tillage (CT) and zero tillage (ZT) were randomly allotted to the main plot and four weed control treatments, *viz*. pre-emergence application (PE) of atrazine 1.0 kg/ha; post-emergence application (PoE) of 2,4-D 0.75 kg/ ha; hand weeding twice at 20 and 40 days after seeding (DAS) and weedy check were allotted to subplots with three replications. Single cross normal maize hybrid "*HM-11*" with medium and semi dent grain type (released by CCSHAU, Karnal, Haryana, 2009) was sown at 60 × 25 cm spacing. Sowing was done by using a zero tillage seed drill with a seed rate of 20 kg/ha. The recommended dose of fertilizer 150 kg N, 60 kg P, and 40 kg K/ha were applied using urea, single super phosphate, and muriate of potash. Fifty percent of N and 100% of P and K were applied as basal dose at the time of sowing and the remaining 50% N was applied in two equal splits at knee high and tasseling stage. As per the treatments, atrazine 1.0 kg/ha PE was applied at 2 DAS; and 2,4-D 0.75 kg/ha PoE was applied at 20 DAS. Herbicides were sprayed using a hand-operated knapsack sprayer fitted with a flat-fan nozzle, whereas, two hand weeding were performed manually at 20 and 40 DAS. The crop was grown under rainfed conditions, however, protective irrigations were applied during dry spells of monsoon.

Observations on weeds

Periodical weed measurements such as density and dry weight (biomass) were recorded at 30 and 60 DAS using the quadrat of 0.5 m^2 and grouped into grassy, broad-leaved, and sedges. To determine weed biomass, weeds were uprooted and shade dried followed by oven drying at 70°C for 72 hours to get the constant weight and then weighed. The weed control efficiency was calculated by using the following formulae,

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

Where, WCE: Weed control efficiency; DWC: Dry weight of weeds in control plot; DWT; Dry weight of weeds in the treated plot.

Observations on maize crop and economics

Measurements on maize plant height and dry matter accumulation were recorded at harvest. The crop was harvested after attaining physiological maturity and sufficient drying at the field. Later yield attributes such as test weight, the number of grains per cob, and final grain and stover yield were recorded from the twenty representative plants treatment-wise. The shelling percentage was computed by dividing the weight of the grain with the weight of the cob and multiplied by 100. Whereas, gross returns was calculated by considering the prevailing maize grain and stover prices and respective yield treatment wise, similarly net returns was calculated by subtracting the total cost of cultivation from gross returns. Further, maize production efficiency in terms of kg/ha/day was calculated by dividing maize grain yield by total crop duration.

Statistical analysis

Data on density and biomass of weeds were subjected to square-root transformation ($\sqrt{x+0.5}$)

before analysis of variance. Analysis of variance (ANOVA) was done to determine treatment effects by using SAS 9.3 program. The post-hoc mean separation was performed to test the significance at 5% level across all the variables using Tukey's honest test.

RESULTS AND DISCUSSION

Weed flora

Weed flora observed at different growth stages of the maize consisted of five species of grasses, *viz. Cynodon dactylon* (L.) Pers, *Dactyloctenium aegyptium* (L.) Beauv, *Digitaria sanguinalis* (L.) Scop, *Echinochloa colona* (L.) Link and *Echinochloa crus-galli* (L.) Beauv; fourteen species of broad-leaved weeds, *viz. Alternanthera polygonoides* (L.) R.Br., *Celosia argentea* Linn, *Commelina benghalensis* Linn, *Commelina diffusa* L., *Corchorus olitorius, Corchorus trilocularis, Digera arvensis, Euphorbia hirta, Leucas aspera* Link, *Phyllanthus niruri, Physalis minima* L., *Trianthema portulacastrum* L., *Trichodesma indicum and Tridax procumbens and* one sedge, *viz. Cyperus rotundus* L. Among the grasses, *Echinochloa colona* and *Echinochloa crus-galli* were predominant. *Celosia argentea* Linn, *Commelina diffusa* L., *Digera arvensis*, *Corchorus olitorius* and *Trianthema portulacastrum* L. were the major broad-leaved weeds. The favorable monsoon conditions might have promoted almost all weeds to germinate and emerge as reported by Kakade *et al.* (2020).

Weed density and biomass

Tillage practices influenced the weed density and biomass in maize at 30 and 60 DAS. The highest total weeds density (7.22 and 7.98/m^2) and weed biomass (3.53 and 4.67 g/m^2) at 30 and 60 DAS, respectively, were recorded with zero tillage. Whereas, conventional tillage practice recorded the lowest total weed density (5.86 and 6.69/m^2) and biomass (2.88 and 3.96/m^2) at 30 and 60 DAS respectively, in maize (**Table 1** and **2**). Among the weed control treatments, significantly lowest total weed density (3.16 and 3.98/m^2) and biomass (1.58 and 2.38 g/m^2) at 30 and 60 DAS were noticed with hand weeding twice at 20 and 40 DAS closely followed by atrazine 1.0 kg/ha PE (**Table 1** and **2**). Atrazine treatment controlled the grassy weeds more effectively, whereas 2.4-D was more effective against the broad-leaved weeds. These results on total weed density and biomass in *Kharif* maize under zero tillage are in agreement with the findings of Stanzen *et al.* (2016). The removal of weeds manually twice at 20 and 40 DAS through hand weeding directly prevented the weeds germination, growth and multiplication compared to the sole application of atrazine or 2,4-D. The later emerged weeds were not controlled in case of herbicides application. The lowest weed density and biomass with hand weeding twice was also reported by Mahajan *et al.* (2002), Jain *et al.* (2007), Singh *et al.* (2015), Stanzen *et al.* (2016) and Weber *et al.* (2017). Therefore, the combined practice of conventional tillage with hand

Table 1. Effect of tillage practices and weed control treatments on weed density in maize (pooled data of 2 years)

Treatment	Weed density (no./m^2)							
	Grassy		Broad-leaved		Sedges		Total	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Tillage practice								
Conventional tillage (CT)	4.07^b	4.92^b	3.48^a	3.75^a	2.49^b	2.70^b	5.86^b	6.69^b
Zero tillage (ZT	5.74^a	6.29^a	3.17^b	3.42^b	3.11^a	3.60^a	7.22^a	7.98^a
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Weed control treatment								
Atrazine 1.0 kg/ha PE at 2 DAS	2.79^c	3.48^c	2.49^b	2.88^b	1.69^c	2.04^c	4.05^c	4.89^c
2,4-D 0.75 kg/ha PoE at 20 DAS	4.10^b	4.91^b	2.15^c	2.37^c	2.64^b	2.89^b	5.29^b	6.12^b
Hand weeding twice at 20 and 40 DAS	2.34^d	3.10^d	1.69^d	1.92^d	1.41^d	1.75^d	3.16^d	3.98^d
Weedy check	10.40^a	10.95^a	6.98^a	7.17^a	5.46^a	5.93^a	13.65^a	14.37^a
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Interaction								
CT × Atrazine 1.0 kg/ha PE at 2 DAS	1.97^f	3.00^f	2.51^c	2.99^c	1.47^{fg}	1.89^e	3.42^f	4.55^e
CT × 2,4-D 0.75 kg/ha PoE at 20 DAS	3.11^e	4.16^d	2.33^c	2.46^d	2.43^d	2.31^d	4.49^d	5.27^d
CT × Hand weeding twice at 20 and 40 DAS	1.37^g	2.37^g	1.80^{de}	2.12^e	1.20^g	1.45^f	2.40^g	3.38^f
CT × Weedy check	9.83^b	10.17^b	7.29^a	7.44^a	4.84^b	5.17^b	13.13^b	13.59^b
ZT × Atrazine 1.0 kg/ha PE at 2 DAS	3.62^d	3.97^{de}	2.47^c	2.76^c	1.90^e	2.19^d	4.69^d	5.22^d
ZT × 2,4-D 0.75 kg/ha PoE at 20 DAS	5.08^c	5.66^c	1.96^d	2.28^{ef}	2.84^c	3.47^c	6.09^c	6.97^c
ZT × Hand weeding twice at 20 and 40 DAS	3.31^e	3.81^e	1.59^e	1.73^g	1.62^{ef}	2.06^{de}	3.91^e	4.58^e
ZT × Weedy check	10.96^a	11.73^a	6.68^b	6.90^b	6.08^a	6.68^a	14.17^a	15.15^a
LSD (p=0.05)	0.0004	0.0023	0.0147	0.0997	0.0007	<.0001	0.0064	<.0001

Values are transformed ($\sqrt{x+0.5}$), DAS; days after sowing. Means with the same letter within the column are not statistically different (p=0.05).

weeding twice at 20 and 40 DAS could effectively control the weeds emergence and subsequently emerged weed growth in maize.

Weed control efficiency (WCE)

Higher WCE (80.83%) was observed with conventional tillage compared to zero tillage which observed the minimum WCE (70.02%) (**Table 2**). Likewise, higher WCE (84.74%) was recorded with hand weeding twice at 20 and 40 DAS followed by atrazine 1.0 kg/ha PE (80.88%) and 2,4-D 0.75 kg/ha PoE (74.16%). Complete removal of the first flush of weeds at 20 DAS and subsequent flush at 40 DAS through hand weeding resulted in higher WCE due to effective control of weeds for a longer period resulting in low weed biomass. These results are in agreement with the findings of Parameshwari (2013) that better weed control was obtained under conventional tillage. Thus, the higher WCE could be achieved under conventional tillage practice with hand weeding twice at 20 and 40 DAS.

Maize growth and yield attributes

Tillage and weed control practices significantly influenced the growth attributes of maize. An increase in maize plant height (213.8 cm) and dry matter accumulation (140.2 g/pl) at harvest was recorded under conventional tillage over zero tillage. However, days to 50% flowering and days to maturity were not influenced by tillage and weed control measures (**Table 3**). The magnitude of increase in maize plant height and dry matter accumulation was maximum between 60 DAS and at harvest due to better weed control at early satges. The improved growth was also related to reduced weed intensity and pressure throughout the crop growth confirming the findings of Stanzen *et al*. (2016). Similarly, among weed control measures, maximum plant height (219.2 cm) and dry matter accumulation (143.3 g/pl) at harvest were recorded with hand weeding twice at 20 and 40 DAS followed by atrazine 1.0 kg/ha PE and 2,4-D 0.75 kg/ha PoE. The lowest maize plant height (186.5 cm) and dry matter accumulation (127.2 g/pl) at harvest were recorded in weedy check due to the associated highest weed density and biomass. The reduction in weed density and biomass, and robust root growth under hand weeding twice has increased the water and nutrient uptake of maize which led to the significant increase in growth attributes as observed by Rao *et al*. (2009) and Parameshwari (2013).

Tillage practices and weed control measures ultimately influenced the maize yield parameters (**Table 3**). The conventional tillage improved the grain yield (38.70%), stover yield (17.26%) and crude protein content (4.1%) of maize compared to zero tillage (**Table 3** and **4**). Similalrly, hand weeding twice at 20 and 40 DAS improved the maize yield attributes and recorded highest grain yield (22.16%), stover yield (34.4%), and crude protein content

Table 2. Weed biomass and weed control efficiency (WCE) as influenced by tillage practices and weed control treatments in maize (pooled data of 2 years)

Treatment	Weed biomass (g/m^2)								WCE (%) at 60 DAS
	Grassy		Broad- leaved		Sedges		Total		
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	
Tillage practice									
Conventional tillage (CT)	*2.30^{b}	3.00^{b}	1.90^{a}	2.27^{a}	0.75^{b}	1.63^{b}	2.88^{b}	3.96^{b}	80.83^{a}
Zero tillage (ZT	3.14^{a}	3.80^{a}	1.73^{b}	2.10^{b}	0.80^{a}	2.00^{a}	3.53^{a}	4.67^{a}	70.02^{b}
LSD (p=0.05)	<.0001	<.0001	0.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Weed control treatment									
Atrazine 1.0 kg/ha PE at 2 DAS	1.63^{c}	2.14^{c}	1.37^{b}	1.77^{b}	0.73^{c}	1.26^{c}	2.05^{c}	2.90^{c}	80.88^{b}
2,4-D 0.75 kg/ha PoE at 20 DAS	2.27^{b}	2.96^{b}	1.23^{c}	1.50^{c}	0.75^{b}	1.66^{b}	2.53^{b}	3.59^{b}	74.16^{c}
Hand weeding twice at 20 and 40 DAS	1.40^{d}	1.92^{d}	0.99^{d}	1.26^{d}	0.72^{d}	1.12^{d}	1.58^{d}	2.38^{d}	84.74^{a}
Weedy check	5.57^{a}	6.57^{a}	3.68^{a}	4.23^{a}	0.90^{a}	3.22^{a}	6.67^{a}	8.40^{a}	-
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Interaction									
CT × Atrazine 1.0 kg/ha PE at 2 DAS	1.23^{f}	1.87^{f}	1.41^{c}	1.83^{c}	0.72^{ef}	1.20^{e}	1.75^{f}	2.71^{e}	81.06^{b}
CT × 2,4-D 0.75 kg/ha PoE at 20 DAS	1.75^{e}	2.53^{d}	1.31^{c}	1.54^{d}	0.73^{de}	1.40^{d}	2.09^{e}	3.13^{d}	76.16^{c}
CT × Hand weeding twice at 20 and 40 DAS	0.97^{g}	1.52^{g}	1.00^{e}	1.36^{e}	0.72^{f}	1.00^{f}	1.20^{g}	2.05^{f}	85.27^{a}
CT × Weedy check	5.23^{b}	6.07^{b}	3.89^{a}	4.36^{a}	0.85^{b}	2.91^{b}	6.49^{b}	7.96^{b}	-
ZT × Atrazine 1.0 kg/ha PE at 2 DAS	2.03^{d}	2.42^{de}	1.34^{c}	1.70^{c}	0.74^{d}	1.31^{de}	2.34^{d}	3.08^{d}	80.71^{b}
ZT × 2,4-D 0.75 kg/ha PoE at 20 DAS	2.79^{c}	3.40^{c}	1.16^{d}	1.45^{de}	0.78^{c}	1.93^{c}	2.97^{c}	4.05^{c}	72.15^{d}
ZT × Hand weeding twice at 20 and 40 DAS	1.83^{e}	2.32^{e}	0.98^{e}	1.17^{f}	0.72^{ef}	1.25^{e}	1.96^{e}	2.72^{e}	84.20^{a}
ZT × Weedy check	5.91^{a}	7.07^{a}	3.47^{b}	4.09^{b}	0.95^{a}	3.52^{a}	6.85^{a}	8.84^{a}	-
LSD (p=0.05)	0.0286	0.0084	0.0049	0.3310	<.0001	<.0001	0.0001	<.0001	0.0010

*Values are transformed ($\sqrt{x+0.5}$), Means with the same letter within the column are not statistically different (p=0.05).

(4.18%) over control. Maximum grain and stover yield might be due to less crop-weed competition because of vigorous crop growth and greater dry matter accumulation. The favorable soil physical condition due to optimum tillage practices promoted the root growth and enhanced the uptake of water and nutrients. This might be attributed to efficient partitioning of metabolites and translocation of photosynthates towards sink, which translated into increased yield attributes and grain yield as reported by Parameshwari (2013), Triveni *et al.* (2017). Hence, practicing conventional tillage and hand weedings twice at 20 and 40 DAS produced higher grain yield of maize by controlling the weeds and favouring the crop growth.

Table 3. Effect of tillage practices and weed control treatments on growth and yield attributes of maize (pooled data of 2 years)

Treatment	Plant height (cm) at harvest	Dry matter (g/pl) at harvest	Days to 50% silking	Days to maturity	No. of grains/ cob	100 grain weight (g)	Shelling (%)	Crude protein content (%)
Tillage practice								
Conventional tillage (CT)	213.8[a]	140.2[a]	65.54[a]	102.79[a]	337.92[a]	26.40[a]	77.79[a]	9.93[a]
Zero tillage (ZT	195.5[b]	128.6[b]	67.19[a]	105.23[a]	310.09[b]	22.61[b]	73.32[b]	9.54[b]
LSD (p=0.05)	<.0001	<.0001	NS	NS	<.0001	<.0001	<.0001	0.046
Weed control treatment								
Atrazine 1.0 kg/ha PE at 2 DAS	212.2[b]	135.7[b]	66.08[a]	103.29[ab]	340.01[b]	24.80[b]	76.84[b]	9.81[a]
2,4-D 0.75 kg/ha PoE at 20 DAS	200.8[c]	131.1[c]	66.67[a]	104.33[ab]	315.97[c]	23.16[c]	73.94[c]	9.63[a]
Hand weeding twice at 20 and 40 DAS	219.2[a]	143.3[a]	65.83[a]	102.25[b]	349.11[a]	27.88[a]	80.01[a]	9.95[a]
Weedy check	186.5[d]	127.2[d]	66.88[a]	106.17[a]	290.92[d]	22.18[d]	71.42[d]	9.55[a]
LSD (p=0.05)	<.0001	<.0001	NS	NS	<.0001	<.0001	<.0001	NS
Interaction								
CT × Atrazine 1.0 kg/ha PE at 2 DAS	225.0[a]	141.5[b]	65.00[a]	102.83[b]	351.50[b]	26.43[b]	78.38[b]	9.96[ab]
CT × 2,4-D 0.75 kg/ha PoE at 20 DAS	207.5[b]	135.8[c]	66.00[a]	103.17[b]	322.89[d]	24.07[c]	76.21[cd]	9.85[ab]
CT × Hand weeding twice at 20 and 40 DAS	226.8[a]	150.1[a]	65.00[a]	101.33[b]	362.44[a]	31.72[a]	81.96[a]	10.17[a]
CT × Weedy check	196.1[cd]	133.6[cd]	66.17[a]	103.83[ab]	314.83[e]	23.40[c]	74.59[d]	9.75[ab]
ZT × Atrazine 1.0 kg/ha PE at 2 DAS	199.3[c]	130.4[d]	67.17[a]	103.75[ab]	328.53[d]	23.17[c]	75.30[d]	9.67[ab]
ZT × 2,4-D 0.75 kg/ha PoE at 20 DAS	194.1[d]	126.3[e]	67.33[a]	105.50[ab]	309.05[e]	22.26[cd]	71.67[e]	9.42[ab]
ZT × Hand weeding twice at 20 and 40 DAS	211.6[b]	136.7[c]	66.67[a]	103.17[b]	335.78[c]	24.05[c]	78.06[bc]	9.73[ab]
ZT × Weedy check	176.9[e]	120.8[f]	67.58[a]	108.50[a]	267.00[f]	20.96[d]	68.25[f]	9.35[b]
LSD (p=0.05)	0.002	0.486	NS	NS	351.50[b]	0.002	0.179	NS

Values are transformed ($\sqrt{x+0.5}$), Means with the same letter within the column are not statistically different (p=0.05)

Table 4. Effect of tillage practices and weed control treatments on grain and stover yield of maize

Treatment	Yield (t/ha)					
	Grain			Stover		
	2015	2016	Pooled	2015	2016	Pooled
Tillage practice						
Conventional tillage (CT)	2.86[a]	3.16[a]	3.01[a]	6.37[a]	6.68[a]	6.52[a]
Zero tillage (ZT)	2.13[b]	2.22[b]	2.17[b]	5.49[b]	5.63[b]	5.56[b]
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Weed control treatment						
Atrazine 1.0 kg/ha PE at 2 DAS	2.74[b]	3.01[b]	2.87[b]	6.10[b]	6.50[b]	6.30[b]
2,4-D 0.75 kg/ha PoE at 20 DAS	2.27[c]	2.46[c]	2.37[c]	5.64[c]	5.78[c]	5.71[c]
Hand weeding twice at 20 and 40 DAS	3.04[a]	3.31[a]	3.17[a]	6.80[a]	7.12[a]	6.96[a]
Weedy check	1.92[d]	1.96[d]	1.94[d]	5.16[d]	5.20[d]	5.18[d]
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Interaction						
CT × Atrazine 1.0 kg/ha PE at 2 DAS	3.24[b]	3.68[b]	3.46[b]	6.60[b]	7.10[b]	6.85[b]
CT × 2,4-D 0.75 kg/ha PoE at 20 DAS	2.54[c]	2.83[c]	2.69[c]	5.84[c]	6.04[c]	5.94[c]
CT × Hand weeding twice at 20 and 40 DAS	3.58[a]	4.03[a]	3.80[a]	7.76[a]	8.26[a]	8.01[a]
CT × Weedy check	2.06[e]	2.09[f]	2.08[f]	5.27[ef]	5.32[ed]	5.29[f]
ZT × Atrazine 1.0 kg/ha PE at 2 DAS	2.24[d]	2.34[e]	2.29[e]	5.60[d]	5.89[c]	5.75[d]
ZT × 2,4-D 0.75 kg/ha PoE at 20 DAS	2.00[e]	2.10[f]	2.05[f]	5.44[ed]	5.53[d]	5.49[e]
ZT × Hand weeding twice at 20 and 40 DAS	2.50[c]	2.59[d]	2.55[d]	5.85[c]	5.99[c]	5.92[d]
ZT × Weedy check	1.78[f]	1.83[g]	1.81[g]	5.06[f]	5.09[e]	5.07[g]
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Means with the same letter within the column are not statistically different (p=0.05)

Economics and maize production efficiency

Different management practices such as tillage and weed control treatments influenced the cost of production and economic returns. Significantly highest gross returns (₹ 64.61×10³/ha), net returns (₹ 29.77×10³/ha), and benefit-cost ratio (1.84) were recorded with conventional tillage. Despite the higher cost of cultivation (₹ 34.84×10³/ha) due to repeated tillage operations and fuel prices conventional tillage still maintained the higher returns, mainly due to higher grain and stover yield of maize over zero tillage (**Table 4** and **5**). Thus, this practice witnessed the highest production efficiency (28.07 kg/ha/day) and economic efficiency (₹ 278.2/ha/day). In contrast, the lower cost of cultivation (₹ 30.73×10³/ha), net returns (₹ 18.47×10³/ha), and economic efficiency (₹ 172.6/ha/day) were recorded under zero tillage. This was mainly due to poor returns over investment due to increased weed competition and decreased maize grain and stover yield under zero tillage. Similarly, among weed control treatments, hand weeding twice at 20 and 40 DAS recorded the higher cost of cultivation (₹ 39.12×10³/ha), gross returns (₹ 68.46×10³/ha), and production efficiency (29.64 kg/ha/day). Interestingly, pre-emergence application of atrazine 1.0 kg/ha registered the highest net returns (₹ 30.30×10³/ha), benefit cost ratio (1.94), and economic efficiency (₹ 283.0/ha/day) compared to hand weeding twice at 20 and 40 DAS. The higher benefit cost ratio was due to the lower cost of weed control in maize with the application of atrazine. Previous authors reported highest net returns, benefit cost ratio, and economic efficiency in maize were attained with the pre-emergence application of herbicides; saflufenacil 68 g/l + diamethanamid-p 600 g/l (Yadav *et al.* 2018). Thus, adoption of conventional tillage plus the application of atrazine 1.0 kg/ha as pre-emergence could be economical option due to reduced cost on weed management.

It was concluded that conventional tillage plus hand weeding twice at 20 and 40 DAS produced significantly higher grain yield (3.80 t/ha) and stover yield (8.01 t/ha) yield in maize due to improved weed control efficiency resulting into lower weed growth and better crop growth and yield attributes. However, pre-emergence application of atrazine 1.0 kg/ha at 2 DAS as under conventional tillage was found to be an alternate and economically efficient weed management practice with higher grain yield of maize under semi-arid conditions of central India as the cost and availability of labor also play an important role in deciding choice of weed control practices.

Table 5. Economics and production efficiency of maize cultivation in response to tillage practices and weed control treatments (pooled data of 2 years)

Treatment	Cost of cultivation (x10³ ₹/ha)	Gross returns (x10³ ₹/ha)	Net returns (x10³ ₹/ha)	Benefit-cost ratio	Production efficiency (kg/ha/day)	Economic efficiency (₹/ha/day)
Tillage practices						
Conventional tillage (CT)	34.84[a]	64.61[a]	29.77[a]	1.84[a]	28.07[a]	278.17[a]
Zero tillage (ZT	30.73[b]	49.20[b]	18.47[b]	1.61[b]	20.27[b]	172.58[b]
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Weed control treatment						
Atrazine 1.0 kg/ha PE at 2 DAS	31.64[b]	61.94[b]	30.30[a]	1.94[a]	26.82[b]	283.00[a]
2,4-D 0.75 kg/ha PoE at 20 DAS	30.84[c]	52.63[c]	21.79[c]	1.70[c]	22.12[c]	203.67[c]
Hand weeding twice at 20 and 40 DAS	39.12[a]	68.46[a]	29.34[b]	1.74[b]	29.64[a]	274.25[b]
Weedy check	29.55[d]	44.59[d]	15.04[d]	1.51[d]	18.10[d]	140.58[d]
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Interaction						
CT × Atrazine 1.0 kg/ha PE at 2 DAS	33.91[c]	72.41[b]	38.50[b]	2.14[a]	32.31[b]	359.67[b]
CT × 2,4-D 0.75 kg/ha PoE at 20 DAS	32.71[d]	58.06[c]	25.34[c]	1.77[c]	25.08[c]	236.67[c]
CT × Hand weeding twice at 20 and 40 DAS	41.52[a]	81.02[a]	39.49[a]	1.95[b]	35.52[a]	369.17[a]
CT × Weedy check	31.23[e]	46.97[f]	15.74[g]	1.50[e]	19.38[f]	147.17[g]
ZT × Atrazine 1.0 kg/ha PE at 2 DAS	29.38[f]	51.48[e]	22.09[d]	1.75[c]	21.33[e]	206.33[d]
ZT × 2,4-D 0.75 kg/ha PoE at 20 DAS	28.97[g]	47.21[f]	18.24[f]	1.63[d]	19.16[f]	170.67[f]
ZT × Hand weeding twice at 20 and 40 DAS	36.72[b]	55.91[d]	19.19[e]	1.52[e]	23.77[d]	179.33[e]
ZT × Weedy check	27.86[h]	42.21[g]	14.35[h]	1.52[e]	16.82[g]	134.00[h]
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Means with the same letter within the column are not statistically different ($p < 0.05$). The prevailing price of maize grain and stover were ₹ 1500 and 300 per quintal, respectively.

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RESEARCH ARTICLE

Enhanced biological control of Parthenium by release of female dominated sex ratio population of *Zygogramma bicolorata* Pallister

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ABSTRACT

Parthenium hysterophorus L. (Asteraceae) is a major weed in both cropped and non-crooped areas of India and many other countries. Considering the magnitude of problems caused by *P. hysterophorus*, its management is essential to prevent future complications. Leaf-feeding beetle *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae) has been proved as the most promising biocontrol agent of Parthenium in India and other countries. In the present study, sex ratio and sexual dimorphism of *Z. bicolorata* was studied using field samples collected during September month of 2013 to 2015 from different sites at Jabalpur (Madhya Pradesh, India). The male and female average sex ratio was observed as 1:1.50, 1:1.61 and 1:1.46 in 2013, 2014 and 2015, respectively. Sex ratio was significantly deviated towards the female. Females were distinctly larger and heavier in body size and abdominal width than the males. Further, experiments were conducted during rainy season of 2015 and 2016 to find out the effect of female dominated sex ratio, body weight and size by releasing of 7500 beetles/ha in two sex ratio *viz*. 1: 1 and 1: 1.60. Significant difference was recorded amongst these two sex ratios on density, height of plants, dry weight and number of flowers in Parthenium weed at 30 and 60 days after release of bioagent. Significantly higher effect of female dominated sex ratio (1:1.60) release was found in suppression of Parthenium. Therefore, for better and assured control, female dominated releases were recommended under biological control programme of Parthenium.

Keywords: Biological control**,** Biocontrol efficiency, Body weight, Body size, Sex ratio, Sexual dimorphism, Parthenium, *Zygogramma bicolorata*

INTRODUCTION

India has become one of the most Parthenium affected country in the world where about 35 million hectares of land is estimated to be affected by Parthenium (Sushilkumar and Varsheny 2010). *Zygogramma bicolorata* Pallister (Coleoptera: Chrysomelidae), a native of Mexico is a proven biological control agent of Parthenium in Australia **(**McFadyen 1992, Dhileepan 2003, Adkin *et al.* 2014) and India (Sushilkumar 2009, 2014). The bioagent has been released in various parts of the world suffering from Parthenium (Dhileepan and Senaratne 2009, Adkins and Shabbir 2014) invasion including India (Sushilkumar 2014).

The sexual dimorphism refers to differences between females and males of a species in terms of behavior, size and appearance. Male and female size affects production of progeny (Emlen and Oring 1977) and also influence mating behavior of insect species (Keller *et al.* 2011). Small size males may be more vulnerable to pressures than larger females while larger females are supposed to produce more eggs having more survival efficacy (Dhiman and Bhargava 2005, Pawar *et al.* 2015).

Sex ratio is one of the most important factors for insect biocontrol agent population establishment and subsequent impact on host in the natural environment where population is increased and established under abiotic and biotic factors (Omkar *et al*. 2013, Hopwood *et al*. 2016). Sex ratio affects population density and dynamics and future predictions for population establishment in natural conditions (Benowitz *et al*. 2013, Lachowsky and Reid 2014, Smith and Belk 2018). Hasan and Ansari (2016) reported that the proportion of male in a mixed population of adults showed greater numbers of female occurrence in future progeny. Sex ratio plays a significant role for species survival in any bisexually breeding population apart from biotic and abiotic factors. Knowledge on sex ratio of a weed bioagent species may help to understand its competence to bring destruction of a weed in a biological control program. Population dynamics is dependent on sex-ratio which influence population growth rates in response to the conditions **(**Southwood and Henderson 2000) and also helpful to

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understand growth and survival of an insect population (Wittmeyer and Coudron 2001).

The research work on *Z. bicolorata* focused, till to date, mainly on its occurrence, spread, and general biology including sex ratio and reproductive behavior besides general effect on Parthenium management after release of the bioagent (Jayanth and Visalakshy 1994, Sushilkumar 2009, Dhileepan *et al*. 2000). But, quantitative data is unavailable on its sex ratio through big size sample collection from fields and impact of release of different sex-ratio population in suppression of Parthenium in context to different biological parameters. In this study, our aim was to quantify the dominance of sex and impact of release of different sex ratio population on their efficiency in the management of Parthenium under the biological control program.

MATERIALS AND METHODS

Collection of beetles

The study was carried out during 2013 to 2015 at ICAR-Directorate of Weed Research (DWR), Jabalpur (Madhya Pradesh). The center is located between 22.49 and 24.8 North latitude, 78.21 and 80.58 East longitude and at an altitude of 412 meters above the mean sea level. Jabalpur comes under the agro-climatic region of Kymore plateau and Satpura hills and lies in the rice-wheat crop zone of the state. The climate of Jabalpur region is typically sub-humid and sub-tropical. Adult beetles were collected by hand from 10 different locations of Jabalpur in the first week of September (most active period of beetle) each year and were brought to the laboratory. Collected *Z. bicolorata* beetles were kept in the laboratory in wire mesh cages with window arrangement to enable us to catch the paired beetles from inside. The fresh Parthenium twigs with leaves were provided for food and perching.

Sex ratio study

In the laboratory, paired beetles in copulation were picked up from cages and sexes were separated as male and female by marking the male mounted over female. Left beetles which were not found paired were identified based on last abdominal sternite as described by McClay (1980). The males and females from different sites in different years were counted and the percentage of male and female were calculated. Sex ratio was analyzed as the proportion of offspring that are males and calculated according to Wilson & Hardy (2002) with the help of formula given below:

Sex ratio = ♂♂/(♀♀ + ♂♂)

Sexual dimorphism

A biometric study for sexual dimorphism was made for 50 individuals of each sex collected during 2015. The body parts namely, antennal length, total body length from head to end of abdomen with elytra, maximum width of abdomen with elytra and head-width with eyes were measured under the binocular microscope (Leica make, model No.WILD M3Z).

Weight and moisture content estimation

For body weight and moisture content study, freshly collected adults after anesthetizing were weighted individually (30 for each sex) in electronic balance (Danwer Scales (India) Pvt. Ltd., Model-Dw302) for fresh net weight. After taking fresh weight, these were dried in vacuum oven at 60 ^{0}C and weighted for dry weight and thus calculated moisture content.

Biocontrol efficiency of bioagent *Z. bicolorata* under equal and female dominated ratio release

The seeds of Parthenium weed, collected during March-April 2015 and 2016, were sown on 20 June 2015 and 15 June 2016, respectively by broadcasting method in three plots each having an area of 0.21 hectare at a distance of about 500 meters from each other. Bioagent *Z. bicolorata* was released in male female ratio of 1:1 and 1:1.6 at the rate of 7500 beetle per hectare in each plot in each year after 30 days of sowing when Parthenium weed grew up to an average of 15±1.30 cm size. The same size area was left untreated (control) at the distance of 500 meter from the treated area. To nullify the effect of stray bioagent in untreated area, spray of insecticide imidacloprid 2 ml/l was done at monthly interval. Density of Parthenium was taken at randomly from 20 places from each bioagent released plots and control plots with the help of 1 m^2 iron quadrat at 60- and 90-days interval after sowing of Parthenium (30 and 60 days after release of beetle). From each quadrat, one plant was sampled at random for total no. of eggs, grubs and adults, height of plants, flowers per plant and dry weight (biomass). Impact of beetles on Parthenium was calculated in terms of reduction in plant density, height, number of flowers and dry weight. Bioagent control efficiency was calculated as per formulae given below:

$$\text{Biocontrol efficiency} = \frac{\text{Dry weight of control plot} - \text{Dry weight of treated plot}}{\text{Dry weight of control plot}} \times 100$$

Statistical analysis

Equality of error variances were checked using F-test for two sample means. Three factor asymmetrical design was adopted to analyze data on the number of male and female in different years observed in 10 sites. These were subjected to ANOVA for comparing means using least significant difference (LSD) value. Statistical analysis was done using SAS 9.3 (SAS Institute *Inc*., USA). Chi square test was applied to the data of male and female count to check whether beetle population carries the male and female proportion in the ratio of 50:50.

RESULTS AND DISCUSSION

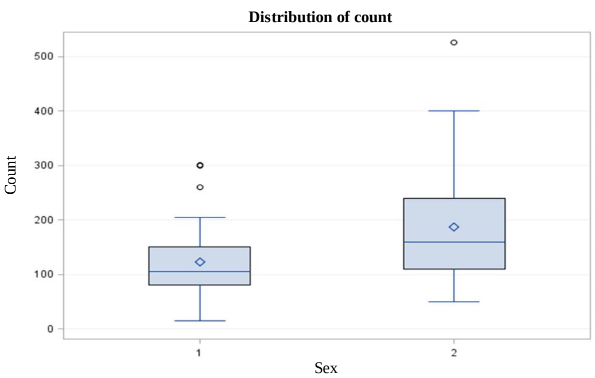
A total of 9296 adult beetles were captured, comprising 2140, 2485 and 4671 during 1st week of September of 2013, 2014 and 2015, respectively from 10 fixed sites at different locations of Jabalpur in each year.

Sex ratio

Sex-ratio was obtained as the proportion of male beetles to the total beetles. A highly significant difference was found between number of males and females. The observations on distribution of male and female population in three years indicated that in all places/sites, female population dominated irrespective of the years (F=10.22; df=1, 54; P=0.01) (**Figure 1**). Hasan and Ansari (2016) also found that the female population was significantly higher over the male population in each month of years in their study.

Male and female *Z. bicolorata* beetles frequencies in different years as well as in different sites have been given in **Table 1** along with their chi-square values and significance level.

The average male and female populations of three years were 120.7 and 182.7, respectively. The percentage of sex ratio varied with each sample. There was male dominance only at sites No. 3 and 4 during 2013; site No. 1, 2 and 3 during 2014 and site no. 9 during 2015, but pooled averaged data revealed the significant dominance of females (chi-square $\div^2$ = 7.9, 13.8, 16.7 (for 2013, 2014, 2015 respectively); df = 1; P=0.01). The level of sex ratio in *Z. bicolorata* varied significantly between years. Results **(Figure 1)** showed that sex ratio (proportion of male) was also greatly influenced each year ($p < 0.05$). Female population was significantly superior over the male population in all the studied years and sex ratio variation was statistically significant.



1-male, 2-female (F=10.22; df=1, 54; p=0.01)

Figure 1. The *Z. bicolorata* male and female population average distribution across three years

Sexual dimorphism and correlation of *Z. bicolorata* body parts

Total average length of male and female *Z. bicolorata* beetles was 5.46±0.50 and 6.48±0.50 mm, respectively. Simultaneously, average abdomen width of male and female beetles was 2.74 ± 0.44 and 3.66 ± 0.47 mm, respectively. Females were distinctly

Table 1. The variation in male and female population of *Z. bicolorata* across different samples and years

Sample no.	Year	*Z. bicolorata* population				Chi-square value with 1 d.f.	Significance level
		Male	Female	Total	Male: Female ratio		
1	2013	80	90	170	1:1.13	0.59	NS
	2014	130	120	250	1:0.92	0.40	NS
	2015	200	286	486	1:1.43	15.2	**
2	2013	110	160	270	1:1.45	9.3	**
	2014	110	60	170	1:0.55	14.7	**
	2015	58	160	218	1:2.76	47.7	**
3	2013	101	80	181	1:0.79	2.4	NS
	2014	120	80	200	1:67	8.0	**
	2015	301	526	827	1:1.75	61.2	**
4	2013	68	50	118	1:0.74	2.7	NS
	2014	100	110	210	1:1.10	0.5	NS
	2015	165	250	415	1:1.52	17.4	**
5	2013	130	225	355	1:1.73	25.4	**
	2014	100	400	500	1:4.00	180.0	**
	2015	300	380	680	1:1.27	9.4	**
6	2013	55	166	221	1:3.02	55.8	**
	2014	100	200	300	1:2.0	33.3	**
	2015	80	185	265	1:2.31	41.6	**
7	2013	20	135	155	1:6.75	85.3	**
	2014	15	95	110	1:6.33	58.2	**
	2015	200	345	545	1:1.73	38.6	**
8	2013	150	170	320	1:1.13	1.3	NS
	2014	50	130	180	1:2.60	35.6	**
	2015	125	145	270	1:1.16	1.5	NS
9	2013	85	110	195	1:1.29	3.2	NS
	2014	125	180	305	1:1.44	9.9	**
	2015	260	240	500	1:0.92	0.8	NS
10	2013	55	100	155	1:1.82	13.1	**
	2014	100	160	260	1:1.60	13.8	**
	2015	205	260	465	1:1.27	6.5	*
Mean	2013	77.64	116.90	467.1	1:1.51	7.9	**
	2014	95	153.5	248.5	1:1.61	13.8	**
	2015	189.4	277.7	467.1	1:1.47	16.7	**

* and ** denote the significant values at 5% and 1% level of significance, respectively

larger both in body size and abdominal width. Average antennal length and head width of male and female beetles were 2.58± 0.49, 2.50 ± 0.50 and 2.68 ± 0.47, 2.68 ± 0.47 mm, respectively. Adult beetles' body parts were correlated with head, antenna, abdomen and body length. The width of head and abdomen also increased with length of antenna and body length. Females were distinctly larger both in body-size and abdominal width while antenna was not significantly different in length but female head was larger than male **(Figure 2).** No significant difference was found between the number of antennal segments of male and female beetles of *Z. bicolorata*. The posterior margin of the female was entirely blunt, while it was slightly serrated at the tip in case of male.

Average fresh weight of male and female *Z. bicolorata* beetles was recorded 2.19±0.08 and 2.89±0.02 mg/beetle and dry weight as 1.29 ±0.20 and 1.82± 0.12 mg/beetle, respectively. Average percentage of moisture content of male and females was 58.9±10.0 and 63.2± 4.19, respectively (**Figure 3**). There was considerable variation in the wet and dry weights of *Z. bicolorata*. The females were distinctly heavier than the males (p<0.001) both in wet and dry weights and moisture content (p<0.001).

The density, biomass and flower production of Parthenium at 30 and 60 days after release of *Z. bicolorata* adult population in different male and female ratio

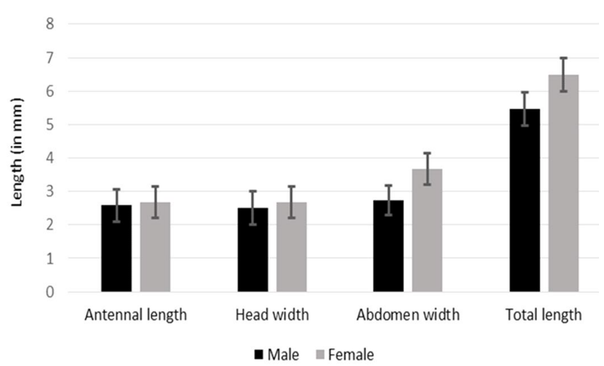
Two treatments with *Z. bicolorata* beetles and without beetles were compared in two different time intervals at 30 and 60 days after release (DAR) of bioagent and with different ratios (1:1 and 1:1.6). Initially at 60 DAR, beetle in 1:1 ratio could able to reduce the Parthenium density, biomass and plant height significantly as compared with the control plots, where beetles were not released (= 38.86, 25.42, 18.25, 53.26 for density, dry weight, plant height and flowers, respectively df = 38; p=0.01) **(Table 2)** while on the other hand, beetles in 1:1 ratio were unable to reduce these parameters in the Parthenium plants at 30 DAR. The beetles released in male: female ratio of 1:1.6 reduced the plant height and biomass significantly, but did not reduce the Parthenium flowers number significantly at 30 DAR, but at 60 DAR, they immensely reduced the Parthenium density, biomass, height and number of flowers (t = 16.79, 18.13, 11.96, 32.31 for density, dry weight, plant height and flowers, respectively; df = 38; p=0.01).

Interaction was also significant at 5% level of significance. It can be seen that beetles in 1:1.60 ratio reduced the density, dry weight, height and flower of Parthenium significantly at both 30 and 60 DAS. Greatest reduction in these parameters were obtained at 60 DAS with 1:1.60 ratio (**Table 3**).

Effect on Parthenium flower production

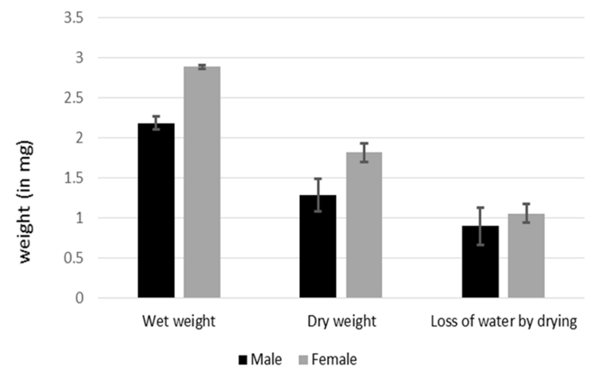
The 1:1.6 male: female ratio of *Z. bicolorata* beetles gave good control of Parthenium with the progress in time, leaving very few flowers to produce seeds and subsequently caused complete damage to plants **(Figure 4)**. Thus, under females dominated ratio (1:1.6) in a defined area, greater suppression of Parthenium weed occurred compared to the 1:1 ratio of male and female. Release of the adult population in 1:1.6 ratio, reduced the flowers at 30 DAR to the extent, which was reduced by release of 1:1 ratio at 60 DAR. Same pattern was also followed in the case of density and biomass of Parthenium.

Analysis revealed significant difference between heights of the plants at 30 and 60 days after release in treated plots (F =126.9; df =1, 76; P=0.0001) with mean values as 44.6 and 34.35 cm, respectively in 1:1 and 1:1.60 ratio of male and female at the rate of 7500 beetles/ha and also showed significant difference on the height of the plants (F=



Error bars shows the standard deviation of the data

Figure 2. Sexual dimorphism between male and female of *Z. bicolorata* beetle



Error bars are the standard deviation among the data points

Figure 3. Variation in weight and moisture content between male and female *Z. bicolorata*

Table 2. Effect of *Z. bicolorata* on Parthenium density, biomass, height and flower number suppression of Parthenium at 30 and 60 days of release (DAR) in comparison to non-release (control) of bioagent

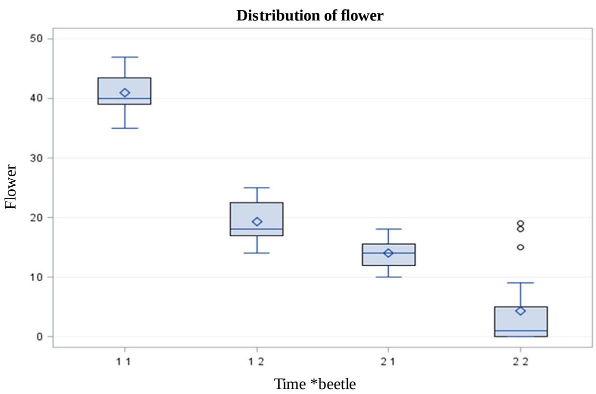
Treatment		Parthenium			
		Density (no./m^2)	Biomass (g/plant)	Height (cm/plant)	Flower (no./plant)
30 DAR	With bioagent (male: female (1:1)	352.1	7.20	31.10	19.35
	Without bioagent	335.8	8.55	33.5	19.30
	|t| value	0.75 (NS)	1.77 (NS)	1.11 (NS)	0.02 (NS)
60 DAR	With beetles (male: female (1:1)	60.8	5.65	49.05	14.05
	Without beetles	159.2	26.15	102.6	363.4
	|t| value	38.86 (S)	25.42 (S)	18.25 (S)	53.26 (S)
30 DAR	With beetles (male: female (1:1.6)	334.5	8.65	37.6	40.95
	Without beetles	389.8	14.65	44.7	45.40
	|t| value	7.69 (S)	23.35 (S)	6.36 (S)	1.27 (NS)
60 DAR	With beetles (male: female (1:1.6)	21.45	1.05	40.15	4.3
	Without beetles	93.35	26.95	103.2	395.7
	|t| value	16.79 (S)	18.13 (S)	11.96 (S)	32.31 (S)

(Significance level is given in parentheses. S-Significant at 1% level of significance, NS-Not significant, DAR-Days after release of beetle)

Table 3. Separate and interactive effect of bioagent *Z. bicolorata* released at different ratios on Parthenium density, biomass, height and flowers numbers

Treatment	Parthenium			
	Density (no./m^2)	Biomass (g/plant)	Height (cm/plant)	Flowers (no./plant)
Time				
30 DAR	343.25±12.44^a	7.93±1.02^a	34.4±4.6^b	30.15±15.27^a
60 DAR	41.13±27.82^b	3.35±3.25^b	44.6±6.29^a	9.17±6.89^b
LSD (p=0.05)	6.81	0.48	1.82	1.82
Release of beetles in ratio (Male: Female)				
1: 1	197.63±93.49^a	7.15±2.12^a	43.3±8.09^a	27.5±19.02^a
1.1.60	186.75±133.77^b	4.13±3.34^b	35.6±6.4^b	11.8±10.64^b
LSD (p=0.05)	6.81	0.48	1.82	1.82
Time× ratio release				
30 DAR×1:1	334.45±21.60^b	8.65±0.48^a	37.60±3.37^c	41.0±3.20^a
30 DAR×1.1.60	352.05±19.31^a	7.20±1.06^b	31.1±2.92^d	19.4±3.76^b
60 DAR×1:1	60.80±6.50^c	5.65±1.08^c	49.1±5.58^a	14.1±1.95^c
60 DAR×1.1.60	21.45±7.29^d	1.05±1.46^d	40.2±3.9^b	4.3±6.2^d
LSD (p=0.05)	9.25	0.72±	2.58	2.34

Different superscripted letters show significant difference in the treatment



1 1 -30 DAR×1:1, 1 2 - 30 DAS×1:1.6, 2 1-60 DAS×1:1; 2 2 - 60 DAS×1:1.6

Figure 4. Number of Parthenium flowers at 30 and 60 days after release (DAR) as influenced by male: female ratios of released beetles' population (F = 126.9; df = 1, 76; P=0.0001), (F = 71.6; df = 1, 76; P=0.0001), (F = 126.9; df = 1, 76; p=0.0001)

1, 76; p=0.0001), (F = 71.6; df = 1, 76; p=0.0001), (F = 126.9; df = 1, 76; p=0.0001) 71.6; df = 1, 76; P=0.0001). Significant effect of number of beetles was observed on the flowers of the plants at different time intervals *i.e.* 30 and 60 DAR as their interaction was significant at 5% level of significance (F = 126.9; df = 1, 76; P=0.0001). Highly significant difference was observed between number of flowers on 30 and 60 DAR with varying number of females' beetles.

The distribution of different stages of *Z. bicolorata* namely eggs, grubs and adults on Parthenium plant showed significant variation during observation against 30 and 60 days after release (DAR) of bioagent. The release of beetles at ratio of 1:1, resulted in 32.95 eggs/plant, 9.1 grubs/plant, 3.45 adults/plant and 40.72 male ratio over female at 30 DAR while 44.27 female ratio over male. On the other hand, the release ratio of 1:1.6, resulted in 70.4

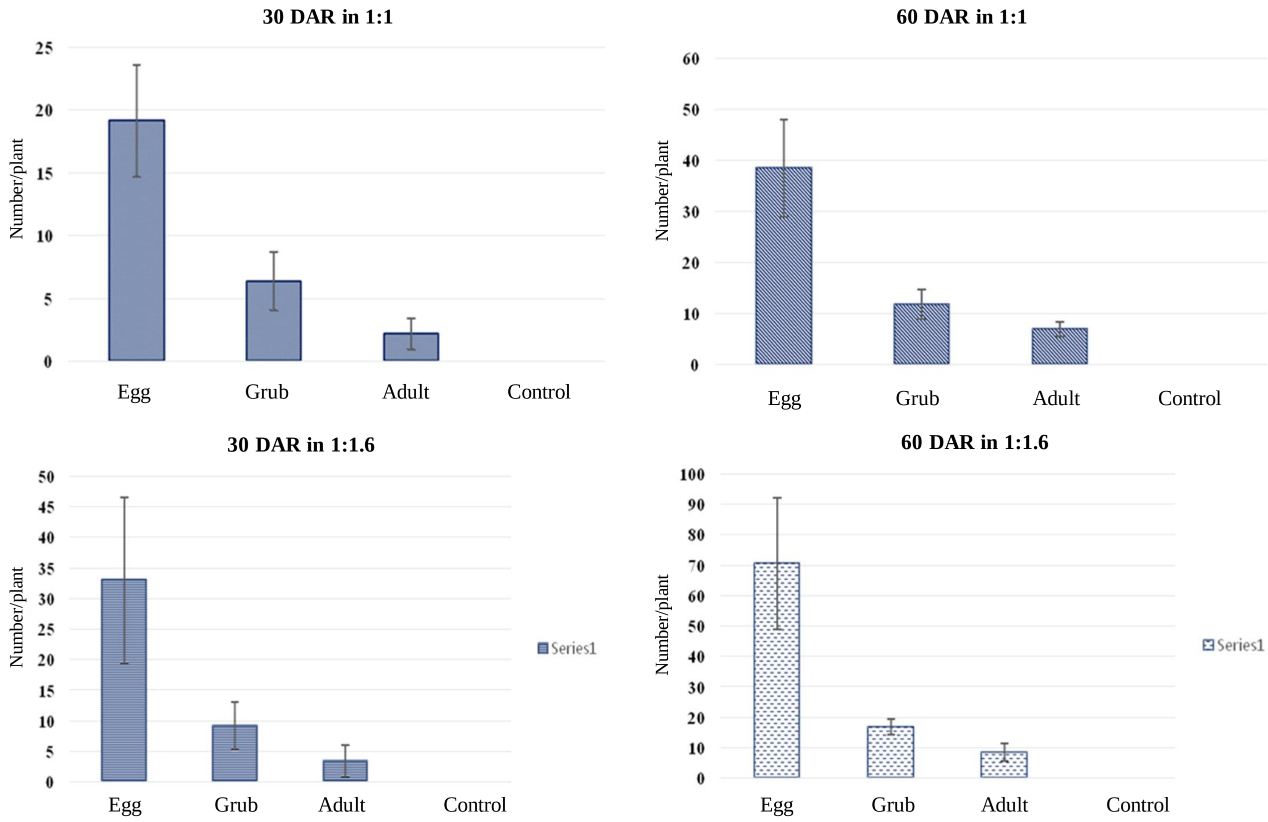


Figure 5. Release effect of *Z. bicolorata* in different male-female ratio on subsequent population increase of eggs, grubs and adults at 30 and 60 days after release

eggs/plant, 16.7 grubs/plant, 30.35 adults/plant and 46.58 male ratio over female while 53.32 female ratio over male at 60 DAR (**Figure 5**).

Among three years, all samples deviated significantly from 50:50 sex ratio ($p<0.005$), while within the same samples, a few were not deviated significantly from the 50:50 sex ratio. However pooled data from within the sample showed slight deviation from the 50:50 sex ratio (chi-square $\div^2$ = 7.9, 13.8, 16.7 (for 2013, 2014, 2015 respectively); df = 1; p=0.01). Thus, sex ratio was towards female dominace in each year. The sex ratio in *Z. bicolorata* inclined significantly towards female was reported in previous studies too (Siddhapara 2011, Omkar *et al*. 2013, Omkar *et al*. 2013, Pawar *et al*. 2015). *Z. bicolorata* population increases gradually from June to September and decreases from October onwards and reaches almost negligible in December to January, while mild population occurs during February to March (Dhiman and Bhargawa 2005, Sushilkumar 2005, 2009). Sufficient population build-up during the rainy season is responsible for minimizing Parthenium density and survival of bioagent for future establishment. Female's dominance in sex ratio in *Z. bicolorata* lead good population build-up responsible for subsequent control of Parthenium in future. Bhoopathi *et al*. (2011) considered sex ratio as an important biological parameter to determine the stability of population of *Z. bicolorata* and adaptability of various stages to prevailing biotic and abiotic factors in the field conditions. Less proportion of male lead greater numbers of female emergences in future. Similarly, Visalakshy and Jayanth (2008) reported a female biased sex ratio from a field collected population of *Z. bicolorata*. Hopwood *et al*. (2016) opined natural selection due to ecological differences between the sexes, an alternative to sexual selection as a cause of sexual dimorphism. In our experiments, there was clear effect of Parthenium suppression in the plots where female dominated releases at 1:1.60 were made compared to equal number of male and female releases. Therefore, female dominated population at 1:1.60 male: female sex ratio or even more female dominated sex ratio releases should be opted under biological control programme of Parthenium.

Anderson and Simmons (2006) explained large size in sexual dimorphism a favorable factor in females to produce more eggs while advantageous to males in mating due to smaller size. Larger males and females are preferred as mates over smaller ones while large-sized females produce more progeny

(Omkar and Uzma Afaq 2011). Omkar *et al.* (2013) found that pairs with larger size had higher fecundity, while the egg viability was influenced by the male size only. The offspring of stronger parents are fast developed and have higher survival rate than smaller parents. It is possible due to better nutrient supply by the female (Claessen *et al.* 2003).

Dhileepan *et al.* (2000) evaluated the impact of defoliation using a visual scoring (0 to 100%) by *Z. bicolorata* on *P. hysterophorus* and found 91–100% defoliation resulting in reductions in weed density by 32–93%, plant height by 18–65%, plant biomass by 55–89%, flower production by 75–100%, soil seed-bank by 13–86% and seedling emergence in the following season by 73–90%, however they did not quantified the effect on these parameters based on the release of total number of beetles or release of numbers of male and female adults in different sex ratio. Bhumannavar and Balasubramanian (1998) found that third instar grubs and egg-laying females ingested maximum food. Omkar and Afaq (2011) reported that in adults, females had higher dry food consumption than males but no difference in tissue growth between males and females. They opined that this could be due to diversion of the increased uptake of nutrients and energy resources for ovarian development and egg production in females.

Conclusion

Sex-ratio of bioagent *Zygogramma bicolorata* was found significantly dominated by females along with larger size and more body weight. The female dominated population releases were found helpful to reduce the height, density, biomass and flowers of Parthenium when released at 1:1.60 male: female sex ratio. Therefore, release of female dominated population at 1:1.60 male: female sex ratio or even more were recommended for better establishment of the bioagent and subsequent control of Parthenium.

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RESEARCH ARTICLE

Sole and sequential application of herbicides for economical weed management in blackgram

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ABSTRACT

A field experiment was conducted at Regional Research and Technology Transfer Station, Chiplima, Odisha, India during the winter *(Rabi)* seasons of 2019-20 and 2020-21 to study the effect of sole and sequential application of herbicides for weed management in blackgram (*Vigna mungo* L.). The treatment combinations consisted pre-emergence herbicides, *viz.* pendimethalin and oxyfluorfen and post-emergence herbicides, *viz.* imazethapyr and clodinafop-propargyl + acifluorfen (ready-mix) in different rates along with weed free and weedy check. The weed competition resulted in 37.6% yield loss in blackgram. The pre-emergence application (PE) of oxyfluorfen 200 g/ha at 1 days after seeding (DAS) followed by (*fb*) post-emergence application of imazethapyr75 g/ha at 20 DAS caused 89.5% reduction in weed biomass with higher weed control efficiency (89.4%) and blackgram yield (0.77 t/ha). The net return (₹ 24.9 x 10^3/ha) and benefit: cost ratios (2.0) were also higher with this treatment and hence be recommended in West Central Table Land Zone of Odisha for better weed control, seed yield and higher economic returns in blackgram.

Keywords: Blackgram, Clodinafop-propargyl + acifluorfen, Imazethapyr, Oxyfluorfen, Sequential application, Weed management

INTRODUCTION

Blackgram (*Vigna mungo* L.) a short duration pulse crop is grown over an area of 5.44 million hectares during of rainy and winter (*Kharif and Rabi*) season with a production of 3.56 million tonnes and productivity of 655 kg/ha, which is lower than the world average of 1808 kg/ha (Anon 2018), indicating wider scope for improving the yield potential in India. It is extensively grown in the states of Madhya Pradesh, Maharashtra, Andhra Pradesh, Tamil Nadu and Uttar Pradesh in India. In Odisha, it is grown in an area of 0.57 million ha with a production of 0.26 million tonnes and productivity of 456 kg/ha, which is below the national average (Anon 2016).

Heavy weed infestation in blackgram, due to slower crop growth during early stages and frequent irrigation during winter and summer season, is a major constraint causing lower blackgram yield. The uncontrolled weeds in blackgram cause yield loss up to 42-51% (Begum and Rao 2006, Malliswari *et al.* 2008). Pendimethalin, a pre-emergence herbicide is used at 750 to 1000 g/ha to control initial flush of weeds in most of pulses including blackgram. This alone is not sufficient to control the diverse weed flora of blackgram. Singh *et al.* (2014) discussed the need of post-emergence herbicide to control the second flush of weeds in pulse and to reduce human labour. Several pre and post – emergence herbicides have been reported (Kumar 2010) to provide a good degree of weed control. However, the information on the herbicide efficacy in managing weeds in *Rabi* blackgram under West Central Table Land Zone of Odisha is inadequate. Therefore, this study was conducted to find out the most selective, effective and economic herbicide and its optimum dose for minimizing the menace of weeds in blackgram.

MATERIALS AND METHODS

The study was undertaken at Regional Research and Technology Transfer Station, Odisha University of Agriculture and Technology, Chiplima, Sambalpur, Odisha during winter *(Rabi)* seasons 2019-20 and 2020-21. The soil of the experimental field was sandy loam with pH 6.6, organic carbon 0.43 % and available N ($KMnO_4$ method), P (Olsen) and K (NH_4OHC method) content of 268, 13.4 and 132 kg/ha, respectively. Eight treatments consisting of pre-emergence application (PE) of oxyfluorfen 200 g/ha

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at 1 days after seeding (DAS); pendimethalin 750 g/ha PE at 1 DAS; pendimethalin 750 g/ha PE at 1 DAS followed by (*fb*) post-emergence application (PoE) imazethapyr 75 g/ha at 20 DAS; oxyfluorfen 200 g/ha PE at 1 DAS *fb* imazethapyr 75 g/ha PoE at 20 DAS; pendimethalin 75 g/ha PE at 1 DAS *fb* clodinafop-propargyl + acifluorfen 240 g/ha PoE at 20 DAS; oxyfluorfen 200 g/ha PE at 1 DAS *fb* clodinafop-propargyl + acifluorfen 240 g/ha PoE at 20 DAS; weed free (hand weeding twice at 20 and 40 DAS) and weedy control. A randomized block design with 3 replications was used. Blackgram cultivar '*LBG 787*' was sown on 15 October, 2019 and 25 October, 2020 at a spacing of 30 x 10 cm and was harvested on 18 January, 2020 and 28 January, 2021. A common fertilizer dose of 20 kg N + 40 kg P + 20 kg K/ha was applied. Full dose of N, P and K was applied as basal. Required quantities of herbicides were applied as per treatment with manually operated knapsack sprayer fitted with flat-fan nozzle using a spray volume of 500l of water/ha. Weed density (number/m^2) and weed biomass (g/m^2) were taken from random sampling at 2 places in the field with the help of 1 m^2 quadrat at 40 DAS.

The weed samples collected in paper bags were air dried in shade initially followed by oven drying at 65^0C for 48 hours till they attain constant weight to determine biomass in g/m^2. Data on individual and total weed density and biomass were subjected to square root transformation $\sqrt{x+0.5}$. Weed control efficiency (WCE) and Weed index (WI) were calculated based on the weed biomass and blackgram seed yield, respectively. At the harvest, yield and yield-attributes of blackgram were recorded.

The nutrients like N, P and K content in seed and stover were determined by modified Kjeldahl method, vanadomolybdophosphoric yellow colour method and flame photometer, respectively (Jackson 1973). The nutrients uptake by seed and stover were calculated by multiplying nutrient content with seed and stover yield (kg/ha). All data were analyzed through analysis of variance (ANOVA) using standard variance techniques suggested by Gomez and Gomez (1984).

Economics was computed using the prevailing market prices for inputs and outputs such as blackgram seed (₹ 70/kg) and manual labour (₹ 287/day); input price (₹/kg): urea, 5.52; diammonium phosphate, 24.45; muriate of potash, 17.44; oxyfluorfen, ₹ 180/100 ml; pendimethalin ₹ 400/l; imazethapyr ₹ 300/250 ml; clodinafop propargyl + acifluorfen ₹ 174/100ml.

RESULTS AND DISCUSSION

The predominant weeds of the experimental field were *Echinochloa colona* and *Digitaria sanguinalis, Dactyloctenium aegyptium, Brachiaria reptans* among the grasses; *Cyperus rotundus, Cyperus difformis* among the sedges and *Cleome viscosa*, *Euphorbia hirta* and *Boerhavia erecta, Euphorbia thymifolia, Celosia argentea, Commelina benghalensis, Phyllanthus niruri* among the broad-leaved weeds during both the years of study. The composition of grasses, sedges and broad-leaved weeds in weedy check plot was 18.7, 30.4 and 50.8%, respectively at vegetative stage of crop. The earlier emergence of sedges and broad-leaved weeds was noticed as compared to grasses as observed earlier by Bhowmick and Gupta (2005)

Effect on weeds

Herbicidal treatments significantly influenced the weed density and biomass. The density and biomass of both broad-leaved and grassy weeds were significantly reduced by all weed control treatments compared to weedy check, however, weed free (two hand weedings) recorded lowest broad-leaved, grassy and total weeds than the rest of the treatments (**Table 1** and **2**). The application of pendimethalin at 750 g/ha PE and oxyfluorfen at 200 g/ha PE alone, effectively reduced density and biomass of the sedges and broad-leaved weeds than weedy check, and were at par. However, sequential application of oxyfluorfen at 200 g/ha PE *fb* imazethapyr at 75 g/ha PoE recorded the lowest total weed density and biomass (18.5/m^2, 9.5 g/m^2), the highest weed control efficiency (89.4%) with the lowest weed index (3.4%).The next best treatment was pendimethalin at 750 g/ha PE *fb* imazethapyr at 75 g/ha PoE. The high selectivity of herbicides to blackgram and non-selectivity to weeds was the reason for better control of weeds. Oxyfluorfen PE or pendimethalin PE caused reduction in germination of emerging weed during initial period of growth and sequential post-emergence application of imazethapyr as PoE has controlled the late emerging sedges and broad-leaved weeds. Imazethapyr inhibits the plastid enzyme acetolactate synthase (ALS) in plants which catalyses the first step in the biosynthesis of essential branched chain aminoacids (valine, leucine, isoleucine). The ALS inhibitors thus stop cell division and reduce carbohydrate translocation in the susceptible plants (Das 2008). Papierniks *et al.* (2003) also recommended use of imazethapyr in legumes. That is why sequential application of pendimethalin or oxyfluorfen PE *fb* imazethapyr or clodinafop propargyl + acifluorfen as PoE was more effective than that of sole application of pendimethalin at 750 g/ha PE and oxyfluorfen at 200 g/ha PE in controlling weeds. Weedy check registered higher total weed density.

Effect on crop

The weed infestation caused 35.2% reduction in mean seed yield of winter (*Rabi*) blackgram as was also reported by Chand *et al*. (2004) and Singh (2011). Weedy control recorded the lowest seed yield (507 kg/ha). The blackgram yield and yield parameters were higher under weed free treatments which were at par with treatment of oxyfluorfen at 200 g/ha PE *fb* imazethapyr 75 g/ha and was significantly superior to pendimethalin 750 g/ha PE at 1 DAS *fb* clodinafop-propargyl + acefluorofen 240 g/ha PoE at 20 DAS (**Table 3**). Pods/plant, seeds/pod and test weight in weed free and pendimethalin 750 g/ha PE *fb* imazethapyr 75 g/ha PoE was found at par with each other. This might be due to minimizing the competition of weeds with main crop for resources, *viz.* light, nutrients and moisture with adaption of effective weed control methods. Thus, reduced crop-weed competition resulted into overall improvement of crop growth as reflected by plant height and dry matter accumulation consequently resulted into better development of reproductive structure and translocation of photosynthates to the sink. The results corroborate with the findings of Yadav *et al*.

Table 1. Effect of weed management on weed density at 40 days after seeding in blackgram

Treatment	Weed density (no./m^2)											
	Grasses			Sedges			Broad- leaved weeds			Total		
	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean
Oxyfluorfen PE	23.4 (4.9)	18.7 (4.4)	21.1 (4.6)	39.4 (6.3)	33.0 (5.8)	36.2 (6.1)	64.0 (8.0)	51.0 (7.2)	57.5 (7.6)	126.8 (11.3)	102.7 (10.2)	114.8 (10.7)
Pendimethalin PE	23.4 (4.9)	18.0 (4.3)	20.7 (4.6)	38.6 (6.3)	32.7 (5.8)	35.7 (6.0)	67.4 (8.2)	53.0 (7.3)	60.2 (7.8)	129.4 (11.4)	103.7 (10.2)	116.6 (10.8)
Pendimethalin PE *fb* imazethapyr PoE	2.0 (1.6)	3.4 (2.0)	2.7 (1.8)	3.3 (1.9)	10.9 (3.4)	7.1 (2.8)	8.3 (3.0)	11.5 (3.5)	9.9 (3.2)	13.6 (3.8)	25.7 (5.1)	19.7 (4.5)
Oxyfluorfen PE *fb* imazethapyr PoE	2.0 (1.6)	3.0 (1.9)	2.5 (1.7)	3.0 (1.9)	10.5 (3.3)	6.8 (2.7)	7.0 (2.7)	11.5 (3.5)	9.3 (3.1)	12.0 (3.5)	25.0 (5.0)	18.5 (4.4)
Pendimethalin PE *fb* clodinafop-propargyl + acifluorfen PoE	6.0 (2.5)	6.3 (2.6)	6.2 (2.6)	30.6 (5.6)	27.7 (5.3)	29.2 (5.4)	24.0 (4.9)	35.7 (6.0)	29.9 (5.5)	60.6 (7.8)	69.7 (8.4)	65.2 (8.1)
Oxyfluorfen PE *fb* clodinafop-propargyl + acifluorfen PoE	4.6 (2.3)	4.7 (2.3)	4.7 (2.3)	30.0 (5.5)	27.0 (5.2)	28.5 (5.4)	13.4 (3.7)	31.0 (5.6)	22.2 (4.8)	48.0 (7.0)	62.7 (7.9)	55.4 (7.5)
Weed free	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weedy check	40.6 (6.4)	26.0 (5.1)	33.3 (5.8)	58.6 (7.7)	50.0 (7.1)	54.3 (7.4)	105.4 (10.3)	76.0 (8.7)	90.7 (9.5)	204.6 (14.3)	152.0 (12.3)	178.3 (13.4)
LSD (p=0.05)	0.4	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.7	0.6	0.7

Data were subjected to square root $\sqrt{x+0.5}$ transformation before analysis and original values are shown in parentheses

Table 2. Effect of weed management on weed biomass and weed control efficiency (WCE) and weed index (WI) at 40 days after seeding in blackgram (pooled data of 2 years)

Treatment	Weed biomass (g/m^2)												WCE (%)	WI (%)
	Grasses			Sedges			Broad- leaved weeds			Total				
	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean	2020	2021	Mean		
Oxyfluorfen PE	10.6 (3.3)	11.8 (3.5)	11.2 (3.4)	11.8 (3.5)	13.9 (3.8)	12.9 (3.7)	34.6 (5.9)	33.1 (5.8)	33.9 (5.9)	57.0 (7.6)	58.8 (7.7)	57.9 (7.6)	36.2	22.9
Pendimethalin PE	10.6 (3.3)	11.4 (3.4)	11.0 (3.4)	11.6 (3.5)	13.7 (3.8)	12.7 93.6)	36.4 (6.1)	34.2 (5.9)	35.3 (6.0)	58.6 (7.7)	59.3 (7.7)	59.0 (7.7)	35.1	20.5
Pendimethalin PE *fb* imazethapyr PoE	0.8 (1.1)	2.1 (1.6)	1.5 (1.4)	1.0 (1.2)	5.0 (2.3)	3.0 (1.9)	4.5 (2.2)	7.6 (2.8)	6.0 (2.6)	6.3 (2.6)	14.7 (3.3)	10.5 (3.3)	88.4	6.0
Oxyfluorfen PE *fb* imazethapyr PoE	0.6 (1.0)	1.9 (1.5)	1.3 (1.3)	0.9 (1.2)	4.4 (2.2)	2.7 (1.8)	3.8 (2.1)	7.4 (2.8)	5.6 (2.5)	5.3 (2.4)	13.7 (3.8)	9.5 (3.2)	89.4	3.4
Pendimethalin PE *fb* clodinafop-propargyl + acifluorfen PoE	2.8 (1.8)	4.0 (2.1)	3.4 (2.0)	9.2 (3.1)	11.6 (3.5)	10.4 (3.3)	13.0 (3.7)	23.0 (4.8)	18.0 (4.3)	25.0 (5.0)	38.6 (6.3)	31.8 (5.7)	64.8	18.6
Oxyfluorfen PE *fb* clodinafop-propargyl + acifluorfen PoE	2.2 (1.8)	2.9 (1.8)	2.6 (1.7)	9.0 (3.1)	11.3 (3.4)	10.2 (3.3)	7.2 (2.8)	20.0 (4.5)	13.6 (3.8)	18.4 (4.3)	34.2 (5.9)	26.3 (5.2)	70.9	14.8
Weed free	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100	0.0
Weedy check	18.3 (4.3)	18.4 (4.3)	18.4 94.3)	17.6 (4.3)	19.8 (4.5)	18.7 (4.4)	56.8 (7.6)	50.8 (7.2)	53.8 (7.4)	92.7 (9.7)	89.0 (9.5)	90.9 (9.6)	0.0	37.9
LSD (p=0.05)	0.2	0.3	0.2	0.2	0.3	0.2	0.4	0.4	0.4	4.5	4.2	6.3		

(2014). Overall seed yield was lower in 2019-20 than 2020-21. Pod length did not vary significantly among the treatments.

Among different treatments, sequential application of oxyfluorfen 200 g/ha PE *fb* imazethapyr 75 g/ha PoE recorded higher seed yield (0.77 t/ha) with 53.1% yield advantages over weedy check. It was at par with pendimethalin 750 g/ha PE *fb* imazethapyr 75 g/ha PoE. Kantar *et al.* (1999) also observed 63.6% higher seed yield over unweeded check with application of imazethapyr. The reduced crop weed competition caused significant increase in growth and yield characters ultimately led to higher seed yield of blackgram. The significant improvement in seed yield as a result of hand weeding twice (weed free) and all herbicidal weed control treatments could be attributed to the fact that yield of crop depends on several yield components which are interrelated. Under weedy situation, at early crop growth stage a greater part of resources present in soil and environment are depleted by weeds for their growth. The crop plant thus, face stress which ultimately affects their growth, development and yield. Like seed yield, stover yield (1.17 t/ha) was also significantly increased due to application of oxyfluorfen 200 g/ha PE *fb* imazethapyr 75 g/ha PoE over weedy check. Increase in stover yield might be due to direct influence of various weed management treatments on the suppression of weeds. The results were in agreement with the earlier findings (Kumar *et al.* 2016 and Tiwari *et al.* 2014).

Nutrient uptake

Significant decrease in total N, P and K uptake by weeds were recorded due to all weed management treatments than weedy check (**Table 4**). Oxyfluorfen 200 g/ha PE *fb* imazethapyr 75g/ha PoE at 20 DAS caused the highest uptake of N, P and K (31.8, 3.9, 12.4 kg/ha) by seed and stover (19.3, 3.5, 14.0 kg/ha) and was at par with weed free check, owing to higher dry matter production of crop and corresponding nutrient contents in these treatments due to negligible competition offered by weeds for N, P and K uptake as also reported by Chhodavadia *et al.* (2013). The highest N, P and K depletion (31.5, 3.2 and 20.0 kg/ha, respectively) by weeds was recorded in weedy check plots as weeds were not controlled effectively and enabled them to absorb more nutrients (Singh *et al.* 2020).

Economics

The monetary returns were significantly influenced by different weed control treatments (**Table 4**). Sequential application of oxyfluorfen 200 g/ha PE *fb* imazethapyr 75g/ha PoE at 20 DAS recorded the highest net return (₹ 24.9 x 10^3/ha) and benefit: cost ratio (2.0) which was closely followed by pendimethalin 750 g/ha PE at 1 DAS *fb* imazethapyr 75 g/ha PoE at 20 DAS and significantly superior to the weed free check. In weed free treatment, the net return was maximum (₹ 21.3 x10^3/ ha), but benefit: cost ratio was less (1.7). This was due to engagement of greater number of laborer which enhanced the cost of cultivation (₹ 29.79x 10^3/ ha) in this treatment. Weedy check though involved the lowest cost of cultivation yet provided the lowest net monetary return (₹ 9.1 x 10^3/ha) and benefit: cost ratio (1.4). These findings are similar to those reported by Kalhapure *et al.* (2013) and Yadav *et al.* (2014).

The broad-spectrum weed control throughout the crop growth period with sequential application of oxyfluorfen at 200 g/ha PE *fb* imazethapyr 75 g/ha at 20 DAS recorded maximum net returns and B:C ratio in winter (*Rabi*) blackgram under West Central Table Land Zone of Odisha.

Table 3. Yield attributes, yield and harvest index of blackgram as influenced by different treatments (pooled data of 2 years)

Treatment	Plant height (cm)	Dry matter /plant (g)	Pods/ plant	Pod length (cm)	Seeds/ pod	Test weight (g)	Seed yield (t/ha)			Stover yield (t/ha)		
							2020	2021	Mean	2020	2021	Mean
Oxyfluorfen PE	33.5	11.8	13.5	4.0	6.4	43.3	0.66	0.58	0.62	0.96	0.90	0.93
Pendimethalin PE	31.5	12.6	14.5	5.0	6.4	45.3	0.70	0.59	0.64	1.01	0.91	0.96
Pendimethalin PE *fb* imazethapyr PoE	34.5	13.7	16.5	6.0	6.6	45.3	0.76	0.65	0.70	1.14	1.13	1.13
Oxyfluorfen PE *fb* imazethapyr PoE	36	13.9	18.3	6.0	6.5	50.5	0.83	0.72	0.78	1.18	1.15	1.17
Pendimethalin PE *fb* clodinafop-propargyl + acifluorfen PoE	29.5	12.2	14	5.0	6.3	44.4	0.71	0.60	0.65	1.02	0.94	0.98
Oxyfluorfen PE *fb* clodinafop-propargyl + acifluorfen PoE	33	12.9	16	5.0	6.5	44.4	0.72	0.62	0.67	1.07	0.99	1.03
Weed free	39.5	14.9	18.5	6.0	7	52	0.87	0.75	0.81	1.22	1.195	1.21
Weedy check	28.5	9.3	11.5	4.0	6.4	41.5	0.51	0.50	0.51	0.79	0.71	70.5
LSD (p=0.05)	3.8	1.1	1.9	NS	1.1	7.5	0.18	0.06	0.11	0.17	0.18	0.17

Table 4. Nutrient uptake by seed, stover, weed and economics of blackgram as influenced by different treatment (pooled data of 2 years)

Treatment	Uptake by seed (kg/ha)			Uptake by stover (kg/ha)			Uptake by weed (kg/ha)			Cost of cultivation (x10^3 ₹/ha)	Net returns (x10^3 ₹/ha)	Benefit : cost ratio
	N	P	K	N	P	K	N	P	K			
Oxyfluorfen PE	25.1	2.57	10.3	14.4	2.88	11.5	21.5	2.1	13.2	23.29	16.0	1.7
Pendimethalin PE	26.1	2.61	10.44	9.83	1.97	10.8	18.9	2.4	13.4	23.49	17.1	1.7
Pendimethalin PE *fb* imazethapyr PoE	28.9	2.82	11.99	17.5	3.4	12.5	3.4	0.4	2.6	24.25	21.3	1.8
Oxyfluorfen PE *fb* imazethapyr PoE	31.8	3.88	12.41	19.3	3.5	14	3.4	0.4	2.3	24.03	24.9	2.0
Pendimethalin PE *fb* clodinafop-propargyl + acifluorfen PoE	26.1	2.68	11.39	17.5	3.09	11.3	10.2	1.2	7.1	25.25	15.8	1.6
Oxyfluorfen PE *fb* clodinafop-propargyl + acifluorfen PoE	28	2.73	10.93	17	3.39	13.6	9.3	1.1	6.1	25.49	16.8	1.7
Weed free	34.1	4.06	13.81	21.7	3.62	14.5	0.0	0.0	0.0	29.79	20.3	1.7
Weedy check	19.8	2.26	7.34	14	2.63	7.88	31.5	3.2	20.0	22.87	9.1	1.4
LSD (p=0.05)	4.8	0.3	1.6	4.6	1.2	0.64	0.54	0.2	0.52		11.8	0.3

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RESEARCH ARTICLE

Influence of mulch-based weed management in organic turmeric production

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ABSTRACT

A study was carried out during two consecutive years (2018-19 and 2019-20) on a loamy sand soil at Anand, Gujarat, India to study the effectiveness of mulch-based weed management in organically grown turmeric (*Curcuma longa* L.) production. The wheat straw mulch 5 t/ha applied at 0-3 days after planting (DAP) *fb* hand weeding (HW) at 30, 60 and 90 DAP and rice straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP were found equally effective in reducing weed biomass with higher weed control efficiency. Both these treatments resulted in significantly higher rhizome yield with higher net return and benefit cost ratio of 1.79 and 1.77, respectively.

Keywords: *Curcuma longa*, Organic cultivation, Mulching, Rice straw mulch, Turmeric, Weed management, Wheat straw mulch

INTRODUCTION

India is the largest producer, consumer and exporter of turmeric (*Curcuma longa* L.). It is also known as golden spice or spice of life belongs to the family Zingiberaceae. Turmeric is the second most important spices crop after chilli in India and it accounts for 78% in world production and 60% in world export (Angles *et al*. 2011). The major turmeric producing states in India are Andhra Pradesh, Orissa, Tamil Nadu, Assam, Gujarat and Maharashtra (Patel *et al*., 2012). Turmeric is a long duration crop and due to delayed emergence, slow initial growth to develop a canopy structure sufficient to compete with weeds and ample land space available due to wider spacing permit more sunlight to reach the soil provide congenial for rapid weed growth. Severe weed infestation leads to reduction in curcumin content and oil per cent. The average productivity is quite low mainly due to the severe competition with weeds for a longer period which causes yield lose up to 63.9-76.5% (Kaur *et al*. 2008). Turmeric requires a weed free condition of 70 to 160 days after planting (DAP) for better production of rhizomes (Dhanapal *et al*. 2017). Different methods are being used to manage the weeds in the turmeric. Mulching was found to reduce the weed growth considerably and enhance sprouting of rhizomes by conserving soil moisture. Application of straw mulch showed favourable effect on growth parameters and yield of turmeric as compared to no mulch which might be explained by early emergence, quick establishment of crop and higher interception of light. Moreover, soil under mulch remains loose, friable and well-aerated therefore, roots have access to adequate oxygen and enhance the microbial activity in the soil. Thus, a study was undertaken to study the effectiveness of mulch-based weed management in organically grown turmeric.

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MATERIALS AND METHODS

An experiment was carried out during 2018-19 and 2019-20 on loamy sand soil at Anand, Gujarat, India to study the effectiveness of mulch-based weed management in organic turmeric production. The soil of the experimental field was low in available nitrogen and medium in available phosphorous and high in potassium. Nine different weed management practices consisted of: rice straw mulch (PSM) 5 t/ha applied at 0-3 days after planting (DAP) followed by (*fb*) hand weeding (HW) at 30, 60 and 90 DAP; wheat straw mulch (WSM) 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP; inter-culture (IC) + HW at 30 DAP *fb* PSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP; IC + HW at 30 DAP *fb* WSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP; plastic mulch (0-3 DAP) *fb* HW at 20, 40 and 60 DAP; plastic mulch (0-3 DAP) *fb* HW at 30 and 60 DAP; turmeric + sun hemp intercropping *fb* HW at 30 DAP *fb* HW + mulch of sun hemp at 60 DAP *fb* HW at 90 DAP; IC *fb* HW at

20, 40, 60 and 80 DAP and weedy check. A randomized block design with three replications was used. Turmeric cv. *GNT 2* was planted on 15 and 6 June 2018 and 2019, respectively keeping distance of 45 x 20 cm by using seed rate of 2500 kg/ha rhizomes. The crop was harvested on 7 and 17 February 2019 and 2020, respectively. The crop was manured equivalent to the recommended rate of fertilizer at 100-50-50 NPK kg/ha applied through organic sources (50% recommended nitrogen from FYM and 50% from vermicompost) at the time of sowing during both the years of experimentation. The rest of the recommended package of practices was adopted to raise the crop. Weed management treatments were adopted as per the treatment wherein, mulching treatment was imposed after planting of turmeric rhizomes.

The monocot, dicot and sedges were collected from randomly selected four spots by using 0.25 m^2 iron quadrat from net plot through destructive sampling method at 30, 60 and 90 DAS and at harvest. Weeds were dried and dry weight of the weeds was recorded as weed biomass (g/m^2). Weed control efficiency (WCE) was calculated on the basis of weed biomass as per the formula suggested by Maity and Mukherjee (2011). Other observation was also recorded from net plot area. Benefit cost ratio was workout based on the gross realization/cost of cultivation following standard procedures.

RESULTS AND DISCUSSION

Weed flora

In the experimental field monocot weeds were dominant during both the year of experimentation. The major weeds observed in the experimental field were *Eleusine indica* (23.9%), *Dactyloctenium aegyptium* (22.6 %), *Digitaria sanguinalis* (9.87%) amongst monocot weeds whereas, *Oldenlandia umbellate* (7.02%), *Digera arvensis* (6.58%), *Phyllanthus niruri* (5.48%), *Trianthema monogyna* (5.26%) amongst dicot weeds. A sedge *Cyperus rotundus* was observed in the field.

Effect on weeds

The biomass of monocot, dicot and total weeds was significantly altered due to different weed management treatments during both the years as well as in pooled analysis however, the sedge was not influenced significantly as per pooled results (**Table 1**). Among the weed management treatments, plastic mulching (0-3 DAP) *fb* HW at 20, 40 and 60 DAP resulted in significantly lower biomass of monocots (2.59 g/m^2), dicots (1.71 g/m^2) and total weeds (3.12 g/m^2) at 30 DAP as compared to rest of the treatments except application of rice straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP and intercropping (IC) *fb* HW at 20, 40, 60 and 80 DAP. Different mulches restricted the penetration of solar radiation to soil surface leading to hampering the germination and emergence of weeds thereby biomass of weed and increased the weed control efficiency as observed by Choudhary *et al.* (2020) in ginger.

At 60 DAP, IC *fb* HW at 20, 40, 60 and 80 DAP resulted in significantly lower biomass of monocot weeds (4.49 g/m^2) as compared to weedy check; IC *fb* HW at 30 DAP + WSM 5 t/ha (0-3 DAP) *fb* HW at 60 and 90 DAP and plastic mulch (0-3 DAP) *fb* HW at 30 and 60 DAP (**Table 2**). However, IC *fb* HW at 30 DAP + WSM 5 t/ha (0-3 DAP) *fb* HW at 60 and 90 DAP caused significantly lower biomass of dicot weeds (4.14 g/m^2) and it was at par with IC *fb* HW at 30 DAP + PSM 5 t/ha (0-3 DAP) *fb* HW at 60 and 90 DAP; plastic mulch (0-3 DAP) *fb* HW at 20, 40 and 60 DAP and IC *fb* HW at 20, 40, 60 and 80 DAP. The beneficial effect of mulching in controlling weeds has resulted from delayed emergence of weeds and by restricted photosynthesis of weeds due to shading by crop plants. Manhas *et al.* (2011) reported that weed density and biomass were significantly lower with 6.25 t/ha mulch than without mulch. The total weed biomass was significantly lower (6.58 g/m^2) under IC *fb* HW at 20, 40, 60 and 80 DAP as compared to plastic mulch (0-3 DAP) *fb* HW at 30 and 60 DAP, turmeric + sun hemp intercropping *fb* HW at 30 DAP *fb* HW + mulch of sun hemp at 60 DAP *fb* HW at 90 DAP and weedy check. Maximum weed control efficiency was recorded under IC *fb* HW at 20, 40, 60 and 80 DAP (87.1%) which was closely followed by plastic mulch (0-3 DAP) *fb* HW at 20, 40 and 60 DAP (85.3%) and IC *fb* HW at 30 DAP + PSM 5 t/ha (0-3 DAP) *fb* HW at 60 and 90 DAP (85.2%).

At 90 DAP, biomass of monocot, dicot, sedges and total weed was significantly influenced by different weed management treatments during both the years individually and when pooled except non-significant on sedges when pooled (**Table 3**). Among all the weed management practices, IC *fb* HW at 20, 40, 60 and 80 DAP proved effective with the lowest biomass of monocot, dicot and total weeds (1.81, 1.83 and 2.68 g/m^2, respectively) at 90 DAP. Further, all the treatments were at par with each other in influencing biomass of monocot, dicot and total weed as compared to weedy check in pooled except wheat straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP and turmeric + sunnhemp inter cropping *fb* HW at 30 DAP *fb* HW + mulch of sunnhemp at 60 DAP *fb* HW at 90 DAP. Maximum weed control efficiency was achieved under IC *fb* HW at 20, 40, 60 and 80 DAP (98.4%) which was followed by plastic mulch (0-3 DAP) *fb* HW at 30 and 60 DAP (87.3%) and plastic mulch (0-3 DAP) *fb* HW at 20, 40 and 60 DAP (84.0%) at 90 DAP.

Significantly lower biomass of monocot and dicot was recorded under IC + HW *fb* PSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP and IC + HW + WSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP, respectively. The total weed biomass was lowest

Table 1. Monocot, dicot and sedges weed biomass as influenced by weed management treatments in turmeric at 30 DAP

Treatment	Weed biomass (g/m^2) Monocot			Dicot			Sedges			Total		
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
Rice straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP	4.01^{de} (15.1)	2.44^{d} (5.00)	3.22^{e} (10.1)	3.83^{cd} (13.7)	1.00^{e} (0.00)	2.41^{cd} (6.85)	2.49^{ab} (5.21)	1.22^{b} (0.500)	1.86 (2.86)	5.91^{d} (34.0)	2.54^{e} (5.50)	4.23^{e} (19.8)
Wheat straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP	4.42^{d} (18.7)	4.23^{c} (16.9)	4.33^{d} (17.8)	3.62^{d} (12.2)	4.32^{d} (17.9)	3.97^{bc} (15.1)	2.27^{b} (4.16)	1.32^{ab} (0.733)	1.79 (2.45)	6.00^{d} (35.1)	6.03^{d} (35.6)	6.01^{d} (35.4)
IC + HW at 30 DAP + PSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP	10.9^{a} (117)	9.48^{a} (89.0)	10.2^{a} (103)	6.01^{a} (35.2)	6.14^{ab} (37.3)	6.07^{a} (36.3)	2.74^{a} (6.52)	1.53^{a} (1.37)	2.14 (3.95)	12.7^{a} (159)	11.3^{ab} (128)	12.0^{a} (144)
IC + HW at 30 DAP + WSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP	10.7^{a} (113)	9.11^{a} (82.0)	9.89^{a} (97.5)	6.09^{a} (36.8)	6.11^{abc} (36.8)	6.10^{a} (36.8)	2.72^{a} (6.57)	1.57^{a} (1.50)	2.15 (4.04)	12.5^{a} (156)	11.0^{ab} (120)	11.8^{ab} (138)
Plastic mulch (0-3 DAP) *fb* HW at 20, 40 and 60 DAP	2.93^{e} (7.59)	2.26^{d} (4.13)	2.59^{e} (5.86)	2.41^{e} (4.80)	1.00^{e} (0.00)	1.71^{d} (2.40)	1.59^{c} (1.54)	1.23^{b} (0.533)	1.41 (1.04)	3.87^{e} (14.0)	2.37^{e} (4.67)	3.12^{e} (9.34)
Plastic mulch (0-3 DAP) *fb* HW at 30 and 60 DAP	6.51^{c} (41.7)	6.71^{b} (44.3)	6.61^{c} (43.0)	4.66^{bc} (20.7)	4.95^{cd} (23.6)	4.80^{ab} (22.2)	2.72^{a} (6.44)	1.21^{b} (0.467)	1.97 (3.45)	8.34^{c} (68.9)	8.32^{c} (68.4)	8.33^{c} (68.7)
Turmeric + sun hemp intercropping *fb* HW at 30 DAP *fb* HW + mulch of sun hemp at 60 DAP *fb* HW at 90 DAP	8.67^{b} (74.9)	8.58^{a} (73.7)	8.63^{b} (74.3)	5.01^{b} (24.4)	5.18^{bcd} (26.4)	5.10^{ab} (25.4)	2.34^{ab} (4.48)	1.36^{ab} (0.867)	1.85 (2.67)	10.2^{b} (103)	10.1^{b} (101)	10.1^{b} (102)
IC *fb* HW at 20, 40, 60 and 80 DAP	2.88^{e} (7.34)	2.30^{d} (4.33)	2.59^{e} (5.84)	2.66^{e} (6.07)	1.00^{e} (0.00)	1.83^{d} (3.04)	1.54^{c} (1.38)	1.14^{b} (0.300)	1.34 (0.840)	3.97^{e} (14.8)	2.36^{e} (4.63)	3.17^{e} (9.72)
Weedy check	10.6^{a} (112)	9.62^{a} (92.7)	10.1^{a} (102)	6.74^{a} (44.6)	6.72^{a} (44.5)	6.73^{a} (44.6)	2.75^{a} (6.60)	1.58^{a} (1.53)	2.16 (4.07)	12.8^{a} (163)	11.8^{a} (139)	12.3^{a} (151)
CV%	9.9	11.0	10.4	10.0	15.1	12.6	9.8	10.4	10.3	8.5	10.6	9.5

Note: Data subjected to ($\sqrt{x+1}$) transformation. Figures in parentheses are means of original values.
*Treatment means with the letter/letters in common are not significant by Duncan's New multiple range test at 5% level of significant, DAP=days after planting, HW = hand weeding, WSM = wheat straw mulch, PSM = rice straw mulch

Table 2. Monocot, dicot and sedges weed biomass (g/m^2) as influenced by weed management practices in turmeric at 60 DAP

Treatment	Monocot			Dicot			Sedges			Total			WCE (%)
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	
Rice straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP	4.57^{cd} (20.1)	5.70^{c} (32.7)	5.14^{cd} (26.4)	5.76^{cd} (32.7)	5.98^{bcd} (35.0)	5.87^{cd} (33.9)	2.65^{ab} (6.04)	1.58^{d} (1.52)	2.12 (3.78)	7.70^{c} (58.8)	8.35^{bc} (69.2)	8.02^{bc} (64.0)	80.7
Wheat straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP	4.83^{bcd} (22.6)	6.11^{bc} (38.0)	5.47^{bcd} (30.2)	5.23^{de} (27.1)	4.97^{cde} (23.9)	5.10^{de} (25.5)	2.29^{b} (4.34)	1.41^{cd} (1.69)	1.85 (3.02)	7.38^{cd} (54.1)	8.00^{bc} (63.6)	7.69^{bc} (58.9)	82.3
IC + HW at 30 DAP + PSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP	4.65^{cd} (20.7)	6.02^{bc} (37.2)	5.34^{bcd} (29.0)	4.27^{e} (17.5)	4.26^{e} (17.6)	4.27^{ef} (17.6)	1.61^{c} (1.60)	2.10^{abc} (3.46)	1.86 (2.53)	6.37^{cd} (39.9)	7.62^{bc} (58.2)	6.99^{c} (49.1)	85.2
IC + HW at 30 DAP + WSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP	4.73^{bcd} (21.6)	8.01^{b} (63.3)	6.37^{b} (42.5)	4.05^{e} (15.5)	4.23^{e} (17.1)	4.14^{f} (16.3)	1.64^{c} (1.72)	2.26^{ab} (4.23)	1.95 (2.98)	6.29^{d} (38.7)	9.25^{b} (84.6)	7.77^{bc} (61.7)	81.4
Plastic mulch (0-3 DAP) *fb* HW at 20, 40 and 60 DAP	3.75^{d} (13.1)	5.40^{c} (29.0)	4.58^{d} (21.1)	4.68^{de} (21.5)	4.84^{de} (23.5)	4.76^{ef} (22.5)	2.56^{ab} (5.61)	2.37^{a} (4.64)	2.47 (5.13)	6.39^{cd} (40.3)	7.51^{bc} (57.1)	6.95^{c} (48.7)	85.3
Plastic mulch (0-3 DAP) *fb* HW at 30 and 60 DAP	5.82^{b} (33.1)	6.50^{bc} (42.0)	6.16^{bc} (34.6)	6.71^{bc} (44.2)	6.42^{bc} (40.5)	6.57^{bc} (42.4)	2.88^{a} (7.30)	1.88^{bcd} (2.55)	2.38 (4.93)	9.23^{b} (84.7)	9.23^{b} (85.0)	9.23^{b} (84.9)	74.4
Turmeric + sun hemp intercropping *fb* HW at 30 DAP *fb* HW + mulch of sun hemp at 60 DAP *fb* HW at 90 DAP	5.07^{bc} (24.7)	5.86^{c} (34.0)	5.47^{bcd} (29.4)	7.58^{b} (56.6)	6.53^{b} (41.9)	7.05^{b} (49.3)	1.67^{c} (1.81)	2.16^{ab} (3.66)	1.91 (2.74)	9.16^{b} (83.1)	8.97^{b} (79.5)	9.06^{b} (81.3)	75.4
IC *fb* HW at 20, 40, 60 and 80 DAP	4.13^{cd} (16.2)	4.85^{c} (22.7)	4.49^{d} (19.5)	4.36^{de} (18.3)	4.45^{e} (18.9)	4.41^{ef} (18.6)	2.50^{b} (5.28)	2.17^{ab} (3.76)	2.34 (4.52)	6.37^{cd} (39.8)	6.79^{c} (45.3)	6.58^{c} (42.6)	87.1
Weedy check	14.7^{a} (217)	15.3^{a} (232)	15.0^{a} (225)	10.7^{a} (115)	9.79^{a} (95.3)	10.3^{a} (105)	1.50^{c} (1.27)	1.65^{cd} (1.74)	1.58 (1.51)	18.3^{a} (333)	18.2^{a} (329)	18.2^{a} (331)	-
CV%	9.8	14.7	13.0	12.5	13.3	12.9	9.9	12.9	11.4	8.4	9.6	9.1	-

Note: Data subjected to ($\sqrt{x+1}$) transformation. Figures in parentheses are means of original values.
*Treatment means with the letter/letters in common are not significant by Duncan's New multiple range test at 5% level of significant, DAP=days after planting, HW = hand weeding, WSM = wheat straw mulch, PSM = rice straw mulch

(8.52 g/m^2) with wheat straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP when compared to other treatments except IC + HW at 30 DAP + PSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP, PSM 5 t/ha (0-3 DAP) *fb* HW at 30, 60, 90 DAP and IC + HW at 30 DAP + WSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP at harvest. The lowest weed biomass under spreading of rice and wheat straw mulch may be due

Table 3. Monocot, dicot and sedges weed biomass as influenced by weed management treatments in turmeric at 90 DAP

Treatment	Monocot			Dicot			Sedges			Total			WCE (%)
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	
Rice straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP	6.69^{b}	6.40^{bc}	6.55^{bc}	4.04^{bc}	4.95^{b}	4.50^{b}	1.70^{bc}	1.87^{b}	1.78	7.88^{b}	8.20^{b}	8.04^{b}	83.9
	(43.8)	(40.5)	(42.2)	(15.4)	(23.8)	(19.6)	(1.90)	(2.53)	(2.22)	(61.1)	(66.8)	(64.0)	
Wheat straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP	6.67^{b}	6.99^{bc}	6.83^{b}	3.62^{c}	4.62^{b}	4.12^{b}	1.46^{d}	1.98^{ab}	1.72	7.60^{b}	8.58^{b}	8.09^{b}	83.7
	(43.7)	(48.1)	(45.9)	(12.1)	(21.6)	(16.9)	(1.13)	(3.09)	(2.11)	(56.9)	(72.8)	(64.9)	
IC + HW at 30 DAP + PSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP	7.12^{b}	5.79^{c}	6.45^{bc}	4.15^{bc}	5.08^{b}	4.61^{b}	1.51^{cd}	2.04^{ab}	1.78	8.27^{b}	7.87^{b}	8.07^{b}	83.7
	(49.9)	(32.8)	(41.4)	(16.5)	(25.9)	(21.2)	(1.28)	(3.31)	(2.30)	(67.6)	(62.0)	(64.8)	
IC + HW at 30 DAP + WSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP	6.40^{b}	6.08^{bc}	6.24^{bc}	4.11^{bc}	5.44^{b}	4.77^{b}	1.47^{d}	2.28^{ab}	1.86	7.62^{b}	8.42^{b}	8.02^{b}	84.0
	(40.2)	(36.3)	(38.3)	(15.9)	(29.4)	(22.7)	(1.17)	(4.20)	(2.69)	(57.3)	(69.9)	(63.6)	
Plastic mulch (0-3 DAP) *fb* HW at 20, 40 and 60 DAP	5.91^{b}	6.37^{bc}	6.14^{bc}	4.13^{bc}	5.31^{b}	4.72^{b}	1.87^{b}	2.58^{a}	2.22	7.32^{bc}	8.68^{b}	8.00^{b}	84.0
	(34.3)	(40.7)	(37.5)	(16.4)	(28.1)	(22.3)	(2.50)	(5.67)	(4.09)	(53.2)	(74.4)	(63.8)	
Plastic mulch (0-3 DAP) *fb* HW at 30 and 60 DAP	4.41^{c}	5.70^{c}	5.06^{c}	4.23^{bc}	5.07^{b}	4.65^{b}	2.16^{a}	2.33^{ab}	2.25	6.34^{c}	7.88^{b}	7.11^{b}	87.3
	(18.7)	(31.8)	(25.3)	(17.0)	(25.0)	(21.0)	(3.70)	(4.55)	(4.13)	(39.4)	(61.3)	(50.4)	
Turmeric + sun hemp intercropping *fb* HW at 30 DAP *fb* HW + mulch of sun hemp at 60 DAP *fb* HW at 90 DAP	6.26^{b}	7.63^{b}	6.94^{b}	4.68^{b}	5.08^{b}	4.88^{b}	1.46^{d}	2.29^{ab}	1.88	7.82^{b}	9.37^{b}	8.60^{b}	81.4
	(38.2)	(57.7)	(48.0)	(20.9)	(25.3)	(23.1)	(1.14)	(4.30)	(2.72)	(60.2)	(87.3)	(73.8)	
IC *fb* HW at 20, 40, 60 and 80 DAP	1.74^{d}	1.89^{d}	1.81^{d}	1.56^{d}	2.09^{b}	1.83^{b}	1.44^{d}	1.74^{b}	1.59	2.35^{d}	3.01^{c}	2.68^{c}	98.4
	(2.00)	(2.60)	(2.30)	(1.40)	(3.40)	(2.40)	(1.09)	(2.18)	(1.64)	(4.60)	(8.18)	(6.39)	
Weedy check	13.8^{a}	16.0^{a}	14.9^{a}	15.9^{a}	9.43^{a}	12.7^{a}	1.71^{bc}	1.66^{b}	1.69	21.1^{a}	18.6^{a}	19.9^{a}	-
	(191)	(257)	(224)	(254)	(89.1)	(172)	(1.92)	(1.79)	(1.86)	(447)	(348)	(398)	
LSD (p=0.05)	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	NS	Sig.	Sig.	Sig.	-
CV%	9.8	13.3	11.8	8.8	20.4	15.8	5.8	16.7	13.7	7.5	9.3	8.5	-

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

*Treatment means with the letter/letters in common are not significant by Duncan's New multiple range test at 5% level of significant, DAP=days after planting, HW = hand weeding, WSM = wheat straw mulch, PSM = rice straw mulch

Table 4. Monocot, dicot and sedges weed biomass as influenced by weed management practices in turmeric at harvest

Treatment	Monocot			Dicot			Sedges			Total			WCE (%)
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	
Rice straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP	5.69^{e}	7.32^{b}	6.51^{cd}	5.83^{def}	6.46^{cd}	6.15^{ef}	1.65^{bc}	1.59^{ab}	1.62^{a}	8.21^{ef}	9.81^{de}	9.01^{d}	76.1
	(31.4)	(52.8)	(42.1)	(33.3)	(41.3)	(37.3)	(1.73)	(1.58)	(1.66)	(66.5)	(95.7)	(81.1)	
Wheat straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP	5.31^{e}	8.14^{b}	6.72^{cd}	4.66^{f}	5.66^{d}	5.16^{f}	1.52^{cd}	1.49^{b}	1.51^{a}	7.10^{f}	9.94^{cde}	8.52^{d}	78.1
	(27.5)	(65.3)	(46.4)	(21.1)	(31.7)	(26.4)	(1.33)	(1.24)	(1.29)	(49.9)	(98.2)	(74.1)	
IC + HW at 30 DAP + PSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP	5.27^{e}	6.55^{b}	5.91^{d}	6.31^{de}	5.58^{d}	5.95^{ef}	1.92^{ab}	1.64^{ab}	1.78^{a}	8.36^{ef}	8.69^{e}	8.53^{d}	78.7
	(27.7)	(43.1)	(35.4)	(38.8)	(30.7)	(34.8)	(2.70)	(1.71)	(2.21)	(69.2)	(75.4)	(72.3)	
IC + HW at 30 DAP + WSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP	7.12^{de}	7.10^{b}	7.11^{cd}	5.28^{ef}	6.12^{d}	5.70^{f}	1.28^{d}	1.63^{ab}	1.46^{a}	8.88^{e}	9.47^{de}	9.18^{d}	75.2
	(50.1)	(51.3)	(50.7)	(27.7)	(36.7)	(32.2)	(0.66)	(1.65)	(1.16)	(78.5)	(89.7)	(84.1)	
Plastic mulch (0-3 DAP) *fb* HW at 20, 40 and 60 DAP	8.49^{cd}	7.93^{b}	8.21^{bc}	8.41^{bc}	8.19^{bc}	8.30^{bc}	1.52^{cd}	1.52^{b}	1.52^{a}	12.0^{cd}	11.5^{bcd}	11.7^{bc}	59.3
	(71.3)	(63.9)	(67.6)	(70.0)	(66.7)	(68.4)	(1.33)	(1.31)	(1.32)	(143)	(132)	(138)	
Plastic mulch (0-3 DAP) *fb* HW at 30 and 60 DAP	10.7^{b}	9.15^{b}	9.91^{b}	7.09^{cd}	8.53^{b}	7.81^{cd}	2.02^{a}	1.72^{ab}	1.87^{a}	12.9^{bc}	12.6^{bc}	12.7^{bc}	52.2
	(113)	(83.4)	(98.2)	(49.7)	(72.0)	(60.9)	(3.13)	(1.99)	(2.56)	(166)	(157)	(162)	
Turmeric + sun hemp intercropping *fb* HW at 30 DAP *fb* HW + mulch of sun hemp at 60 DAP *fb* HW at 90 DAP	10.1^{bc}	9.00^{b}	9.53^{b}	9.52^{ab}	8.71^{b}	9.12^{b}	1.27^{d}	1.79^{ab}	1.53^{a}	13.9^{b}	12.7^{b}	13.3^{b}	47.5
	(101)	(86.7)	(93.9)	(89.8)	(76.0)	(82.9)	(0.62)	(2.21)	(1.42)	(191)	(165)	(178)	
IC *fb* HW at 20, 40, 60 and 80 DAP	8.67^{cd}	9.42^{b}	9.05^{b}	6.96^{cd}	6.99^{bcd}	6.98^{de}	1.64^{c}	1.83^{a}	1.74^{a}	11.2^{d}	11.8^{bcd}	11.5^{c}	61.1
	(74.4)	(88.0)	(81.2)	(47.9)	(48.3)	(48.1)	(1.71)	(2.37)	(2.04)	(124)	(139)	(132)	
Weedy check	14.2^{a}	14.0^{a}	14.1^{a}	11.0^{a}	12.6^{a}	11.8^{a}	1.00^{e}	1.00^{c}	1.00^{b}	18.0^{a}	18.8^{a}	18.4^{a}	-
	(201)	(195)	(198)	(122)	(159)	(141)	(0.00)	(0.00)	(0.00)	(323)	(354)	(339)	
CV%	11.3	18.1	15.2	11.5	12.1	11.8	9.1	9.8	9.5	8.0	12.0	10.3	-

*Data subjected to ($\sqrt{x+1}$)transformation. Figures in parentheses are means of original values. Treatment means with the letter/letters in common are not significant by Duncan's New multiple range test at 5% level of significant. DAP=days after planting, HW = hand weeding, WSM = wheat straw mulch, PSM = rice straw mulch

Table 5. Effect of weed management practices on plant stand, rhizome yield, weed index and economics of turmeric

Treatment	Plant stand at harvest (no./net plot)			Rhizome yield (t/ha)			Weed index (%)			Net returns (x10^3 `/ha)	Total cost of cultivation (x10^3 `/ha)	B:C
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled			
Rice straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP	144^{a}	151^{a}	148^{a}	23.4^{ab}	23.0^{a}	1.79	3.31	-	-	153.42	194.58	1.79
Wheat straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP	145^{a}	149^{ab}	147^{a}	24.2^{a}	21.7^{ab}	1.77	-	5.80	1.29	148.92	194.58	1.77
IC + HW at 30 DAP + PSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP	139^{ab}	146^{ab}	143^{ab}	19.3^{c}	18.0^{cd}	1.40	20.2	21.9	19.8	79.26	199.74	1.40
IC + HW at 30 DAP + WSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP	141^{a}	143^{b}	142^{ab}	19.5^{bc}	18.9^{bc}	1.44	19.4	17.7	17.2	88.26	199.74	1.44
Plastic mulch (0-3 DAP) *fb* HW at 20, 40 and 60 DAP	124^{b}	132^{c}	128^{bc}	13.5^{de}	12.3^{ef}	0.90	44.2	46.4	44.4	-22.01	215.51	0.90
Plastic mulch (0-3 DAP) *fb* HW at 30 and 60 DAP	123^{b}	136^{c}	129^{bc}	13.1^{de}	11.2^{f}	0.85	45.9	51.4	47.8	-32.23	213.73	0.85
Turmeric + sun hemp intercropping *fb* HW at 30 DAP *fb* HW + mulch of sun hemp at 60 DAP *fb* HW at 90 DAP	124^{b}	144^{ab}	134^{b}	11.0^{e}	10.3^{f}	0.85	54.5	55.3	54.3	-27.77	186.77	0.85
IC *fb* HW at 20, 40, 60 and 80 DAP	129^{ab}	143^{b}	136^{b}	14.9^{d}	14.8^{de}	1.13	38.4	35.5	35.8	25.40	198.10	1.13
Weedy check	60.7^{c}	55.0^{d}	57.8^{d}	2.30^{f}	2.33^{g}	0.20	90.5	89.9	90.0	-139.25	173.90	0.20
CV%	6.8	2.8	5.1	13.0	11.3	12.2	-	-	-		-	

*Treatment means with the letter/letters in common are not significant by Duncan's New multiple range test at 5% level of significant. DAP: Days after planting, HW: Hand weeding, WSM: Wheat straw mulch, PSM: Rice straw mulch

to their effective suppression of the weed growth as observed in garlic and onion (Chaudhari *et al.* 2019) and also due to maintenance of the moisture as well as congenial condition, *i.e.* optimum temperature for better growth of the crop. Amoroso *et al.* (2010) reported that mulch controls the weeds by smothering, prevent day light which helps foster germination from reaching weed seeds and prevents airborne seeds from taking hold on the soil surface. Maximum weed control efficiency was observed under IC + HW at 30 DAP + PSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP which was closely followed by wheat straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP, PSM 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP and IC + HW at 30 DAP + WSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP at harvest.

Effect on turmeric and economics

The turmeric plant stand was optimal at 35 DAP during 2018-19, 2019-20 and in pooled at harvest. Significantly lower plant stand was recorded under plastic mulch (0-3 DAP) *fb* HW at 20, 40 and 60 DAP and plastic mulch (0-3 DAP) *fb* HW at 30 and 60 DAP as compared to rest of the treatment except weedy check which had significantly lowest plant stand (57.8/net plot) at harvest. Vanlalhluna *et al.* (2010) also observed beneficial effects of mulch on early sprouting of turmeric through moisture retention.

The rice straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP and wheat straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP remaining at par with each other resulted in significantly highest rhizome yield (23.2 and 22.9 t/ha, respectively). This might be attributed to effective reduction in the weeds biomass by mulches which was indicated from the higher rhizome yield as compared to no mulch. The next better treatment in order was IC + HW at 30 DAP + PSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP and IC + HW at 30 DAP + WSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP which gave rhizome yield of 19.2 and 18.9 t/ha, respectively as compared to rest of the treatment. Similarly, higher yield of garlic under rice straw much was also observed by Chaudhari *et al.* (2019). Increased growth parameters and reduced weed pressure on crop has led to increase in yield as reported by Ashok and Sanjay (2014). Further. the lowest turmeric rhizome yield (2.31 t/ha) was recorded under weedy check treatment as observed by Dhanapal *et al.* (2017). Yield reduction due to presence of weed was recorded minimum under wheat straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP (1.29%) followed by IC + HW at 30 DAP + WSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP (17.2%) and IC + HW at 30 DAP + PSM 5 t/ha (30 DAP) *fb* HW at 60 and 90 DAP (19.8%) while maximum yield reduction was observed under weedy check (90.0%) followed by turmeric + sun hemp intercropping *fb* HW at 30 DAP *fb* HW + mulch of sunnhemp at 60 DAP *fb* HW at 90 DAP (54.3%). Yield reduction of 78.2% due to weeds in weedy check was reported by Sachdeva *et al.* (2015).

Economics of different treatments indicated that maximum net returns of ` 1,53,420/ha with the highest benefit cost ratio of 1.79 was achieved under rice straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP, which was closely followed by wheat straw mulch 5 t/ha (0-3 DAP) *fb* HW at 30, 60 and 90 DAP which has recorded net return of ₹ 1,48,920/ha with the benefit cost ratio of 1.77. Similar observations were made by Roy and Dharminder (2015).

It was concluded from this study that integration of rice straw and wheat straw as mulching 5 t/ha with HW at 30, 60 and 90 DAP provides effective control of weeds, increases turmeric rhizome yield as well as higher net return and benefit cost ratio under organic production system.

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RESEARCH ARTICLE

Effect of herbicides in managing weeds and on *Gladiolus hybridus* Hort. growth and flowering

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ABSTRACT

An experiment was carried out to evaluate the efficacy of herbicides application in managing weeds and improving the gladiolus *(Gladiolus hybridus* Hort. cv. *Novalux)* growth and flowering. Treatments evaluated include: two doses each of atrazine, metribuzin, butachlor, pendimethalin and two controls, *viz*. weed free and weedy. All herbicide treatments significantly (p=0.05) affected the *G. hybridus* plant growth, flowering and associated weeds growth. Butachlor 1.0 kg/ha pre-emergence application (PE) recorded significantly greater plant height (90.23 cm), number of florets (12.46) while weed free control recorded significantly maximum spike length (60.64 cm) and floret size (7.58 cm). Metribuzin 0.25 kg/ha PE was at par with these treatments. All herbicide treatments caused significant reduction in weed density. Weed free control and metribuzin 0.25 kg/ha PE were most effective in reducing weed density, fresh and dry weed biomass with highest weed control efficiency and weed control index. Metribuzin at 0.25 kg/ha PE could be recommended for controlling the weeds and improving growth and flowering of *Gladiolus hybridus* cv. *Novalux*.

Key words: *Gladiolus hybridus* Hort., Herbicides, Metribuzin, Weed management

INTRODUCTION

Gladiolus (*Gladiolus hybridus* Hort.), known for its elegant spikes of different shapes and hues with excellent vase life is one of the most beautiful bulbous cut flowers in the floriculture industry and occupies fifth position in the international floriculture trade (Butt *et al.* 2015). Weeds are major constraints to the crop production as they directly affect crop growth and yield by competing for the essential growth resources or by releasing allelopathic substances which even results in crop failure (Pereira *et al.* 2011, Kumar *et al.* 2012, Rao *et al.* 2014). Weed control is difficult in Gladiolus as it is grown for cut flowers and corm production. Generally, 4-5 manual weedings are required in gladiolus cultivation which increases costly labour employment and increased cost of cultivation and moreover if not done properly may damage plants and corms. Hence resorting to chemical control would be ideal (Kumar *et al.* 2012.). Herbicides are economical, convenient and efficient in eradicating weeds and are considered viable option as they provide effective weed control without any phytotoxic effect on gladiolus (Leghari 2015; Queiroz *et al.* 2016) and with an enhancement in growth, flowering and production of corms (Swaroop *et al.* 2017). The herbicides like atrazine and metribuzin are found among the most widely used worldwide (Sattin *et al.* 1995) for effective weed control. The other herbicide like butachlor and pendimethalin are broad spectrum with low toxicity and soil persistence. These herbicides are selected for the present study because most of the weeds occurring in gladiolus field are broad-leaved weeds, hence these weedicides have broad spectrum and low toxicity. Thus, considering the above facts, the present study was undertaken to evaluate the effectiveness of different herbicides for manging weeds and to assess their effect on growth and production of *Gladiolus hybridus* cv. *Novalux*.

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MATERIALS AND METHODS

The experiment was conducted during 2017-19 at Department of Floriculture and Landscaping, Punjab Agricultural University, Ludhiana. The weather data with maximum and minimum average temperature, rainfall and RH for the two years has been given in **Table 1**. The experiment consisted of ten treatments: pre-emergence application (PE) of atrazine at 1.0 and 1.5 kg/ha; metribuzin at 0.25 and 0.50 kg/ha PE; butachlor at 1.0 and 1.5 kg/ha PE; pendimethalin 0.75 and 1.0 kg/ha PE; weed free and weedy control. The corms of uniform size were planted during October and pre-emergence

Table 1. Monthly meteorological data during the crop season 2017-2019 at PAU, Ludhiana

Months	Average temperature (^{0}C)	Relative Humidity (%)	Rainfall (mm)
September, 2017	29.89	29.6	0.0
October, 2017	25.66	26.1	0.0
November, 2017	20.12	20.5	0.0
December, 2017	14.47	16.3	0.0
January, 2018	12.5	75	18.4
February, 2018	16.0	64	27
March, 2018	21.6	61	0
April, 2018	27.8	43	10
September, 2018	28.0	75	250.6
October, 2018	24.2	64	0
November, 2018	19.3	63	2.6
December, 2018	13.9	68	0
January, 2019	12.3	70	66
February, 2019	14.7	75	95.6
March, 2019	18.6	67	7.4

herbicides were applied within 72 hours after planting the corms using sprayer fitted nozzle with working pressure of 30 psi using 600 liter of water per hectare. All cultural operations were followed as per standard package of practices. All treated plots were kept free of manual weeding except in weed free control, where weekly manual weeding was carried out.

The experiment was laid out in randomized block design (RBD) with three replications. At 60 days after planting (DAP) sampling was done using a quadrat of 50 × 50 cm placed randomly at two places in each plot to determine the weed density and fresh weight (fresh biomass) of different weeds. Weeds dry biomass was recorded by weighing after drying the weed samples at 60°C for 48 hours. The plant growth and floral parameters, corm yield, weed density and weed indices were recorded for two years and was analyzed statistically through ANOVA test (Steel *et al*. 1997) by CPCS1 software in which year was used as fixed factor and critical differences were worked out at five percent level. The pooled data was also statistically analyzed with two years considered as replications. Weed control efficiency and weed control index was worked out by using following formula (Mani *et al*. 1973, Mishra and Tosh 1979).

$$\text{Weed control efficiency} = \frac{\text{Weed density in control} - \text{Weed density in treated plot}}{\text{Weed density in control}} \times 100$$

$$\text{Weed control index} = \frac{\text{Weed biomass in control} - \text{Weed biomass in treated plot}}{\text{Weed biomass in control}} \times 100$$

RESULTS AND DISCUSSION

Gladiolus growth

The application of butachlor at 1.0 kg/ha PE resulted in significantly highest plant height (90.23 cm) which was at par with metribuzin at 0.25 k/ha and 0.5 kg/ha PE (88.60 and 87.97 cm) in pooled data of two years. (**Table 2**). Significantly lowest plant height was observed with atrazine at 1.0 kg/ha and 1.5 kg/ha PE (71.54 and 72.13 cm). The earliest flowering was recorded with butachlor at 1.5 kg/ha PE (107.88 days) which was significantly different from other treatments. The longest time to flowering was recorded with metribuzin at 0.25 kg/ha PE (113.50 days) which was at par with herbicidal treatments (**Table 2**). These results of delay in flowering with application of metribuzin are in conformity with earlier reports (Dhakar *et al*. 2016).

Gladiolus flowering and corm yield

The gladiolus floral characters and corm yield were significantly affected by herbicide treatments (**Table 2**). Significantly highest spike length was recorded in weed free control (60.64 cm) followed by butachlor 1.0 kg/ha PE (59.75 cm) and metribuzin 0.25 kg/ha PE (58.92 cm) which were at par amongst them. The minimum spike length was recorded with

Table 2. Effect of different treatments on plant growth and flowering parameters of gladiolus cv. *Novalux*

Treatment	Plant height (cm)			No. of leaves per plant			Days to flowering			Flowering duration (days)		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Atrazine 1.0 kg/ha PE	71.03	72.06	71.54	7.43	9.00	8.21	111.48	110.82	111.15	14.81	14.50	14.65
Atrazine 1.5 kg/ha PE	71.60	72.67	72.13	7.30	9.00	8.15	113.46	112.26	112.86	13.60	14.27	13.93
Metribuzin 0.25 kg/ha PE	87.20	90.00	88.60	9.11	9.16	9.13	113.00	113.32	113.16	13.83	15.50	14.66
Metribuzin 0.50 kg/ha PE	86.12	89.83	87.97	9.65	9.33	9.49	114.67	112.33	113.50	13.47	14.14	13.80
Butachlor 1.0 kg /ha PE	91.63	88.83	90.23	9.60	9.00	9.30	112.00	112.65	112.32	14.70	15.00	14.85
Butachlor 1.5 kg /ha PE	76.80	76.33	76.56	8.86	8.33	8.59	107.55	108.22	107.88	12.57	12.77	12.67
Pendimethalin 0.75 kg/ha PE	83.02	85.22	84.12	7.35	8.67	8.01	110.54	110.54	110.54	14.23	14.23	14.23
Pendimethalin 1.00 kg/ha PE	86.28	85.55	85.91	7.13	9.00	8.06	113.23	113.23	113.23	13.57	13.57	13.57
Control (weedy)	81.90	87.45	84.67	7.63	7.67	7.65	111.96	112.63	112.29	14.43	14.04	14.23
Control (weed free)	87.32	83.76	85.54	6.70	8.67	7.68	112.80	112.80	112.80	13.36	15.00	14.18
LSD (p=0.05)	9.37	8.09	4.55	NS	NS	NS	NS	NS	1.55	NS	NS	NS

*NS: Non-significant; PE: Pre-emergence application atrazine at 1.0 kg/ha and 1.5 kg/ha PE (42.55 and 42.86 cm). Metribuzin 0.25 kg/ha PE resulted in significantly highest rachis length (40.52 cm) followed by weed free control (39.32 cm), pendimethalin 1.00 kg/ha PE (39.03 cm) and metribuzin 0.50 kg/ha PE (39.01 cm) which were at par amongst them. The minimum rachis length was observed with atrazine 1.5 kg/ha and 1.0 kg/ha PE (31.23 and 32.34 cm). The highest number of florets per spike were recorded with butachlor 1.0 kg/ha PE (12.46) which was at par with metribuzin 0.50 kg/ha PE (12.19); metribuzin 0.25 kg/ha PE (12.09); pendimethalin 1.00 kg/ha PE (11.60); pendimethalin 0.75 kg/ha PE (10.86) and significantly different from other treatments. The largest floret size was recorded with weed free control (7.58 cm) which was at par with metribuzin 0.25 kg/ha PE (7.38 cm) and differed significantly from other treatments. Atrazine 1.5 kg/ha and 1.0 kg/ha PE resulted in smallest floret size (6.61 and 6.81 cm). The highest number of corms per plant was observed with atrazine 1.5 kg/ha PE (1.77) which was at par with weed free control (1.71) and differed significantly from metribuzin 0.50 kg/ha PE (1.60). The application of metribuzin resulted in reduced weed growth; therefore, the available nutrients were used by the crop which ultimately resulted in improved plant height, spike length, rachis length, and number of floret per spike and floret size with delay in flowering. The shorter plant height, spike length, rachis length and smaller florets observed with weedy control and atrazine was due to higher weed density resulting in greater weed competition (Burud *et al.* 2020).

Effect on weeds

The prominent weed species observed in experimental plots during both the years of study were *Cynodon dactylon, Cyperus rotundus, Parthenium hysterophorus, Chenopodium album, Phalaris minor* and others. Significantly lowest weed density and fresh weed biomass were recorded in metribuzin 0.25 kg/ha PE (95.51); pendimethalin 0.75 kg/ha PE (96.86) and metribuzin 0.50 kg/ha PE (102.06) which were at par amongst them (**Table 4**). The significantly highest weed density was recorded with weedy control (258.36) followed by atrazine 1.5 kg/ha and 1.0 kg/ha PE (187.20 and 157.29). The minimum weed dry biomass and maximum weed control efficiency (WCE) and weed control index (WCI) were recorded with metribuzin 0.25 kg/ha PE

Table 3. Effect of different treatments on floral characteristics and corm yield of gladiolus cv. Novalux

Treatment	Spike length (cm)			Rachis length (cm)			No. of floret/spikes			Floret size (cm)			Corms/corm			Corm diameter (cm)		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Atrazine 1.0 kg/ha PE	41.78	43.33	42.55	31.23	33.46	32.34	9.96	10.00	9.98	6.80	6.83	6.81	1.53	1.42	1.47	4.91	4.84	4.87
Atrazine 1.5 kg/ha PE	40.06	45.67	42.86	29.40	33.06	31.23	9.76	11.00	10.38	6.46	6.76	6.61	1.77	1.77	1.77	4.82	4.95	4.88
Metribuzin 0.25 kg/ha PE	57.85	60.00	58.92	43.00	38.05	40.52	12.35	11.83	12.09	7.42	7.34	7.38	1.54	1.39	1.46	4.87	4.77	4.82
Metribuzin 0.50 kg/ha PE	55.67	58.33	57.00	43.52	34.50	39.01	12.05	12.33	12.19	7.37	7.11	7.24	1.59	1.62	1.60	4.86	4.86	4.86
Butachlor 1.0 kg /ha PE	57.83	61.67	59.75	39.20	36.10	37.65	12.93	12.00	12.46	7.06	7.30	7.18	1.38	1.45	1.41	4.89	4.84	4.86
Butachlor 1.5 kg /ha PE	52.26	58.67	55.46	40.37	29.33	34.85	9.00	9.33	9.16	6.75	7.04	6.89	1.58	1.60	1.59	4.97	4.97	4.97
Pendimethalin 0.75 kg/ha PE	49.42	52.33	50.87	36.00	35.33	35.66	10.86	10.86	10.86	7.14	7.14	7.14	1.35	1.35	1.35	5.00	5.00	5.00
Pendimethalin 1.00 kg/ha PE	56.85	56.85	56.85	41.96	36.11	39.03	11.60	11.60	11.60	7.03	7.07	7.05	1.53	1.55	1.54	5.38	5.40	5.39
Control (weedy)	54.33	58.01	56.17	35.50	34.23	34.86	7.83	10.00	8.91	7.34	7.25	7.29	1.48	1.58	1.53	5.61	5.24	5.42
Control (weed free)	59.96	61.33	60.64	43.37	35.27	39.32	8.84	11.00	9.92	7.50	7.66	7.58	1.76	1.67	1.71	4.86	5.36	5.11
LSD (p=0.05)	11.21	10.32	3.11	NS	NS	1.68	2.45	2.44	1.68	NS	NS	0.29	NS	NS	0.12	NS	NS	0.34

*NS = non-significant

Table 4. Effect of different treatments on weeds in gladiolus cv. Novalux

Treatment	Weed density (no./m^2)			Weed fresh biomass (g/m^2)			Weed dry biomass (g/m^2)			WCE (%)	WCI (%)
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	Pooled	Pooled
Atrazine 1.0 kg/ha	164.33	150.26	157.29	44.67	76.00	60.33	25.35	38.23	31.79	39.10	77.20
Atrazine 1.5 kg/ha	203.88	170.53	187.20	91.00	87.33	89.16	26.00	39.21	32.60	27.50	76.83
Metribuzin 0.25 kg/ha	96.33	94.70	95.51	49.36	47.44	48.40	24.00	23.60	23.80	63.09	83.51
Metribuzin 0.50 kg/ha	100.20	103.93	102.06	52.00	70.33	61.16	22.50	25.93	24.21	60.49	83.06
Butachlor 1.0 kg/ha	118.30	97.93	108.11	198.33	95.00	146.66	59.00	55.33	57.16	58.13	60.53
Butachlor 1.5 kg/ha	121.46	111.07	116.26	310.00	149.00	229.50	91.70	69.00	80.35	54.98	45.29
Pendimethalin 0.75 kg/ha	95.36	98.37	96.86	245.00	191.00	218.00	72.00	54.44	63.22	62.50	56.94
Pendimethalin 1.00 kg/ha	101.93	102.90	102.41	356.80	202.00	279.40	77.36	56.77	67.06	60.45	54.40
Control (weedy)	257.03	259.70	258.36	396.00	311.22	353.61	164.70	128.40	146.55	0.00	0.00
Control (weed free)	0.00	0.00	00.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00
LSD (p=0.05)	16.25	18.22	19.84	131.92	9.76	113.88	40.70	0.91	26.22	7.80	10.30

WCE: Weed control efficiency; WCI: Weed control index

(23.80 g/m^2) and metribuzin 0.50 kg/ha PE (24.21 g/m^2) which were at par amongst them. The maximum fresh (353.61 g/m^2) and dry weed biomass (146.55 g/m^2) was recorded with weedy control. The WCE and WCI were higher in all herbicide treatments compared to weedy check. All herbicidal treatments caused significant reduction in weed density (Chahal *et al*. 2013). Metribuzin 0.25 kg/ha PE reduced the weed density due to reduced germination and emergence of weeds which might be due to its control of weeds by inhibiting photosystem by disrupting electron transfer which results in death due to starvation in the target plant. The atrazine has same mode of action but metribuzin possesses higher solubility and lower absorption and persistence than atrazine (Vencill 2002), which implies a high potential for movement in soil and thus the effect differed. The minimum dry biomass with metribuzin application was due to better control of weeds and suppression of weed growth (Biradar and Yenag 1999) and at later stage; it might be due to longer persistence of this herbicide. The variability in weed densities in different treatments may be due to the fact that some herbicides are more effective for weed control than others (Khan *et al*. 2008) with lower herbicidal activity and were not able to control newly emerged weeds for longer periods (Patel *et al*. 2006). The higher WCE in herbicidal treatments was owing to lower weed dry biomass and due to effective control of complex weed flora (Priya and Kubsad 2013).

It was concluded that metribuzin at 0.25 kg/ha PE could be recommended for effectively controlling weeds and improving growth and flower quality of *Gladiolus hybridus* cv. Novalux.

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RESEARCH ARTICLE

The enhancement of root yield and quality of ashwagandha [*Withania somnifera* (L.) Dunal] by weeds leaves extracts

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ABSTRACT

Ashwagandha, having multiple therapeutic uses, is a highly valuable medicinal plant for pharmaceutical industry. In order to meet the industrial demand, both quality as well as yield of ashwagandha needs to be improved agronomically. In this study, effect of weed leaves extracts (WLE) as bio-stimulants to improve yield and quality of ashwagandha roots were studied in pot experiments during 2020-21. The treatments consisted of combinations of four commercial preparations with microorganisms (Pusa zinc solubilizing biofertilizer, Pusa Azotobacter liquid biofertilizer, Pusa PSB liquid biofertilizer, Pusa Potash solubilizing liquid biofertilizer) with four weeds [*Cyperus rotundus* L., *Amaranthus viridis* L., *Echinochloa colona* (L.) Link, *Digera arvensis* Forsk.] leaves extracts. The treated plants exhibited stimulatory responses in growth and physiology, leading to enhanced dry root yield of ashwagandha compared to control. Yield enhancing effects of different treatments, when used separately, without combination was the highest in case of *Amaranthus viridis* WLE, followed by *Digera arvensis* WLE and PSB solubilizing biofertilizer, however co-application resulted in synergistic effect. Among different combination of treatments, Pusa PSB liquid biofertilizer + *Amaranthus viridis* WLE recorded the highest whole ashwagandha plant dry matter production (157.3 g/plant), root fresh weight per plant (65.0 g) and root dry weight (23.0 g). Different bioactive compounds in ashwagandha roots (withanoloides A, withanosides IV and withanone) were also enhanced with this treatment indicating the potentiality of weed leaves extracts as biostimulants, with a possibility to use as a novel eco-friendly approach for enhancing root yield and quality of ashwagandha.

Keywords: Ashwagandha, Bio-stimulants, Weed leaves extracts, Bio-fertilizers, Root yield and quality, *Withania somnifera*

INTRODUCTION

Ashwagandha [*Withania somnifera* (L.) Dunal] is highly valuable medicinal plant having immense pharmaceutical uses. Ashwagandha is grown on an estimated area of 10,780 hectares in India, with a total dry root yield of 8,429 tonnes. India exported a total amount of about 132.72 tons of *W. somnifera* valuing 8.17 crores (USD 1,202,740) during 2014–2016 (Srivastava *et al.* 2018). It is widely used in more than 100 formulations in traditional medicine systems like Siddha, Unani, and Ayurveda, since over 3000 years. *W. somnifera* possess diverse pharmacological properties such as anti-carcinogenic, anti-apoptotic, anti-tumor, bone healing, neuroprotective, cardioprotective, anti-tumor, anti-oxidant, immunomodulatory, anti-stress, and anti-inflammatory (Sangwan *et al.* 2017). Because of its therapeutic applications, antioxidants, and anticancerous activities, products like herbal tea, powders, tablets, and syrups are prepared through its extracts (Leyon and Kuttan 2004). Ashwagandha owes its medicinal benefits to the presence of distinct group natural steroidal lactones called withanolides of alkaloid metabolites, mainly in the roots (Chaurasiya *et al.* 2000). Withanolides, which are polyoxygenated C28 steroidal lactones, are the major pharmacologically active constituents of *W. somnifera* roots.

In order to meet the current industrial demand, researchers are focusing towards enhancing yield and quality by low-cost organic inputs. Weeds may also act as potential biostimulant, because of having higher nutrient concentration in their respective biomass as they accumulate these nutrients from the cropping soil. They usually absorb mineral nutrients, both macro and micro with a faster rate as compared to several other crops and are able to accumulate them in larger amounts in their tissues (Mahajan and Jha 2009, Rao and Matsumoto 2017). The weeds (*Tephrosia vogelii* and *Tithonia diversifolia)* leaves extracts (WLE) were reported to significantly increased chlorophyll content, the number of pods per plant and overall seed yield of beans (Mkindi *et al.* 2020). Hence, a study was conducted to quantify the biostimulant

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potential of leaves extracts of common weeds, *viz*. *Cyperus rotundus, Amaranthus viridis, Echinochloa colona and Digera arvensis* to enhance yield and quality of ashwagandha.

MATERIALS AND METHODS

Experimental site and weather conditions

The experimental site was the research farm of CSIR–Central Institute of Medicinal and Aromatic Plants (CIMAP), located at 26°5´ N latitude 80°5´ E longitude with an elevation of about 120 m above mean sea level Lucknow, Uttar Pradesh, India which is classified as a subtropical region of north Indian plains. The climate of the site is characterized with hot summers, fairly cool winters and with an average annual precipitation of 1000 mm. The soil of experimental field was categorized as loamy sand having pH 8.03 with organic carbon of 3.21 g/kg soil and N, P, K as 202.1, 52.06, and 152.24 kg/h soil, respectively. Pot experiment was conducted during October, 2020 to April, 2021.

Crop raising

Quality seed material of *Withania somnifera* was procured from the gene bank of CSIR-CIMAP, Lucknow. During the cropping periods, standard agronomic procedures were performed for the cultivation of crops. In all pots required amount of applicable bio-fertilizer recommended dose were applied through microbial cultures. The amount of different microbial cultures according to the treatments was applied and weed leaf extract sprayed treatment wise as recommended duration after sowing. All the recommended cultural practices like irrigation, weeding and foliar applications etc. were followed according to the requirement during crop growth period.

Treatment and experimental design

The main pot experiment was designed in completely randomized block design (CRBD) with three replications comprising of 17 treatments including control. The treatments were combinations of four commercial preparations with micro-organisms (Pusa zinc solublizing biofertilizer, Pusa Azotobacter liquid biofertilizer, Pusa PSB liquid biofertilizer, Potassium solublising bacteria) with four weeds (*cyperus rotundus* L., *Amaranthus viridis* L., *Echinochloa colona* (L.) Link, *Digera arvensis* Forsk.) leaves extracts. The treatments include: Pusa zinc solubilizing biofertilizer + *Cyperus rotundus* weed leaf extracts (WLE); Pusa zinc solubilizing biofertilizer + *Amaranthus viridis* WLE; Pusa zinc solubilizing biofertilizer + *Echinochloa colona* WLE; Pusa zinc solublizing biofertilizer + *Digera arvensis* WLE; Pusa azotobacter liquid biofertilizer + *cyperus rotundus* WLE; Pusa azotobacter liquid biofertilizer + *Amaranthus viridis* WLE; Pusa azotobacter liquid biofertilizer + *Echinochloa colona* WLE; Pusa azotobacter liquid biofertilizer + *Digera arvensis* WLE; Pusa phosphate solubilizing bacteria (PSB) liquid biofertilizer + *Cyperus rotundus* WLE; Pusa PSB liquid biofertilizer + *Amaranthus viridis* WLE; Pusa PSB liquid biofertilizer + *Echinochloa colona* WLE; Pusa PSB liquid biofertilizer + *Digera arvensis* WLE; Potash solubilizing liquid biofertilizer + *Cyperus rotundus* WLE; Potash solubilizing liquid biofertilizer + *Amaranthus viridis* WLE; Potash solubilizing liquid biofertilizer+ *Echinochloa colona* WLE; Potash solubilizing liquid biofertilizer+ *Digera arvensis* WLE and control. Control plants were sprayed with distilled water to maintain the same moisture content.

Another set of pot experiment was also conducted to compute individual effect of these four biofertiliser's and four weed leaves extracts with one control (total nine treatments) on root yield of ashwagandha. The effective microorganism (EM) culture, commercially known as Pusa zinc solublizing biofertilizer, Pusa Azotobacter liquid biofertilizer, Pusa PSB liquid biofertilizer and potash solublizing liquid biofertilizer were obtained from Indian Agricultural Research Institute, New Delhi, India. Potash solublizing liquid biofertilizer contains *Bacillus decolorationis*. Pusa Azotobacter liquid formulation have highly efficient nitrogen fixing *Azotobacter chroococcum*. Pusa zinc solublizing biofertilizer, a liquid formulation contains highly efficient zinc solubilizing bacteria (*Bacillus endophyticus*). Pusa PSB liquid biofertilizers are liquid formulations of P-solubilizing bacteria containing *Paenibacillus tylopili*.

Fresh solution of biofertilizers for use was prepared from stock. Tap water was added to the stock to prepare a 0.2% solution. Liquid biofertilizers were administered during the time of sowing via seed treatment and soil application in each respective pot. Foliar applications of the different weed leaves extracts were done twice consecutively at an interval of 60 and 75 days after sowing. Graduated atomizer or sprayer (5 ml) was used for the careful foliar application of weed leaves extracts (WLE).

Prepartion of weed leaves extracts

The leaves of selected weeds were collected individually from research farm of CSIR-CIMAP, Lucknow. One kg leaves of each weed were air-dried under shade for two weeks and subsequently grinded using pestle mortar. For the preparation of 1% stock extract, 10 g leaf powder was soaked in 1-liter distilled water and kept on shaker for 24 hrs at temperature (25 ± 1æ%°C). The extract was purified by filtering twice through (Whatman No. 1) filter paper. The extracts were used within five hours from cutting and extracting (Mahdavikia and Saharkhiz 2015). The mineral content and chemical composition in weed leaf extracts were analyzed (**Table 1**).

Plant growth related observations and harvesting of crop

Plant height (cm), number of leaves, plant canopy, LAI, branches per plant, root girth (mm), and root length (cm) were measured from the plants in each pot. 200 days after sowing, the roots were dug, rinsed with plain water, and oven dried. The roots were dried till they had 7-8% of the original moisture content following which, they were stored in air-tight packs for further chemical analysis.

Chemical profiling of roots

The percentages of total alkaloid, withaferin A, withanolide, withanolide A, and 12 deoxywithastra-monolide were also estimated in the properly dried root samples of each treatment using high-performance liquid chromatography (HPLC) as per the standard method (API 2010). Fresh plant root samples were collected and kept for dry in oven. The dried roots were grinded for making fine powder. The root powder (2 gm) was soaked in methanol in 50 ml and sonicated for 30 minutes. The solution was filtered twice through Whatman No.1 filter paper after cooling. In a 100-ml volumetric flask, the filtrates were mixed, concentrated, and the volume was made up. 2 ml of each sample were filtered using a 0.45-µm membrane filter and subjected into the High-performance liquid chromatography (HPLC) for the analysis of bioactive compounds. HPLC analysis was performed on a SHIMADZU (Nexera XR, autosampler), Phenomenex C18 column (250 × 4.6 mm i.d.; 5 µm) were used. The gradient elution was carried out using solvent system A) phosphate buffer (prepared by dissolving 0.14 g of potassium dihydrogen orthophosphate in 500 ml of water, adding 0.5 ml of orthophosphoric acid and diluting up to 1000 ml) and B) only acetonitrile (100%). Injection volume was 20 µl and flow rate 1.5 ml/min. Run time of injection was 45min and absorbance recorded at 227 nm.

Statistical analysis

The data recorded were analyzed statistically using the techniques described by Panse and Sukhatme (1985). LSD values at 5% level of probability were calculated for comparing the treatment means where the "F" test was found significant at p=0.05.

RESULTS AND DISCUSSION

Plant growth characteristics

Ashwagandha crop growth parameters at 90 DAS were significantly influenced by combined application of biofertilizers and WLE (**Table 2**). Among the different treatments, Pusa PSB liquid biofertilizer + *Amaranthus viridis* WLE recorded significantly highest plant height (53.33 cm), closely followed by T 10 (51.0) and potash solubilizing liquid biofertilizer + *Echinochloa colona* WLE (48.5) as compared to untreated control (30.33). Leaf area index and number of leaves per plant also followed similar trend. At harvest stage, plant growth attributes as well as root and shoot yield was significantly higher in Pusa PSB liquid biofertilizer + *Amaranthus viridis* WLE, closely followed by Pusa PSB liquid biofertilizer + *Cyperus rotundus* and Potash solubilizing liquid biofertilizer + *Echinochloa colona* WLE than control (**Table 3**). Root biomass per pot increased with Pusa PSB liquid biofertilizer + *Amaranthus viridis* WLE application, as compared to control. Similar results were reported in Senna (Anisuzzaman *et al*. 2014) and *Thymus vulgaris* (Yadegari *et al.* 2012), upon treatments with different microbial biostimulants.

Root yield and quality

Quality of root (length and girth) of ashwagandha forms an important quality parameter. Marked variation was observed on both individual and combined effect of different biofertilizer and WLE treatments on ashwagandha whole plant and root dry matter production (**Table 4** and **5**). Among all the nine treatments of secondary pot experiment, yield enhancing effects of individual treatments was the highest in case of *Amaranthus viridis* WLE, followed by *Digera arvensis* WLE and PSB solubilizing biofertilizer (**Table 5**). Among the combined application of biofertilizer and WLE treatments (main pot experiment), Pusa PSB liquid

Table 1. Major nutrient content found in weeds leaves extracts

Selected weed	N mg/L	P mg/L	K mg/L	Cu mg/L	Fe mg/L	Mn mg/L	Zn mg/L
Amaranthus viridis	381	79.89	206	0.77	2.345	-	0.05
Digera arvensis	274	62.16	132	1.32	4.88	0.415	0.025
Echinochloa colona	40	20.1	307	5.1	2.975	0.085	0.085
Cyperus rotundus	-	16.84	350	0.4	1.505	0.005	0.08

biofertilizer + *Amaranthus viridis* WLE recorded the highest whole plant dry matter production (157.3 g per plant), root fresh weight/plant (65.0 g) and root dry weight (23.0 g) while the minimum values were reported in control. Taiwo and Makinde (2005) have reported stimulatory effects of foliar application of *Tithonia diversifolia* extract on growth and yield of *Vigna unguiculata*. Mkindi *et al.* 2020 reported that foliar application of plant extracts from *Tephrosia vogelii* and *Tithonia diversifolia* contributed to plant nutrition as a foliar fertilizer, by enhancing growth and yield of common bean plant. Mkindi *et al.* 2020 further suggested that this contribution to growth and yield was related to the addition of nitrogen as *T. diversifolia* and *T. vogelii* were known to produce nitrogen-rich green biomass. Our results were also supported by weed leaf extracts helping in indirect physiological assistance by acting as a topical green fertilizer (Jama *et al.* 2000), bio-stimulant (Pretali *et al.* 2016), or foliar feed (Shaaban 2001). The consortia of biostimulants (biofertilisers and WLE), having beneficial soil microbes, and plant nutrients resulted in improved root yield in the present investigation. The synced administration of biostimulants (biofertilizers and WLE) could have dramatically trigerred the soil processes and increased the bioavailability of nutrients as leguminous weeds like *Amaranthus viridis* and *Digera arvensis* contained large amount of N, P, K nutrients and their extract contain these nutrients in

Table 2. Effect of biofertilizers and weeds leaves extracts (WLE) on ashwagandha plant height, number of leaves per plant and Leaf area index at 90 DAS

Treatment	Plant height (cm)	No. of leaves	Leaf area index
Control (sprayed with distilled water)	30.33	18.0	0.41
Pusa zinc solublizing biofertilizer + *Cyperus rotundus* WLE	40.33	23.3	0.56
Pusa zinc solublizing biofertilizer + *Amaranthus viridis* WLE	38.00	25.6	0.67
Pusa zinc solublizing biofertilizer + *Echinochloa colona* WLE	39.33	20.6	0.49
Pusa zinc solublizing biofertilizer +*Digera arvensis* WLE	41.00	26.3	0.79
Pusa Azotobacter liquid biofertilizer + *Cyperus rotundus* WLE	45.33	24.3	0.68
Pusa Azotobacter liquid biofertilizer + *Amaranthus viridis* WLE	47.00	26.0	0.72
Pusa Azotobacter liquid biofertilizer + *Echinochloa colona* WLE	42.66	22.3	0.56
Pusa Azotobacter liquid biofertilizer + *Digera arvensis* WLE	42.66	23.6	0.62
Pusa PSB liquid biofertilizer + *Cyperus rotundus* WLE	51.00	36.3	1.05
Pusa PSB liquid biofertilizer + *Amaranthus viridis* WLE	53.33	38.0	1.19
Pusa PSB liquid biofertilizer + *Echinochloa colona* WLE	42.66	27.6	0.85
Pusa PSB liquid biofertilizer +*Digera arvensis* WLE	45.33	30.6	0.85
Potash solublizing liquid biofertilizer+ *Cyperus rotundus* WLE	40.66	25.0	0.66
Potash solublizing liquid biofertilizer+ *Amaranthus viridis* WLE	40.15	25.6	0.73
Potash solublizing liquid biofertilizer+ *Echinochloa colona* WLE	48.50	35.40	1.00
Potash solublizing liquid biofertilizer+*Digera arvensis* WLE	48.00	32.33	0.92
LSD (p=0.05)	2.97	2.61	0.13

Table 3. Effect of biofertilizers and foliar applied weeds leaves extracts (WLE) on ashwagandha crop growth parameters of at harvest stage

Treatment	Ashwagandha			
	Plants height (cm)	Plants canopy (cm)	No. of branches	Plant biomass per plant (gm)
Control (sprayed with distilled water)	55.0	36.7	9.0	77.7
Pusa zinc solublizing biofertilizer + *Cyperus rotundus* WLE	68.6	55.0	13.0	100.3
Pusa zinc solublizing biofertilizer + *Amaranthus viridis* WLE	66.6	57.7	10.0	117.0
Pusa zinc solublizing biofertilizer + *Echinochloa colona* WLE	61.5	58.3	11.0	110.7
Pusa zinc solublizing biofertilizer +*Digera arvensis* WLE	75.0	63.3	11.3	120.3
Pusa Azotobacter liquid biofertilizer + *Cyperus rotundus* WLE	71.7	60.0	10.0	107.3
Pusa Azotobacter liquid biofertilizer + *Amaranthus viridis* WLE	76.7	59.0	9.7	100.0
Pusa Azotobacter liquid biofertilizer + *Echinochloa colona* WLE	68.7	61.7	11.0	111.6
Pusa Azotobacter liquid biofertilizer + *Digera arvensis* WLE	71.3	67.0	11.6	131.0
Pusa PSB liquid biofertilizer + *Cyperus rotundus* WLE	78.0	57.0	11.5	132.7
Pusa PSB liquid biofertilizer + *Amaranthus viridis* WLE	73.3	66.7	11.7	157.3
Pusa PSB liquid biofertilizer + *Echinochloa colona* WLE	69.0	56.7	8.0	124.0
Pusa PSB liquid biofertilizer +*Digera arvensis* WLE	62.7	53.3	10.3	83.3
Potash solublizing liquid biofertilizer+ *Cyperus rotundus* WLE	70.7	55.3	10.7	97.3
Potash solublizing liquid biofertilizer+ *Amaranthus viridis* WLE	71.0	53.0	9.0	107.7
Potash solublizing liquid biofertilizer+ *Echinochloa colona* WLE	76.3	68.3	11.0	131.3
Potash solublizing liquid biofertilizer+*Digera arvensis* WLE	67.7	53.3	11.3	109.0
LSD (p=0.05)	10.99	NS	NS	NS

available form, (**Table 1**) which significantly influenced the ashwagandha plant growth and yield. Similar effects of combined application of vermicompost and biofertilizers have been reported previously in rosemary (*Salvia rosmarinus* L.), thyme (*Thymus vulgaris* L.) (Sudhakar 2005) and *Withania somnifera* (Basak *et al.* 2020).

Bioactive compounds and their content

The highest withanolide A content was detected in Pusa Azotobacter liquid biofertilizer + *Amaranthus viridis* WLE (0.268 mg/g) closely followed by Pusa PSB liquid biofertilizer + *Amaranthus viridis* WLE (0.268 mg/g) while it was detected 1.48 mg/g in control. Withanone content in control 0.034 mg/g whereas 0.061 mg/g found in Pusa PSB liquid biofertilizer + *Cyperus rotundus* WLE treatment (**Table 5**). Highest content of withanoside IV was found in Pusa Azotobacter liquid biofertilizer + *Cyperus rotundus* WLE and Pusa Azotobacter liquid biofertilizer + *Amaranthus viridis* WLE treatment (0.096 mg/g). Pusa Azotobacter liquid biofertilizer + *Amaranthus viridis* WLE treatment has given highest content of withanoloides A and withanoside IV in comparison to the control and other treatments, while Pusa PSB liquid biofertilizer + *Cyperus rotundus* WLE treatment recorded the highest withanone content. In the present investigation, the increased content of withanoloides A, withanosides IV and withanone post biostimulant application might be due its beneficial role in improving soil health and quality and increasing nutrient bioavailability. Increased nutrient availability has been associated with enhanced production of bioactive compounds in several medicinal plants like *Centella asiactica* (Jat and Gajbhiye 2017), Kalmegh (Jat and Gajbhiye 2019), and ashwagandha (Rajasekar and Elango 2011).

The spraying of microbial bio-elicitors along with foliar application of weed leaves extracts improved plant growth, root yield and quality in ashwagandha in this study, indicating the potentiality of weeds as a valuable ‘resource’ rather than ‘waste’.

Table 4. Effect of biofertilizers and foliar applied weeds leaves extracts (WLE) on ashwagandha growth and yield at harvest stage

Treatment	Ashwagandha			
	Root length (cm)	Root diameter (mm)	Root fresh weight / plant (gm)	Root dry weight / plant (gm)
Control (sprayed with distilled water)	14.66	19.26	38.33	11.66
Pusa zinc solublizing biofertilizer + *Cyperus rotundus* WLE	17.33	24.53	55.00	15.00
Pusa zinc solublizing biofertilizer + *Amaranthus viridis* WLE	15.00	23.40	58.00	16.88
Pusa zinc solublizing biofertilizer + *Echinochloa colona* WLE	16.00	23.10	48.30	13.25
Pusa zinc solublizing biofertilizer +*Digera arvensis* WLE	18.66	22.93	56.76	15.80
Pusa Azotobacter liquid biofertilizer + *Cyperus rotundus* WLE	17.00	23.33	47.33	12.80
Pusa Azotobacter liquid biofertilizer + *Amaranthus viridis* WLE	19.00	20.76	41.25	12.00
Pusa Azotobacter liquid biofertilizer + *Echinochloa colona* WLE	17.33	23.10	51.00	15.33
Pusa Azotobacter liquid biofertilizer + *Digera arvensis* WLE	19.00	21.566	52.00	15.66
Pusa PSB liquid biofertilizer + *Cyperus rotundus* WLE	19.33	25.76	62.00	21.33
Pusa PSB liquid biofertilizer + *Amaranthus viridis* WLE	16.66	27.56	65.00	23.00
Pusa PSB liquid biofertilizer + *Echinochloa colona* WLE	16.33	23.45	64.00	22.20
Pusa PSB liquid biofertilizer +*Digera arvensis* WLE	18.00	22.26	41.00	11.90
Potash solublizing liquid biofertilizer+ *Cyperus rotundus* WLE	18.00	25.43	54.45	16.40
Potash solublizing liquid biofertilizer+ *Amaranthus viridis* WLE	20.33	23.2	50.60	14.85
Potash solublizing liquid biofertilizer+ *Echinochloa colona* WLE	23.66	24.86	54.00	16.20
Potash solublizing liquid biofertilizer+*Digera arvensis* WLE	17.00	22.70	42.00	12.50
LSD (p=0.05)	NS	NS	NS	NS

Table 5. Effect of biofertilizers and foliar applied weeds leaves extracts (WLE) (applied alone, without combination) on ashwagandha growth and yield at harvest stage

Treatment	Ashwagandha			
	Root length (cm)	Root diameter (mm)	Root fresh weight/plant (gm)	Root dry weight/plant (gm)
Control (sprayed with distilled water)	14.02	18.79	37.57	11.20
Amaranthus viridis WLE	16.75	23.49	54.52	15.23
Digera arvensis WLE	19.75	24.05	51.21	14.99
Echinochloa colona WLE	17.42	22.19	47.90	13.95
Cyperus rotundus WLE	18.08	22.84	50.26	14.59
Pusa zinc solubilizing biofertilizer	13.39	18.79	43.61	12.18
Pusa Azotobacter	16.09	19.75	42.64203	12.41
Pusa PSB liquid biofertilizer	17.11	22.44	50.31	14.33
Potassium solubilizing bacteria)	15.79	19.23	40.21	11.99
LSD (p=0.05)	NS	NS	NS	NS

Table 6. HPLC profiling for analysis of withanolide content in dry root powder of *Withania somnifera*

Treatment	Withanoside IV (mg/g)	Withanolide A (mg/g)	Withanone (mg/g)
Control (sprayed with distilled water)	ND	0.148	0.038
Pusa zinc solublizing biofertilizer + *Cyperus rotundus* WLE	ND	0.125	0.024
Pusa zinc solublizing biofertilizer + *Amaranthus viridis* WLE	ND	0.141	0.018
Pusa zinc solublizing biofertilizer + *Echinochloa colona* WLE	0.050	0.129	0.022
Pusa zinc solublizing biofertilizer +*Digera arvensis* WLE	0.007	0.115	0.010
Pusa azotobacter liquid biofertilizer + *Cyperus rotundus* WLE	0.096	0.181	0.038
Pusa azotobacter liquid biofertilizer + *Amaranthus viridis* WLE	0.096	0.268	0.044
Pusa azotobacter liquid biofertilizer + *Echinochloa colona* WLE	0.064	0.168	0.046
Pusa azotobacter liquid biofertilizer + *Digera arvensis* WLE	0.046	0.134	0.030
Pusa PSB liquid biofertilizer + *Cyperus rotundus* WLE	0.011	0.141	0.061
Pusa PSB liquid biofertilizer + *Amaranthus viridis* WLE	0.000	0.118	0.010
Pusa PSB liquid biofertilizer + *Echinochloa colona* WLE	ND	0.183	0.032
Pusa PSB liquid biofertilizer +*Digera arvensis* WLE	ND	0.258	0.054
Potash solublizing liquid biofertilizer+ *Cyperus rotundus* WLE	0.010	0.171	0.015
Potash solublizing liquid biofertilizer+ *Amaranthus viridis* WLE	0.040	0.200	0.022
Potash solublizing liquid biofertilizer+ *Echinochloa colona* WLE	ND	0.246	0.028
Potash solublizing liquid biofertilizer+*Digera arvensis* WLE	0.017	0.218	0.014

* ND- Not Detected

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RESEARCH NOTE

Non chemical weed management in organically grown direct-seeded aerobic upland rice in newly cleared forest area

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ABSTRACT

A field experiment was conducted in newly cleared forest area under organic production system at College of Agriculture (CAU-I), Kyrdemkulai, Meghalaya, India during rainy (*Kharif)* season of 2020. The objective of experiment was to evaluate timing and frequency of manual and mechanical methods of weed management on weeds, growth and yield of direct-seeded upland aerobic rice. The grain yield for both *Sahbhagi Dhan* and *Bhalum-1* rice varieties was highest in weed free and it was at par with yield in mechanical weeding twice at 23-25 and 45-50 days after seeding (DAS).The manual and mechanical weeding didn't differ significantly due to the use of higher seed rate, lower weed density and uniform distribution of inter and intra-row weeds. The mechanical weeding was found economical than manual weeding due to lesser labour and time requirements for weeding.

Keywords: Aerobic rice, Mechanical weeding, Non-chemical weed management, Organic production system, *Sahbhagi Dhan*

The rice is the staple food in Meghalaya and is grown on 1.11 lakh ha area with production and productivity of 3.04 lakh tonnes and 2740 kg/ha, respectively (Anonymous 2019). In Meghalaya, the rice is mainly grown under rainfed upland and rainfed lowland ecosystems due to significantly higher variation in rainfall across the state. The use of agrochemicals for nutrient and biotic stress management is very less in Meghalaya on account of farmers preference to traditional cultivation methods using indigenous technical knowledge (ITK) which suits the socio-economic conditions of local production system. The washing out of agrochemicals due to heavy rains, non-availability of agrochemicals on time and low seed replacement ratio with less prominence of improved varieties are few other reasons for non-adoption of agro-chemical based crop management systems. In rice production, weed management is of immense importance (Deka and Barua 2015) considering losses caused by weeds in rice, particularly in direct-seeded upland rice (Rao *et al.* 2007). The losses due to weed in direct-seeded rice were reported to be 20 to 100% (Singh *et al.* 2016). In Meghalaya, nearly 42.3% area is occupied by forests (Anonymous 2019a) and the rice cultivated area is surrounded by forest and prominence of wild vegetation and therefore, greater species diversity is common in rice cultivation. Considering both non-use of herbicides and yield losses in upland rice due to weeds, the alternative best non-chemical combinations of manual and mechanical weeding is need to be identified for managing weeds effectively and improve rice yield. Hence, a study was conducted with an objective to evaluate timing and frequency of manual and mechanical methods of weed management on weeds, growth and yield of direct-seeded upland aerobic rice.

The study was conducted during rainy (*Kharif)* season of 2020 at Research Farm of College of Agriculture (CAU-I), Kyrdemkulai, Ri-Bhoi district of Meghalaya (25^0.74' N and 91^0 81' E), India in recently cleared forest area. The climate of selected area is subtropical type with average seasonal (South West monsoon) and annual precipitation of 1424.1 and 2119.3 mm, respectively. The area selected is at the hill top where trees and wild vegetations were cleared six months before the sowing of rice by cutting trees and removing wild vegetation without burning. As the area is at the top and vegetation is cleared well ahead of sowing, soil was poor in organic carbon and acidic in reaction. The experiment was conducted in split-plot design with rice cultivars (*viz. Sahbhagi Dhan* and *Bhalum-1*) in main plots and seven weed management treatments in subplots, *viz*. control, manual weeding twice at 25-30 and 45-50 days after sowing (DAS), manual weeding thrice at 25-30, 45-50 and 60 DAS, mechanical

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weeding at 23-25 and 50 DAS, manual weeding at 25-30 DAS followed by (*fb*) mechanical weeding at 50 DAS, mechanical weeding at 23-25 DAS *fb* manual weeding at 45-50 DAS and weed free. Rice was grown as direct-seeded rice under rainfed upland aerobic conditions by sowing manually in 3rd and 4th July using 20 cm row spacing with seed rate of 60 kg/ha. The nutrients were applied using poultry manure equivalent to 120 kg nitrogen/ha and 1.5 t/ha lime was applied. Both poultry manure and lime were applied and soil incorporated before the sowing of rice. The crop was grown as rainfed crop and irrigation was not applied. In weed free plots, weeding was done 4 times and for manual weeding, treatment weeds were removed by hand and also using *khurpi* as per the treatment details. For mechanical weeding, manual operated rake was used. The standard recommended practices were followed for recording of rice growth attributes and yield data. To measure rice total biomass yield and grain yield, net plots were harvested and sun-dried in the field and then weighed. Rice grain yield was measured after cleaning and drying. For measurement of weed density and biomass, 25 × 25 cm quadrat was used and samples at three spots were taken for recording all the observations. The data recorded was statistically analyzed using F-test as per the standard statistical procedure (Gomez and Gomez 1984) and least significant difference (LSD) were used for determination of treatment significance. For analysis of weed density and biomass data, logarithmic transformation was used.

Effect on weeds

The predominent weed species in experiment field were: *Chromolaena odorata* (L.) R.M.King & H.Rob., *Elephantopus scaber* L., *Galinsoga parviflora* Cav., *Heliotropium indicum* L., *Lophatherum gracile* Brongn. (L. gracile), *Mimosa pudica* L., *Spilanthes acmella* Murr., *Sida acuta* Burm.f., *Spilanthes acmella* Murr. and *Panicum repens* L. The weed density was higher at 30 DAS in both varieties and decreased at 60 DAS. Significant and negative relation was observed between the dry matter production of rice varieties *Bhalum-1* and in *Sahbhagi Dhan* and weed biomass at 60 DAS (**Table 1**). The weed density at both observations was higher in *Sahbhagi Dhan*; while weed biomass at 30 DAS was higher in *Sahbhagi Dhan* and at 70 DAS it was higher in *Bhavum-1* rice. The variation in weed biomass at 30 DAS was mainly due to the occurred weed density; while at 70 DAS, it was mainly due to applied treatment. The highest weed density and biomass was recorded in weedy check at both 30 and 70 DAS.

Effect on rice growth and yield attributes

The greater height of *Bhalum-1* was observed at 30, 60, 90 DAS and at harvest. Among weed management treatments, weed free and manual weeding twice recorded greater rice height (**Table 2**). The highest tillers/m^2 was observed in weed free. The variation in crop growth in response to weed management treatment was reported by Deka and Barua (2015). The manual and mechanical weeding didn't show any significant difference indicating the intra row weed competition was not influencing the growth attributes of both rice varieties. The highest increase in shoot dry matter accumulation from 30 to 90 DAS was recorded in *Bhalum-1*. The manual weeding twice and mechanical weeding twice recorded higher rice dry matter accumulation than weedy check at 90 DAS.

Table 1. Weed density and biomass at 30 and 70 days after seeding (DAS) as influenced by two rice varieties and non-chemical weed management treatments

Treatment	Weed density (no./m^2)		Weed biomass (g/m^2)	
	30 DAS	70 DAS	30 DAS	70 DAS
Rice variety				
Sahbhagi Dhan	1.51 (32.7)	1.27 (19.6)	0.61 (4.3)	1.43 (27.3)
Bhalum-1	1.44(27.9)	1.21 (17.1)	0.46 (3.2)	1.52 (33.3)
LSD (p=0.05)	0.01	0.14	0.07	0.08
Weed management				
Control (farmers' practice)	1.52(33.7)	1.42 (26.5)	0.77 (6.0)	1.58 (38.3)
Manual weeding twice at 25-30 DAS and 45-50 DAS	1.44(27.7)	1.10 (12.8)	0.64 (4.5)	1.43 (27.5)
Manual weeding thrice at 25-30 DAS,45-50 DAS and 60 DAS	1.50(31.8)	1.27 (19.0)	0.46 (3.2)	1.44 (28.0)
Mechanical weeding twice at 23-25 DAS and 45-50 DAS	1.50 (31.8)	1.21 (16.5)	0.44 (2.8)	1.50 (32.0)
Manual weeding at 25-30 DAS *fb* mechanical weeding at 45-50 DAS	1.45 (28.3)	1.31 (20.8)	0.47 (3.2)	1.48 (30.7)
Mechanical weeding at 23-25 DAS *fb* manual weeding 45-50 DAS	1.51 (32.8)	1.30 (20.3)	0.53 (3.5)	1.53 (33.7)
Weed free	1.41 (25.7)	1.08 (12.5)	0.45 (3.0)	1.34 (22.2)
LSD (p=0.05)	0.06	0.11	0.13	0.07

Note: The values in parentheses are the original values

The yield attributes recorded (filled, unfilled and total spikelet number) and yield (grain and straw) were higher in *Bhalum-1* across varieties indicating its superior performance (**Table 2**). *Bhalum-1* variety had higher total grains, filled and unfilled grains than *Sahbhagi Dhan* variety. The total and filled spikelet number didn't differ significantly amongst weed management treatments in *Bhalum-1*; while in *Sahbhagi Dhan,* they were significantly higher in weed free and mechanical weeding twice. The grain yield of both *Sahbhagi Dhan* and *Bhalum-1* was highest in weed free. The variation in response of rice varieties to weed competition was reported earlier (Mahajan *et al.* 2014). The yield of both rice varieties was sub-optimal due to possible reasons such as light textured soil with acidic soil reaction, washing of manure applied due to heavy rainfall, termite infestation and incidence of blast disease. The yield in weed free check was at par with yield obtained with mechanical weeding twice and can be considered as most viable / effective options for weed management in upland direct-seeded rice. Weeding three times was at par with hand weeding twice (both in manual and mechanical) in both rice varieties which was due to initial lesser weed occurrence and at the end of the weeding time. This indicates that, hand weeding twice was adequate for effective weed management. The manual and mechanical weeding didn't differ significantly which was due to use of higher seed rate, lower weed population, use of hand hoes as mechanical weed management option and equitable distribution of weed between inter and

Table 2. Rice growth attributes, yield attributes and yield as affected by non-chemical weed management treatments in organic production system

Treatment	Rice plant height (cm)				Rice tillers/m^2 (no.)		Rice yield attributes and yield				
	30 DAS	60 DAS	90 DAS	At harvest	60 DAS	At harvest	Filled spikelets (no.)	Unfilled spikelets (no.)	Total spikelets (no.)	Grain yield (t/ha)	Straw yield t/ha
Rice variety											
Sahbhagi Dhan	40.1	56.9	78.8	87.5	540.1	273.8	50.6	16.4	67.0	0.89	1.91
Bhalum-1	42.1	61.8	91.1	96.1	524.7	268.1	60.3	18.8	79.1	1.26	2.98
LSD (p=0.05)	0.6	1.4	1.2	3.5	8.8	8.7	3.7	2.2	2.8	0.054	0.07
Weed management											
Control (farmers' practice)	39.7	55.5	81.0	86.3	534.5	260.3	38.3	19.8	58.2	0.72	1.76
Manual weeding twice at 25-30 DAS and 45-50 DAS	41.7	60.4	86.6	93.6	529.0	277.5	56.7	16.8	73.5	1.14	2.57
Manual weeding thrice at 25-30 DAS,45-50 DAS and 60 DAS	41.9	58.1	84.0	91.6	529.3	267.3	58.0	18.7	76.7	1.13	2.52
Mechanical weeding twice at 23-25 DAS and 45-50 DAS	41.7	60.8	86.5	93.4	532.2	275.3	59.8	16.5	76.3	1.16	2.60
Manual weeding at 25-30 DAS *fb* mechanical weeding at 45-50 DAS	40.5	58.3	83.6	91.6	534.8	269.3	58.7	17.0	75.7	1.12	2.51
Mechanical weeding at 23-25 DAS *fb* manual weeding 45-50 DAS	40.8	60.1	85.5	92.7	529.8	262.3	56.7	18.3	75.0	1.11	2.51
Weed free	41.9	62.1	87.5	93.6	537.2	284.7	60.0	16.2	76.2	1.18	2.64
LSD (p=0.05)	1.7	2.3	3.9	3.4	11.0	10.9	2.5	1.6	2.7	0.05	0.06

Table 3. Effects of different non-chemical weed management treatments on economics of rice cultivation in rice varieties

Treatment	Gross returns (x10^3 \`/ha)	Cost of cultivation (x10^3 \`/ha)	Net returns (x10^3 \`/ha)	B:C ratio
Rice variety				
Sahbhagi Dhan	41.55	32.03	9.52	1.30
Bhalum-1	59.49	32.03	27.46	1.86
LSD (p=0.05)	2.22	-	2.22	0.07
Weed management				
Control (farmer practice)	33.97	25.70	8.27	1.32
Manual weeding twice at 25-30 DAS and 45-50 DAS	53.18	31.70	21.48	1.68
Manual weeding thrice at 25-30 DAS, 45-50 DAS and 60 DAS	52.86	35.70	17.16	1.48
Mechanical weeding twice at 23-25 DAS and 45-50 DAS	54.10	29.87	24.23	1.81
Manual weeding at 25-30 DAS *fb* mechanical weeding at 45-50 DAS	52.39	31.12	21.28	1.68
Mechanical weeding at 23-25 DAS *fb* manual weeding 45-50 DAS	51.98	31.12	20.86	1.67
Weed free	55.15	39.03	16.12	1.41
LSD (p=0.05)	1.85	-	1.85	0.06

intra-row. Hence, mechanical weeding was found economical than manual weeding due to greater labour, time and cost required for manual weeding. The need for mechanical weeding in the organic production systems was also stressed by Weide *et al.* (2008).

The highest gross returns were observed in weed free plot and remained at par with mechanical weeding twice (23-25 DAS and 45-50 DAS) (**Table 3**), However, the net return was highest with mechanical weeding twice (23-25 DAS and 45-50 DAS). The net returns were lowest in weed free plot amongst all treatments (except control) due to higher number of weeding that increased cultivation cost and non-proportionate yield improvement. This trend in higher net returns was reflected in B:C ratio with higher B:C ratio of 1.81 with mechanical weeding twice. The B:C ratio in weed free and manual weeding thrice (25-30 DAS, 45-50 DAS and 60 DAS) was lowest among the tested weed management treatments (except control). Across the varieties, *Bhalum-1* found superior in gross and net returns due to higher yield. In the context of the rice farmers of North East Hill region, mechanical weeding is relevant as minor light weight and small weeder can be very good alternatives to reduce drudgery associated with manual hand weeding and attain optimal economic upland rice yield in the organic farming adopting region under upland situation.

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RESEARCH NOTE

Impact of sole and sequential application of herbicides on weeds, nutrients uptake and productivity of maize

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ABSTRACT

A field experiment was carried out during rainy *(Kharif)* season 2019 at agricultural research farm of Trihut College of Agriculture (TCA), Dholi under Rajendra Prasad Central Agricultural University (RPCAU) Pusa, Samastipur, Bihar, (India) to quantify the efficacy of sole and sequential application of herbicides in managing weeds and enhance the productivity of maize (*Zea mays* L.). Eleven treatments were tested in randomised block design with three replications. Atrazine 1.0 kg/ha pre-emergence application (PE) followed by (*fb*) post-emergence application (PoE) of tembotrione 0.120 kg/ha at 25 days after seeding (DAS) significantly reduced weed density, weed biomass, N, P, K removal by weeds and increased the yield attributes, grain yield and benefit-cost ratio of maize compared to sole and tank mixed application of atrazine, topramezone and tembotrione.

Keywords: Atrazine, Maize, Nutrient uptake by weeds, Tembotrione, Topramezone, Weed management

Maize (*Zea mays* L.) is an important cereal crop grown for food, feed and industrial purpose in the world and it occupy third position after rice and wheat in India. The maize productivity is affected by the weeds due to severe competition between the crop and weeds in early growth stage of the crop. The yield loss may extend from 33 to 50%, if weeds are not controlled adequately (Sharma *et al.* 2000). It has been reported that application of herbicides alone was not sufficient to control weeds in the maize crop (Sweta *et al.* 2015, Kumar and Chawla 2019). The use of pre-and post-emergence herbicides or herbicide mixture would be more effective to manage weeds in maize (Kakade *et al.* 2020) as the pre-emergence application of herbicides will control the weeds upto 25 days and later the post-emergence herbicide application further controls weeds. Therefore, an experiment was conducted to quantify the efficacy of sole and sequential application and mixture herbicides on weeds management in maize during rainy (*Kharif*) season.

A field trial was conducted during the rainy (*Kharif*) season 2019 at agricultural research farm of Trihut College of Agriculture (TCA) Dholi under the Rajendra Prasad Central Agricultural University (RPCAU) Pusa, Samastipur Bihar, (India). The soil was alkaline in nature, it has pH 7.9. The soil was low in soil organic carbon (0.46%), medium in available N (238 kg/ha), P (17.4 kg/ha) and available K (126.2 kg/ha). The total rainfall during experimental period was 935.6 mm, which was distributed well during crop growth period and made environment congenial for proper expansion of crop. The highest (250.6 mm) rainfall received in 39 meteorological weeks (24-30 Sep.) (**Figure 1**). During the experimental period, maximum temperature was 35.5^{0}C and the lowest temperature was 21^{0}C in July and October, respectively. The evaporation was high during August and the lowest was in September and it was inversely related to rainfall (**Figure 1**).

The weed management treatments tested included weedy check; post-emergence application (PoE) of topramezone 25.2 g/ha at 25 days after seeding (DAS), tembotrione 0.120 kg/ha PoE at 25 DAS; pre-emergence application (PE) of atrazine 1.0 kg followed by (*fb*) hand weeding (HW) at 25 DAS; atrazine 0.75 kg/ha pre-emergence (PE) followed by (*fb)* topramezone 25.2 g/ha PoE at 25 DAS; atrazine 0.75 kg PE followed by (*fb*) tembotrione 0.120 kg/ha PoE at 25 DAS; atrazine 1.0 kg PE followed by (*fb*) topramezone 25.2 g/ha PoE at 25 DAS; atrazine 1.0 kg/ha PE followed by (*fb*) tembotrione 0.120 kg/ha PoE at 25 DAS; topramezone 25.2 g/ha + atrazine 0.75kg/ha PoE at 15 DAS; tembotrione 0.120 kg/ha + atrazine 0.75kg/ha PoE at 15 DAS and weed free. A randomized block design with three replications was

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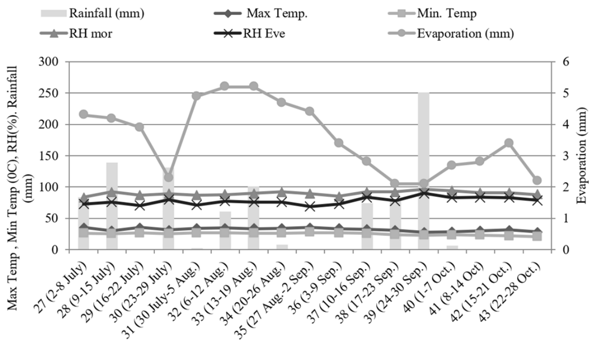


Figure1. Weather parameter during experimental period (July to October 2019)

used. The maize crop variety '*Shaktiman 5'* was grown with recommended package and practices and need based irrigation except the weed control practices. All the herbicides were applied as per treatment by using knap sack sprayer with flat fan nozzle using 500 l/ha of water as per treatments. Weeds were sampled by randomly placing a quadrate of 0.25 m^2 (0.5 × 0.5 m^2) in each plot at two spots. The weeds within the quadrat were counted, identified and classified into groups of sedges, grasses and broad-leaved weeds (BLW) and the density presented as number/ m^2. Later, weeds were uprooted sun dried before keeping in oven at 60-65^{0}C temperature for 48 hrs for complete dry and then weighed for determined its dry weight (weed biomass).

The five plants were selected randomly from each plot to determine the yield attributes. Net plot area was harvested for estimating grain and straw yield of crop. Plant analysis for N, P and K was done as per methods describe in Jackson (1973). Economics of different treatments was calculated as per prevailing market price. The data for different weed and crop parameters was analyzed with the help of ANOVA technique for randomized block design. To normalize the data of weed density and biomass, values were transformed by square root transformed $\sqrt{x+0.5}$ before analysis. The least square difference (LSD) post hoc was applied for pair wise comparison at $p<0.05$.

Weed flora

A total of twelve weed species were observed in the experimental field, of which four were grasses, *viz.*, *Digitaria sanguinalis* (L.) Scop., *Sorghum helepense* (L.) Pers, *Brachiaria reptans* (L.) C.A.Gardner and C.E.Hubb., *Dactyloctenium aegyptium* (L.) Willd., seven were broad-leaved weeds (BLW), *viz. Digera arvensis* Forssk., *Commelina benghalensis* L., *Cleome viscose* L., *Euphorbia hirta* L., *Boerhavia erecta* L. and *Celosia argentea* L., *Ipomea pes-tigradis* and a sedge, *viz. Cyperus rotundus* L. The grass weeds were dominant with relative density (RD) of 42% followed by BLW with RD of 33% and sedge with RD of 25% in the control plot of experimental field.

Effect on weeds

Application of atrazine 1.0 kg/ha PE followed by (*fb*) tembotrione 0.120 kg/ha PoE significantly reduced the sedge density (3.01 plants/m^2) than the unweeded and topramezone 25.2 g/ha PoE (4.76 plants/m^2) and tembotrione 0.120 kg/ha PoE (4.37 plants/m^2) alone, (**Table 1**). This result was corroborated with the results of Kakade *et al.* (2020). However, it was statistically at par with atrazine 1.0 kg/ha PE followed by (*fb*) topramezone 25.2 g/ha (3.28 plant /m^2) and atrazine 1.0 kg/ha PE *fb* hand weeding at 25 DAS (3.18/m^2). Tank mixing application of tembotrione 0.120 kg/ha + atrazine 0.75 kg/ha PoE and topramezone 25.2 g/ha + atrazine

Table 1. Effect of weed management treatments on weed density, weed biomass, weed control efficiency (WCE) and weed index (WI) at 50 days after seeding (DAS)

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)	WCE (%)	Weed index
	Sedges	Broad-leaved	Grasses	Total weeds			
Weedy check	8.04(64.3)	8.16(66.3)	9.26(85.3)	14.69(216.0)	12.44(154.6)	0	57.5
Topramezone 25.2 g/ha at 25 DAS	4.76(22.3)	4.0(15.6)	5.88(34.3)	8.51(72.3)	6.85(46.6)	69.7	38.3
Tembotrione 0.120 kg/ha at 25 DAS	4.37(18.6)	3.57(12.3)	5.29(27.6)	7.67(58.6)	6.21(38.3)	75.2	23.1
Atrazine 1.0 kg/ha PE *fb* HW at 25 DAS	3.18(9.6)	2.75(7.3)	4.31(18.3)	5.97(35.3)	4.79(22.6)	85.3	10.0
Atrazine 0.75 kg/ha PE *fb* topramezone 25.2 g/ha at 25 DAS	3.71(13.3)	3.43(11.3)	5.03(25.3)	7.09(50.0)	5.75(32.6)	78.8	29.2
Atrazine 0.75 kg/ha PE *fb* tembotrione 0.120 kg/ha at 25 DAS	3.43(11.3)	3.11(9.3)	4.76(22.3)	6.57(43.0)	5.29(27.6)	81.9	10.6
Atrazine 1.0 kg/ha PE *fb* topramezone 25.2 g/ha at 25 DAS	3.28(10.3)	2.74(7.33)	4.66(21.33)	6.27(39.0)	5.07(25.3)	83.6	12.8
Atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha at 25 DAS	3.01(8.6)	2.43(5.6)	4.12(16.6)	5.60(31.0)	4.54(20.3)	86.8	2.7
Topramezone 25.2 g/ha + atrazine 0.75 kg/ha at 15 DAS	4.36(18.6)	3.32(10.6)	6.13(37.3)	8.18(66.6)	6.56(42.66)	72.2	31.2
Tembotrione 0.120 kg/ha + atrazine 0.75 kg/ha at 15 DAS	3.69(14.6)	3.01(8.6)	5.83(33.6)	7.55(57.0)	6.14(37.3)	75.8	20.5
Weed free check	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	100	00.0
LSD (p=0.05)	0.28	0.28	0.40	0.66	0.35	-	--

#Weed data was transformed by square root transformed $\sqrt{x+0.5}$. The value in parentheses is original value; PE: Pre-emergence; DAS: Days after seeding

0.75 kg/ha PoE have recorded significantly lower sedge density than all except atrazine 1.0 kg/ha PE *fb* topramezone 25.2 g/ha PoE and atrazine PE *fb* hand weeding (HW). Atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha PoE and atrazine 1.0 kg/ha PE *fb* topramezone 25.2 g/ha PoE recorded significantly lower BLW density than sequential application of lower dose of atrazine 0.75 kg/ha PE with either with topramezone 25.2 g/ha or tembotrione 0.120 kg/ha PoE. Atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha PoE significantly reduced the grasses weed density (4.12/m^2), compared to all other practices but it was at par with atrazine 1.0 kg/ha PE *fb* HW at 25 DAS (4.31/m^2).

Atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha PoE significantly decreased the total weed density and its biomass compared from all treatments except atrazine 1.0 kg/ha *fb* HW. The atrazine as PE controlled the initial weed population and then sequential application of tembotrione 0.120 kg/ha as PoE controlled the second flushes of weeds. This result was corroborated with the results of Dey and Pratap (2018) and Verma *et al.* (2018).

It was corroborated with the results of Kakade *et al.* (2020). The highest WI (57.6) was recorded with weedy check and the lowest (2.7) with atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha PoE at 25 DAS.

Nutrient uptake by weeds and maize

The highest N (40.35 kg/ha), P (10.2 kg/ha), and K (11.9 kg/ha) removal by weeds was recorded in weedy check. Atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha at 25 DAS significantly reduced N, P and K removal by weeds compared to all other treatments (**Table 2**). This treatment effectively controlled the weeds in field thereby reduced the removal of nutrients. The highest N, P and K uptake through crop (grain and straw) recorded with weed free and the lowest uptake of those nutrients by crop in weedy check. Atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha PoE significantly increased N, P and K uptake by grain and straw compared from other practices and it was at par on weed free check.

Effect on maize

Atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha PoE recorded significantly higher seed weight (23.3 g) than other treatments and was at par with weed free (24.2 g) (**Table 3**). The weed free obtained the highest grain yield (6.42 t/ha) and weedy check recorded lowest (2.72 t/ha). Atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha PoE at 25 DAS recorded significantly higher maize grain yield (6.24 t/ha) and straw yield (8.61 t/ha) than all other herbicides treatments. This treatment effectively controlled the weeds and provided completive free microclimate to the maize crop resulted in higher yield. Similar results were recorded by Verma *et al.* (2018), Nazreen *et al.* (2018), Mitra *et al.* (2018), Singh *et al.* (2012), Chhokar *et al.* (2019)

Maize cob length, grains/cob and 1000-grain weight and grain yield increased with better weed control in the field resulting in greater nutrients uptake compare to the unweeded plot, as also reported by Nazreen *et al.* (2017), Yakadri *et al.* (2015) and Singh *et al.* (2017).

Economics

The highest gross returns was recorded with the weed free but net returns was found with the application of atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha PoE compared to the other all treatments due to lesser cost of cultivation involved in this treatment (₹ 34445/ha) **(Figure 2)** than normal manually weeding practice (₹ 42786/ha.).

Table 2. Effect of weed management treatments on nutrients uptake by weeds and maize

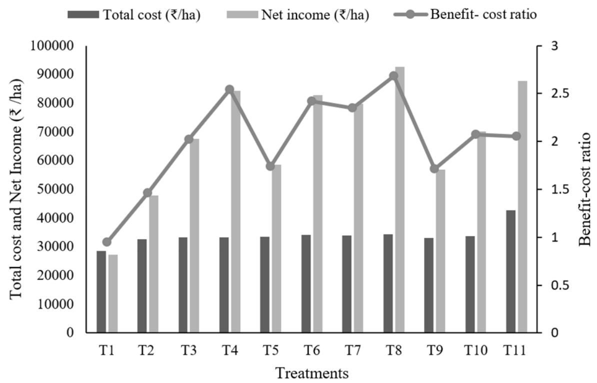
Treatment	N uptake (kg/ha)			P uptake (kg/ha)			K uptake (kg/ha)		
	Weeds	Maize		Weeds	Maize		Weeds	Maize	
		Grain	Straw		Grain	Straw		Grain	Straw
Topramezone 25.2 g/ha at 25 DAS	20.5	76.3	23.1	4.3	16.6	3.95	5.3	12.2	48.9
Tembotrione 0.120 kg/ha at 25 DAS	15.9	94.7	28.5	3.4	22.2	5.08	3.4	16.2	66.1
Atrazine 1.0 kg/ha PE *fb* HW at 25 DAS	10.9	111.4	34.2	2.1	28.2	5.65	3.1	19.1	72.5
Atrazine 0.75 kg/ha PE *fb* topramezone 25.2 g/ha at 25 DAS	12.5	86.6	25.5	2.6	21.3	4.49	3.1	14.9	56.5
Atrazine 0.75 kg/ha PE *fb* tembotrione 0.120 kg/ha at 25 DAS	11.7	110.6	34.2	2.4	27.5	5.89	2.8	17.7	74.8
Atrazine 1.0 kg/ha PE *fb* topramezone 25.2 g/ha at 25 DAS	14.6	108.9	31.1	3.0	27.3	5.46	3.5	17.8	67.6
Atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha at 25 DAS	9.2	121.6	36.9	1.6	31.8	6.44	1.6	21.8	87.6
Topramezone 25.2 g/ha + atrazine 0.75 kg/ha at 15 DAS	16.4	84.1	25.4	3.5	21.1	4.41	4.1	14.9	56.5
Tembotrione 0.120 kg/ha + atrazine 0.75 kg/ha at 15 DAS	15.8	98.3	29.7	2.8	24.9	5.02	3.5	16.8	63.1
Weedy check	40.3	49.3	15.5	10.2	13.1	2.72	11.9	8.1	31.1
Weed free check	0.0	124.4	36.0	0.0	35.9	6.93	0.0	24.3	90.5
LSD (p= 0.05)	1.33	2.81	0.68	0.21	0.71	0.12	0.24	0.48	1.6

PE: Pre-emergence; DAS: Days after seeding; *fb*: followed by

Table 3. Effect of weed management treatments on yield attributes, yield and harvest index of maize

Treatment	100 seed weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index
Topramezone 25.2 g/ha at 25 DAS	19.1	3.95	5.55	0.41
Tembotrione 0.120 kg/ha at 25 DAS	20.2	4.94	6.96	0.41
Atrazine 1.0 kg/ha PE *fb* HW at 25 DAS	21.3	5.77	7.97	0.42
Atrazine 0.75 kg/ha PE *fb* topramezone 25.2 g/ha at 25 DAS	19.7	4.54	6.08	0.42
Atrazine 0.75 kg/ha PE *fb* tembotrione 0.120 kg/ha at 25 DAS	21.2	5.73	7.97	0.41
Atrazine 1.0 kg/ha PE *fb* topramezone 25.2 g/ha at 25 DAS	20.8	5.69	7.60	0.42
Atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha at 25 DAS	23.3	6.24	8.61	0.42
Topramezone 25.2 g/ha + atrazine 0.75 kg/ha at 15 DAS	19.0	4.41	6.21	0.41
Tembotrione 0.120 kg/ha + atrazine 0.75 kg/ha at 15 DAS	19.9	5.09	7.08	0.41
Weedy check	16.9	2.72	3.90	0.41
Weed free check	24.2	6.42	8.79	0.42
LSD (p=0.05)	1.61	0.15	0.16	NS

PE: Pre-emergence; DAS: Days after seeding; *fb*: followed by



T1: Weedy check; **T2**: Topramezone 25.2 g/ha at 25 DAS; **T3**: Tembotrione 0.120 kg/ha at 25 DAS; **T4**: Atrazine 1.0 kg/ha PE *fb* HW at 25 DAS; **T5**: Atrazine 0.75 kg/ha PE *fb* topramezone 25.2 g/ha at 25 DAS; **T6**: Atrazine 0.75 kg/ha PE *fb* tembotrione 0.120 kg/ha at 25 DAS;**T7**: Atrazine 1.0 kg/ha PE *fb* topramezone 25.2 g/ha at 25 DAS; **T8**: Atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha at 25 DAS; **T9**: Topramezone 25.2 g/ha + atrazine 0.75 kg/ha at 15 DAS; **T10**: Tembotrione 0.120 kg/ha + atrazine 0.75 kg/ha at 15 DAS; **T11**: Weed free check

Figure 2. Cost of cultivation, net return and benefit-cost ration of different treatments

Based on this study, it was concluded that atrazine 1.0 kg/ha PE *fb* tembotrione 0.120 kg/ha PoE effectively controls the weeds resulting in higher grain yield of maize, net return and benefit-cost ratio of maize crop compare to manual weeding and other treatments.

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RESEARCH NOTE

Effect of weeds control measures on weeds and yield of pearl millet [*Pennisetum glaucum* L.]

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ABSTRACT

A field experiment was conducted at the Instructional Farm, Agricultural Research Station, S.K. Rajasthan Agricultural University, Bikaner, Rajasthan during rainy *(Kharif)* season 2018 to identify effective weed control measures to manage weeds and increase yield of pearl millet [*Pennisetum glaucum* L.]. The experiment was laid out in randomised block design having 12 treatments with three replications. The pre-emergence application (PE) of atrazine 0.5 kg/ha was significantly superior in reducing weed density and biomass of both broad-leaved and grassy weeds.Weed free, atrazine 0.5 kg/ha PE and post-emergence application (PoE) of 2,4-D 0.5 kg/ha at 30 days after seeding (DAS), hand hoeing twice at 20 and 40 DAS and hand wheel hoeing twice at 20 and 40 DAS registered 2.48, 2.42, 2.39, 2.33 and 2.28 t/ha seed yield, respectively as against 1.31 t/ha seed yield in weedy check. The maximum gross returns of ₹ 86360/ha was recorded under weed free treatment while highest B:C ratio was recorded with 2,4-D 0.5 kg/ha PoE at 30 DAS (3.17), which was closely followed by atrazine 0.5 kg/ha PE (3.16).

Keywords: Atrazine, 2,4-D, Herbicides, Hoeing, Pearle millet, *Pennisetum glaucum* L., Weed management

Pearl millet [*Pennisetum glaucum* L.], also known as candle millet or bajra, is an important millet crop of India. Its nutritious grain forms the important component of human diet and stover forms the principal maintenance ration for ruminant livestock during the dry season. It is a drought resistant cereal having the maximum potentiality of grain production in adverse conditions (Acharya *et al*. 2017). As pearl millet is grown predominantly in warm rainy season, heavy infestation of weeds deprives the crop of vital nutrients, moisture, light and space. Like other rainy season crops, pearl millet faces severe weed competition during initial slow growth stage leading to heavy (20-72%) reduction in grain yield due to heavy weed infestation (Das and Yaduraju 1995, Banga *et al.* 2000). Pearl millet picks up growth, start tillers and increase in height after 25-30 days after seeding (DAS) and becomes more competitive against the weeds. Thus, the field should be kept free from weeds at least for the initial 25-30 DAS for attaining higher pearl millet yield. The predominant methods of weed management used in pearl millet by farmers are inter-culturing and hand weeding. The use of herbicides for weed management reduces the cost of cultivation due to non-availability of labour and increased wages. Atrazine is a broad-spectrum herbicide and is recommended for pre-emergence application (PE). Post-emergence herbicides application (PoE) appears to be as more practical and economical as these can be applied after weeds emergence. Hence, in this study both pre- and post-emergence applications of herbicides were evaluated to identify the best effective and economical option for weed management in pearl millet.

A field study was conducted during rainy *(Kharif)* season of 2018 at Instructional Farm (28.01^{0}N latitude and 73.22^{0}E longitude at an altitude of 234.7 M above mean sea level) of SKRAU, Bikaner, Rajasthan. The soil was loamy sand, low in organic carbon (0.08 %) and available N (78 kg/ha) and medium in available P (22 kg/ha) and available K (210 kg/ha) with pH 8.3. The 12 treatments, *viz*. weedy check, weed free, hand hoeing twice at 20 and 40 DAS, hand wheel hoeing twice at 20 and 40 DAS, atrazine 0.125 kg/ha PE, atrazine 0.25 kg/ha PE, atrazine 0.5 kg/ha PE, atrazine 0.1 kg/ha PoE 20 DAS, atrazine 0.2 kg/ha PoE 20 DAS, atrazine 0.3 kg/ha PoE 20 DAS, 2,4-D 0.3 kg/ha PoE 30 DAS and 2,4-D 0.5 kg/ha PoE 30 DAS. The experiment was laid out using randomised block design with three replications. Pearl millet variety "*HHB-67*" was sown

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at 45 x15 cm row spacing using seed rate of 4 kg/ha. Except management of weeds, all other agronomic practices were adopted as per the University recommendation. Weed density was taken from two random spots in each plot by counting the number of weeds per quadrat of 1.0 m^2 and the average was computed. In order to draw valid conclusion, the weed density data were subjected to square root transformation before subjecting to statistical analysis. Weed control efficiency of each treatment was calculated by using the following formula:

$$\text{WCE (\%)} = \frac{\text{Weed biomass in weedy check plot} - \text{Weed biomass in treated plot}}{\text{Weed biomass in treated plot}} \times 100$$

Grain and stover yields were recorded from net plot and economics was worked out in terms of net return and B:C ratio to find out most economic treatment using prevailing market prices of inputs and out puts.

The tested weed control treatments markedly reduced crop-weed competition. Atrazine 0.5 kg/ha PE significantly lowered the density of grassy weeds compared to hand wheel hoeing twice at 20 and 40 DAS, atrazine 0.3 kg/ha PoE at 20 DAS, 2,4-D 0.3 kg/ha PoE and 2,4-D at 0.5 kg/ha PoE and was statistically at par with, atrazine 0.25 kg/ha PE. Atrazine was superior than 2,4-D because of its efficacy on both broad-leaved and grassy weeds. In case of broad-leaved weeds also, lowest weed density was recorded with atrazine 0.5 kg/ha PE which was significantly superior to two hand wheel hoeing at 20 and 40 DAS, atrazine 0.25 kg/ha PE, atrazine 0.125 kg/ha PE and atrazine 0.1 kg/ha PoE at 20 DAS and was statistically at par with two hand hoeing at 20 and 40 DAS, atrazine 0.2 kg/ha PoE at 20 DAS, atrazine 0.3 kg/ha PoE at 20 DAS, 2,4-D at 0.3 kg/ha PoE, and 2,4-D at 0.5 kg/ha PoE. Atrazine 0.5 kg/ha PE significantly reduced the biomass of grassy weeds compared to atrazine 0.1 kg/ha PoE at 20 DAS, 2,4-D at 0.3 kg/ha PoE at 30 DAS and 2,4-D at 0.5 kg/ha PoE at 30 DAS and was statistically at par with hand hoeing twice at 20 and 40 DAS, hand wheel hoeing twice at 20 and 40 DAS, atrazine 0.25 kg/ha PE and atrazine 0.125 kg/ha PE. With respect to broad-leaved weed biomass also, atrazine 0.5 kg/ha PE was found superior than rest of the treatments. Lowest broad-leaved weed biomass was recorded with atrazine 0.5 kg/ha (PE) and which was statistically at par with 0.1 kg/ha PoE at 20 DAS, atrazine 0.2 kg/ha PoE at 20 DAS, 0.3 kg/ha PoE at 20 DAS, 2,4-D at 0.5 kg/ha PoE at 30 DAS, hand hoeing twice at 20 and 40 DAS and hand wheel hoeing twice at 20 and 40 DAS. The 2,4-D treated plot had lower broad-leaved weed biomass than atrazine PE as it effectively controlled only broad-leaved weeds. Weed control efficiency is directly associated with the weed biomass under these treatments. The atrazine PE had high weed control efficiency as it effectively controlled broad-leaved weeds as well as grassy weeds.

The increase in seed, straw and biological yield were by 88.88, 77.00 and 79.34%, respectively with weed free treatment when compared to weedy check. The maximum seed yield was recorded with atrazine 0.5 kg/ha which was significantly superior over the atrazine 0.1 kg/ha PoE at 20 DAS and atrazine 0.125 kg/ha PE, and it remained at par with hand hoeing

Table 1. Effect of weed control treatments on grasses, broad-leaved weeds and total weed density and biomass at pearl millet harvest

Treatment	Weed density (no./m^2)			Weed biomass (g/m^2)			WCE (%)		
	Grasses	Broad-leaved	Total	Grasses	Broad-leaved	Total	Grasses	Broad-leaved	Total
Atrazine 0.125 kg/ha PE	1.96 (3.3)	2.32 (5.00)	2.96 (8.33)	3.87	11.00	14.87	85.50	75.56	79.26
Atrazine 0.25 kg/ha PE	1.35 (1.33)	2.73 (7.00)	2.94 (8.33)	3.00	13.33	16.33	88.75	70.37	77.21
Atrazine 0.5 kg/ha PE	1.34 (1.33)	0.91 (0.33)	1.46 (1.66)	2.00	2.33	4.33	92.50	94.81	93.95
Atrazine 0.1 kg/ha PoE 20 DAS	2.54 (6.00)	1.46 (1.67)	2.85 (7.67)	6.07	3.00	9.07	77.25	93.33	87.35
Atrazine 0.2 kg/ha PoE 20 DAS	2.41 (5.33)	1.22 (1.00)	2.61 (6.33)	4.67	2.89	7.56	82.50	93.58	89.46
Atrazine 0.3 kg/ha PoE 20 DAS	2.27 (4.66)	1.08 (0.66)	2.41 (5.33)	4.33	2.83	7.17	83.75	93.70	90.00
2,4-D 0.3 kg/ha PoE 30 DAS	4.04 (16.33)	1.08 (0.66)	4.13 (17.00)	21.00	7.00	28	21.26	84.44	60.93
2,4-D 500 g/ha PoE 30 DAS	3.94 (15.33)	0.91 (0.33)	3.99 (15.66)	17.50	2.67	20.17	34.38	94.07	71.86
Hand hoeing twice 20 and 40 DAS	2.11 (4.00)	1.07 (0.66)	2.26 (4.66)	2.00	3.00	5.00	92.50	93.33	93.02
Hand wheel hoeing twice 20 and 40 DAS	2.19 (4.33)	1.46 (1.67)	2.54 (6.00)	3.25	3.37	6.62	87.80	92.52	90.76
Weedy check	4.55 (20.33)	6.14 (40.67)	7.67 (61.00)	26.67	45.00	71.67	0.00	0.00	0.00
Weed free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.00	0.00	0.00	100.00	100.00	100.00
LSD (p=0.05)	0.49	0.41	0.56	3.21	3.75	12.78	-	-	-

Data in the parentheses were subjected to square root transformation $\sqrt{x+0.5}$

Table 2. Effect of weed control treatments on pearl millet yield and economics

Treatment	Grain yield (t/ha)	Stover yield (t/ha)	Biological yield (t/ha)	Harvest index (%)	Net returns (₹) (x10^3/ha)	B:C ratio
Atrazine 0.125 kg/ha PE	1.97	7.73	9.71	20	43084	2.64
Atrazine 0.25 kg/ha PE	2.03	7.81	9.84	21	44368	2.68
Atrazine 0.5 kg/ha PE	2.42	9.15	11.57	21	57273	3.16
Atrazine 0.1 kg/ha PoE 20 DAS	1.96	7.23	9.19	22	40823	2.55
Atrazine 0.2 kg/ha PoE 20 DAS	2.18	7.93	10.11	22	47876	2.82
Atrazine 0.3 kg/ha PoE 20 DAS	2.15	8.22	10.37	21	48401	2.83
2,4-D 0.3 kg/ha PoE 30 DAS	2.21	8.75	10.96	21	51662	2.95
2,4-D 500 g/ha PoE 30 DAS	2.39	9.41	11.80	20	57642	3.17
Hand hoeing twice 20 and 40 DAS	2.33	8.83	11.17	21	50306	2.65
Hand wheel hoeing twice 20 and 40 DAS	2.28	8.40	10.68	21	49728	2.75
Weedy check	1.31	5.37	6.68	20	20810	1.79
Weed free	2.48	9.50	11.98	21	54768	2.73
LSD (p=0.05)	0.41	2.28	2.34	NS		

twice at 20 and 40 DAS and hand wheel hoeing twice at 20 and 40 DAS, 2,4-D 0.5 kg/ha PoE, 2,4-D 0.3 kg/ha PoE and atrazine 0.2 kg/ha PoE. Highest stover and biological yield were recorded with 2,4-D 0.5 kg/ha PoE at 30 DAS. However, it was statistically at par with all other treatments.

The maximum net return of ₹ 57642 /ha was recorded with 2,4-D 0.5 kg/ha PoE at 30 DAS and it was closely followed by atrazine 0.5 kg/ha PE; weed free; 2,4-D 0.3 kg/ha PoE, hand hoeing twice; hand wheel hoeing twice, atrazine 0.3 kg/ha PoE and atrazine 0.2 kg/ha PoE. The maximum B:C ratio was obtained with 2,4-D 0.5 kg/ha PoE and it was closely followed by atrazine 0.5 kg/ha PE, 2,4-D 0.3 kg/ha, atrazine 0.3 kg/ha PoE and atrazine 0.2 kg/ha, two hand hoeing, two hand wheel hoeing. Similar observations were made by Mishra *et al.* (2016, 2017), Bhuva and Detroja (2018).

It may be concluded that application of 0.5 kg/ha atrazine PE and 2,4-D 0.5 kg/ha PoE 30 DAS are equally effective in better weed management, higher pearl millet yields and economic returns.

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RESEARCH NOTE

Comparative efficacy of herbicides and hand weeding in managing weeds in irrigated summer finger millet (*Eleusine coracana* L. Gaertn.)

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ABSTRACT

A field experiment was conducted at M.S. Swaminathan School of Agriculture, Bagusala farm, Gajapati district, Odisha during the summer season of 2020 to assess the comparative efficacy of herbicides and hand weeding in managing weeds and improve productivity of irrigated summer finger millet (*Eleusine coracana* L. Gaertn.). The pre-emergence herbicide application (PE) of pendimethalin 500 g/ha or oxadiargyl 80 g/ha PE at 3 days after transplanting (DAT) followed by post-emergence application (PoE) of ethoxysulfuron 12 g/ha or bispyribac- sodium 20 g/ha at 20 DAT were found to be equally effective as hand weeding twice at 20 and 40 DAT in effectively managing weeds and improving the productivity of finger millet.

Keywords: Bispyribac-sodium, Ethoxysulfuron, Finger millet, Herbicides, Oxadiargyl, Pendimethalin, Weed management

Finger millet (*Eleusine coracana* L. Gaertn.) is cultivated over an area of 0.97 Mha with a production of 1.68 Mt giving an average productivity of 1.73 t/ha in India (Tonapi 2020). The crop is mainly cultivated in Karnataka, Maharashtra, Uttarakhand, Tamil Nadu, Andhra Pradesh, Jharkhand, Odisha, Chhattisgarh and Gujarat. Weeds are the constraints limiting the productivity of finger millet. A wide diversity in weed flora was reported to be associated with finger millet and the extent of finger millet yield loss due to weed competition was reported to be influenced by the types of weeds species and their density (Shubhashree and Sowmyalatha 2019). The grain yield losses ranging from 34 to 61% was reported due to uncontrolled weeds in finger millet (Patil *et al*. 2013). Thus, weed management was found to contribute to 43% increase in finger millet yield (Kumara *et al*. 2007). Weeds in the crop can be managed either by cultural, mechanical or chemical techniques or by means of integration of all these methods (Rao and Nagamani 2010). Hand weeding is the conventional method used by farmers for managing weeds in finger millet. The hand weeding has turn out to be a costly operation due to unavailability of labour and high labour wages. Hence, as an alternative to hand weeding, herbicides are being evaluated for managing weeds in finger millet (Kumar *et al*. 2015). The current experiment was conducted with an objective to identify suitable herbicides and compare them with hand weeding in effectively managing weeds in irrigated summer finger millet.

The field experiment was conducted in summer season of 2020 at Bagusala farm, M.S Swaminatham School of agriculture, Gajapati district, Odisha. The experimental field's soil was sandy clay loam in texture, slightly acidic in reaction with pH of 6.4. The available nitrogen is 208 kg/ha, phosphorus is 139 kg/ha and potassium is 390 kg/ha. The experiment consisted of ten weed management treatments replicated thrice in randomized block design. The treatments include: oxadiargyl 80 g/ha pre-emergence application (PE) at 3 days after transplanting (DAT), pendimethalin 500 g/ha PE at 3DAT; bispyribac-sodium 20 g/ha post-emergence application (PoE) at 20 DAT; ethoxysulfuron 12 g/ha PoE at 20 DAT; oxadiargyl 80 g/ha PE at 3 DAT followed by (*fb*) bispyribac-sodium 20 g/ha PoE at 20 DAT, oxadiargyl 80 g/ha PE at 3 DAT *fb* ethoxysulfuron 2 g/ha at 20 DAT, pendimethalin 500 g/ha at 3 DAT *fb* bispyribac-sodium 20 g/ha PoE at 20 DAT, pendimethalin 500 g/ha PE at 3 DAT *fb* ethoxysulfuron 12 g/ha PoE at 20 DAT.

Finger millet variety *'GPU-28'* was transplanted at a spacing of 20 x 25 cm on 6th February 2020, using 30-day old seedlings which were grown separately in nearby field. The recommended dose of

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fertilizer (RDF) (90:45:45 kg/ha) was applied to all the treatments. The entire level of P and K along with the 45 kg Nitrogen/ha was applied at the time of transplanting. The remaining nitrogen was applied at 20 DAT. The fertilizer nitrogen was made through urea, P through SSP and K through MOP. The crop was irrigated at 20, 40 and 50 DAT.

The herbicides were applied as per the treatments by using hand operated knap sack sprayer fitted with the flat pan nozzle at a spray volume of 500 l/ha. The observations on weeds were recorded from the area of 0.5 x 0.5 m at 20, 40 and 60 DAT and harvest and it was converted to square root transformation and analysed statistically by following the procedure given by Panse and Sukhatme (1985). The weed index was calculated by following the formula given by Gill and Kumar (1969). The weed control efficiency was calculated by using the following formula (Mani *et al.* 1981). The growth and yield and yield attributes were per standard procedure and subjected to standard statistical analysis.

The weeds recorded in the summer irrigated finger millet experimental field include: grasses: *Digitaria sanguinalis, Eleusine indica, Dactyloctenium aegyptium, Cynodon dactylon, Echiniochloa colona, Sorghum helepense;* sedges*: Cyperus rotundus, and Cyperus iria* and broad-leaved/dicot weeds*: Chenopodium album, Parthenium hysterophorus.*

The weed density and biomass were lower and finger millet plant dry weight was higher in hand weeded plot as compared to other treatments (**Table 1**). Significantly higher finger millet grain yield was obtained with hand weeding twice (**Table 2**). The application of pre-emergence herbicides in combination with post-emergence herbicides has given higher grain yield when compared to application of pre- or post-emergence herbicides alone.

The grain, straw and dry matter yield of finger millet at harvest was significantly greater with pendimethalin 500 g/ha PE *fb* ethoxysulfuron 12 g/ha PoE; oxadiargyl 80 g/ha PE at 3 DAT *fb* bispyribac-sodium 20 g/ha PoE; pendimethalin 500 g/ha PE *fb* bispyribac-sodium 20 g/ha PoE and oxadiargyl 80 g/ha PE *fb* ethoxysulfuron12 g/ha PoE treatments than that observed with ethoxysulfuron 12 g/ha PoE at 20 DAT, oxadiargyl 80 g/ha PE ; bispyribac-sodium 20 g/ha PoE and pendimethalin 500 g/ha PE **(Table 2)**. The grain yield in the latter treatments was significantly higher over unweeded control.

The gross and net returns and B:C ratio were higher with pre-emergence application of oxadiargyl 80 g/ha at 3 DAT followed by post-emergence application of bispyribac-sodium 20 g/ha or ethoxysulfuron 12 g/ha PoE, and Pendimethalin 500 g/ha PE at 3 DAT *fb* bispyribac-sodium 20 g/ha PoE or ethoxysulfuron 12 g/ha PoE at 20 DAT as compared to all other treatments (**Table 2**). However, the gross returns were lower and net returns were comparable to that of hand weeding at 20 and 40 DAT. The increase in net returns in the former treatments was 20 to 47% over that of application of pre-emergence herbicides. The net returns were negative with no weed control treatment.

The improvement in yield due to combined application of herbicides was due to lower weed biomass and increase in yield attributing characters. The sequential application of pre- and post-emergence herbicides has resulted in lower weed density and biomass and higher finger millet plant dry weight as compared to pre- or post-emergence

Table 1. Effect of weed management treatments on weed and crop growth and yield attributes of summer finger millet

Treatment	Weed density at 40 DAT (no./ 0.25 m^2)	Weed biomass at 40 DAT (g/0.25 m^2)	Weed control efficiency at 40 DAT (%)	Weed control efficiency (%) at harvest	Weed index (%)	Plant dry weight (g/ plant) at 60 DAT	No. of fingers per ear head	No. of effective tillers/ hill	Grain yield/ ear head (g)	1000 grain weight (g)
Oxadiargyl 80 g/ha PE at 3 DAT	76.6 (8.7)	10.6	54.15	78.5	36	113	5.4	8.4	1.5	4.7
Pendimethalin 500 g/ ha PE at 3 DAT	69.6(8.3)	15.8	34.86	46.6	39	109.3	5.5	8.1	1.4	4.9
Bispyribac-sodium 20 g/ha PoE at 20 DAT	90(9.4)	15.8	11.68	46.2	37	111.7	5.2	8.1	1.2	4.6
Ethoxysulfuron 12 g/ha PoE at 20 DAT	81.6(9.04)	16.9	12.35	39.5	33	109.3	5.2	8.2	1.2	4.3
Oxadiargyl 80 g/ha PE at 3 DAT *fb* bispyribac-sodium 20 g/ha PoE at 20 DAT	81(9)	12.5	26.90	66.5	11	107.7	5	8	1.2	4.4
Oxadiargyl 80 g/ha PE at 3 DAT *fb* ethoxysulfuron 12 g/ha PoE at 20 DAT	72(8.4)	16.0	32.15	45.4	14	111.7	5.1	8.2	1.3	4.7
Pendimethalin 500 g/ ha PE at 3 DAT *fb* bispyribac-sodium 20 g/ha PoE at 20 DAT	87(9.3)	17.6	32.32	35.1	12	111.3	4.9	8.1	1.5	4.8
Pendimethalin 500 g/ha at 3 DAT *fb* ethoxysulfuron 12 g/ha PoE at 20 DAT	85.3(9.2)	16.5	32.65	42.1	10	108	5	8.3	1.3	4.6
Hand weeding twice at 20 and 40 DAT	52(7.2)	16.3	51.27	43.3	0	116	5.3	8.3	1.5	4.7
Weedy check	98.6(9.9)	23.4	0	0	61	88.7	3.5	5.3	1.1	3.9
LSD (p=0.05)	7.5(4.5)	1.89	-	-		5.07	0.6	0.5	NS	0.5

Table 2. Effect of weed management treatments on yield and economics of summer finger millet

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Dry matter at harvest (grain + straw) (t/ha)	Harvest index (%)	Gross return (x10^3 `/ha)	Cost cultivation/ treatment (x10^3 `/ha)	Net returns (x10^3 `/ha)
Oxadiargyl 80 g/ha PE at 3 DAT	1.13	3.17	4.30	26.26	54.18	46.87	7.31
Pendimethalin 500 g/ ha PE at 3 DAT	1.09	3.29	4.38	24.81	52.16	46.65	5.51
Bispyribac-sodium 20 g/ha PoE at 20 DAT	1.12	3.06	4.18	26.77	53.76	46.67	7.09
Ethoxysulfuron 12 g/ha PoE at 20 DAT	1.19	3.23	4.42	26.87	57.02	46.43	10.59
Oxadiargyl 80 g/ha PE at 3 DAT *fb* bispyribac-sodium 20 g/ha PoE at 20 DAT	1.58	4.07	5.65	27.95	75.84	47.71	28.13
Oxadiargyl 80 g/ha PE at 3 DAT *fb* ethoxysulfuron 12 g/ha PoE at 20 DAT	1.52	4.08	5.60	27.14	72.96	47.47	25.49
Pendimethalin 500 g/ ha PE at 3 DAT *fb* bispyribac-sodium 20 g/ha PoE at 20 DAT	1.57	4.10	5.67	27.65	75.26	47.49	27.78
Pendimethalin 500 g/ha PE at 3 DAT *fb* ethoxysulfuron 12 g/ha PoE at 20 DAT	1.60	4.17	5.77	27.68	76.61	47.24	29.36
Hand weeding twice at 20 and 40 DAT	1.77	4.78	6.56	27.05	85.15	53.83	31.32
Weedy check	0.69	2.62	3.32	20.92	33.31	45.83	-12.52
LSD (p=0.05)	0.10	0.34	0.36	-			

PE: pre-emergence; PoE: post-emergence; DAT: Days after transplanting; *fb*: Followed by

application of herbicides alone due to better control of weeds in the herbicide treatments that received sequential application of pre- and post-emergence herbicides. The greater herbicide efficiency was owing to superior weed control both in terms reduction in density and biomass (Kujur *et al.* 2019). as reported earlier (Bhargavi *et al.* 2016).

It can be concluded that hand weeding twice controlled the weed efficiently, but it is the laborious and costly method of weed control. Thus when labour shortage conditions prevail, pre- and post-emergence herbicide combination of pendimethalin 500 g/ha PE or oxadiargyl 80 g/ha PE at 3 DAT followed by ethoxysulfuron 12 g/ha or bispyribac-sodium 20 g/ha PoE at 20 DAT can be used for effective weed management and higher finger millet yield under summer irrigated conditions.

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RESEARCH NOTE

Impact of integration of inter-cultivation, herbicides and manual weeding in winter groundnut yield

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ABSTRACT

A field experiment was conducted in sandy loam soils at College of Agriculture, Professor Jayashankar Telangana State Agricultural University, Hyderabad, during winter *(Rabi)* season 2020-21. The objective was to study the effect of integration of inter-cultivation with pre- and post-emergence application of herbicides and manual weeding on weeds growth and yield of groundnut. A randomized block design, replicated thrice was used with ten treatments. The broad-spectrum weed control, lower weed biomass, higher weed control efficiency, higher groundnut pod and haulm yield were obtained with inter-cultivation followed by (*fb*) hand weeding at 20 and 40 days after sowing (DAS). The herbicides based integration revealed the greater weed management efficacy of pre-emergence application (PE) of diclosulam at 26 g/ha *fb* inter-cultivation at 20 DAS. The next best options for higher WCE and pod yield were imazethapyr + pendimethalin (ready-mix) at 960 g/ha PE *fb* inter-cultivation at 20 DAS and sodium acifluorfen + clodinofop- propargyl 250 g/ha *fb* inter-cultivation at 40 DAS.

Keywords: Diclosulam, Groundnut, Iimazethapyr + pendimethalin (ready-mix), Inter-cultivation, Sodium acifluorfen + clodinofop- propargyl (ready-mix) and Weed control efficiency

Groundnut (*Arachis hypogaea* L.) is an important oilseed and cash crop in India. Groundnut is often included in crop rotation as it fixes atmospheric nitrogen being a leguminous crop. Groundnut contributes 67% of total edible oil produced in India. The demand for edible oils is rising at about 6 per cent per year. Therefore, concerted efforts are now being made to stabilize and increase oilseed production. In Telangana, state of India, it is grown in an area of 0.99 lakh hectares with an annual production of 0.23 million tons and average productivity of 2.35 kg/ha (www.indiastat .com 2019-20). India ranks first in the world in groundnut cultivated area but imports 8.3 million tons of edible oil to meet its requirement. The major problems limiting production of groundnut are poor cultural practices as well as inadequate weed management (Naim *et al.* 2010). The weed problem gets more severe due to certain unforeseen factors such as inefficient and untimely weeding or interculture and continuous rains during the early crop growth period, coupled with the non-availability of labour for weeding in time (Mishra *et al.* 2016). Depending upon nature, the density of weeds, and severity of competition, losses in groundnut yield ranged from 13- 80% (Rao and Chauhan 2015). Besides competing for nutrients, soil moisture, sunlight, weeds inhibit pegging, pod development in groundnut and interfere with harvest. In groundnut, less crop canopy during the first 6 weeks of growth favours strong competition with weeds causing significant reduction in yield (Shanwad *et al.* 2011). Minimizing the crop weed competition particularly at the early stages of the growth, the yield could be improved by 20-30%. To overcome the deleterious effects of weeds in groundnut, it is imperative that weeds population be kept below the economic threshold level. For this purpose, several pre-emergence and pre-plant incorporated herbicides have been recommended to control the weeds in groundnut crop (Regar *et al*. 2021). In groundnut, herbicide use followed by inter-cultivation has been found to be easier; less time consuming and more cost effective and efficient in reducing weed menace (Patel *et al.* 2020) compared to hand weeding alone (Kumar 2009).

A field experiment was carried out at College Farm, College of Agriculture, Professor Jayashankar Telangana State Agricultural University (PJTSAU), Rajendranagar, Hyderabad, Telangana State during winter *(Rabi)* season of 2020-2021. The objective of

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the study was to quantify the effect of integration of inter-cultivation with pre- and post-emergence application of herbicides and manual weeding on weeds growth and yield of groundnut. The farm is geographically situated at an altitude of 542.3 m above mean sea level at 17°19' N latitude and 78°23' E longitude in the Southern Telangana agro-climatic zone of Telangana and it is classified under semi-arid tropics (SAT) according to Troll's classification. A randomized block design with three replications was used with 10 treatments, which include: diclosulam 26 g/ha pre-emergence application (PE) followed by (*fb*) inter-cultivation at 20 days after seeding (DAS), imazethapyr 2% EC + pendimethalin 30% EC (ready-mix) 960 g/ha PE and *fb* inter-cultivation at 20 DAS; pyroxasulfone 127.5 g/ha PE *fb* inter-cultivation at 20 DAS, propaquizofop 2.5% + imazethapyr 3.75% w/w ME (ready-mix) 125 g/ha post-emergence application (PoE) *fb* inter-cultivation at 40 DAS; imazethapyr 35% + imazomox 35% WG (ready-mix) 70 g/ha PoE *fb* inter-cultivation at 40 DAS; sodium acifluorfen 16.5% EC + clodinafop-propargyl 8% EC (ready-mix) 250 g/ha post-emergence application (PoE) *fb* inter-cultivation at 40 DAS; imazethapyr 100 g/ha PoE *fb* inter-cultivation at 40 DAS; inter-cultivation (20 and 40 DAS); inter-cultivation *fb* hand weeding (20 and 40 DAS) (weed-free) and unweeded control. Groundnut crop (variety *Kadiri-9*) was sown on 8th October 2020 at spacing of 30 x 10 cm using a seed rate of 300 kg/ha. Herbicides were applied using a Knap sack sprayer fitted with flat fan nozzle calibrated to deliver 500 litres of water per hectare. Inter-cultivation was done with power weeder and pre-emergence herbicides application was done at 2 DAS and post-emergence herbicides application was done at 20 DAS. Cultural practices recommended by PJTSAU for groundnut were adopted during the crop growth period. The crop was fertilized with recommended dose of fertilizers with 20 kg N, 40 kg P and 50 kg K/ha using urea, single super phosphate and muriate of potash, respectively as basal. Top dressing of 10 kg N was applied in form of urea at 25 DAS. Weed density and dry weight (biomass) were recorded on 40 DAS and transformed to square root transformation ($\sqrt{x+0.5}$) to normalize their distribution. The groundnut yield and yield attributes were recorded at its harvest on 12th February 2021, following standard procedured.

Weed flora

The weed flora of the experimental field was dominated by grasses: *Dactyloctenium aegyptium* and *Digitaria sanguinalis*; broad-leaved weeds: *Commelina benghalensis*, *Phyllanthus niruri*, *Cleome viscosa*, *Boerhavia diffusa*, *Brachiaria reptans*, *Euphorbia hirta*, *Digera arvensis*, *Celosia argentea*, *Physalis minima*, *Amaranthus viridis*, *Datura stramonium*, *Parthenium hysterophorus* and a sedge *Cyperus rotundus.*

Weed density and biomass

The lowest total weed density and biomass was recorded with inter-cultivation *fb* hand weeding twice at 20 and 40 DAS which was comparable with diclosulam at 26 g/ha PE *fb* inter-cultivation at 20 DAS (**Table 1**). Diclosulam 26 g/ha PE was found to be very effective in controlling all the categories of weeds including the predominant perennial sedge, *Cyperus rotundus* and broad-leaved weeds in groundnut.

Weed control efficiency

Maximum weed control efficiency was recorded with inter-cultivation *fb* hand weeding twice at 20 and 40 DAS followed by diclosulam at 26 g/ha PE *fb* inter-cultivation at 20 DAS and imazethapyr + pendimethalin at 960 g/ha PE *fb* inter-cultivation at 20 DAS. The initial flush of weeds was controlled by

Table 1. Weed density, weed biomass, weed control efficiency (WCE), pod and haulm yield of groundnut as influenced by different weed management treatments

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	WCE (%)	Pod yield (t/ha)	Haulm yield (t/ha)
Diclosulam 26 g/ha PE *fb* inter-cultivation at 20 DAS	3.87(14.0)	2.31(4.3)	88.99	2.64	3.17
Imazethapyr + pendimethalin 960 g/ha PE *fb* inter-cultivation at 20 DAS	4.08(15.7)	3.01(8.0)	79.49	2.61	3.13
Pyroxasulfone127.5 g/ha PE *fb* inter-cultivation at 20 DAS	4.25(17.0)	3.17(9.1)	76.90	2.07	2.54
Propaquizofop + imazethapyr 125 g/ha PoE *fb* intercultivation at 40 DAS	4.32(17.7)	3.05(8.3)	78.81	2.16	2.95
Imazethapyr + imazomox 70 g/ha PoE *fb* inter-cultivation at 40 DAS	4.51(19.3)	3.06(8.4)	78.90	2.00	2.94
Sodium-acifluorfen + clodinafop-propargyl 250 g/ha PoE *fb* inter-cultivation at 40 DAS	4.58(20.0)	2.80(6.8)	82.55	2.45	3.02
Imazethapyr 100 g/ha PoE *fb* inter-cultivation at 40 DAS	5.42(28.3)	3.07(8.4)	78.47	1.93	2.63
Inter-cultivation twice at 20 and 40 DAS	4.80(22.0)	3.18(9.1)	76.75	2.39	2.99
Intercultivation*fb* hand weeding twice 20 and 40 DAS (weed free)	3.74(13.0)	1.97(2.9)	92.92	2.74	3.25
Unweeded control	7.85(60.7)	6.34(39.2)	-	1.46	1.90
LSD (p=0.05)	0.37	0.49	-	0.27	0.20

PE: Pre-emergence; PoE: Post-emergence; *fb*: followed by; DAS: days after seeding

Table 2. Economics of groundnut as influenced by different weed management treatments

Treatment	Cost of cultivation ($x10^3$ ₹/ha)	Gross returns ($x10^3$ ₹/ha)	Net returns ($x10^3$ ₹/ha)	Benefit -cost ratio
Diclosulam 26 g/ha PE *fb* intercultivation at 20 DAS	52.04	139.25	87.21	1.68
Imazethapyr + pendimethalin 960 g/ha PE *fb* intercultivation at 20 DAS	53.00	137.70	84.70	1.60
Pyroxasulfone 127.5 g/ha PE *fb* intercultivation at 20 DAS	55.99	109.23	53.24	0.95
Propaquizafop + imazethapyr 125 g/ha early PoE *fb* intercultivation at 40 DAS	52.34	113.98	61.64	1.18
Imazethapyr + imazamox 70 g/ha Early PoE *fb* intercultivation at 40 DAS	52.24	105.30	53.06	1.02
Sodium acifluorfen + clodinafop-propargyl 250 g/ha PoE *fb* intercultivation at 40 DAS	51.76	129.18	77.42	1.50
Imazethapyr 100 g/ha PoE *fb* intercultivation at 40 DAS	52.32	101.62	49.30	0.94
Intercultivation (20 and 40 DAS)	55.24	125.99	70.75	1.28
Intercultivation *fb* hand weeding (20 and 40 DAS) (weed free)	60.04	144.69	84.65	1.41
Unweeded control	46.44	77.02	30.58	0.66
LSD (p=0.05)	-	14.23	14.24	-

applied herbicides and the later flush by the inter-cultivation resulting in higher WCE which reduced the crop weed competition.

Yield

Higher pod yield (2.74 t/ha) and haulm yield (3.25 t/ha) of groundnut was obtained with inter-cultivation *fb* hand weeding at 20 and 40 DAS, which was closely followed by pre-emergence application of diclosulam 26 g/ha *fb* inter-cultivation at 20 DAS (**Table 1**). Application of diclosulam as pre-emergence controlled all the categories of weeds, which in turn increased the yield components and yield of groundnut. The diclosulam was reported to be effective in managing weeds in groundnut, alone (Grey *et al.* 2001) and in combination with hand weeding (Kumar *et al.* 2019). The identified effective treatments will be useful to farmers for effectively managing weeds and improve productivity of groundnut in Southern-Telangana region of Telangana State.

Economics

Cost of cultivation and gross returns were highest with the inter-cultivation followed by hand weeding at 20 and 40 DAS whereas net returns and benefit cost ratio were highest with the diclosulam at 26 g/ha *fb* intercultivation at 20 DAS. This was due to high yield and the less cost of cultivation compared to all other treatments (**Table 2**).

Conclusion

Monetary returns play a major role for adopting the any refined agri-techniques. In this study, pre-emergence application of diclosulam at 26 g/ha *fb* inter-cultivation at 20 DAS proved practically more convenient and economically best feasible integrated weed management practice for groundnut as it recorded the highest yield and net returns comparable with other treatments. If inter-cultivation is not possible, post-emergence application of sodium acifluorfen + clodinafop propargylat 250 g/ha could be an alternative method for managing the weeds effectively and improving the productivity of winter groundnut considering the present scarcity and high cost of labor.

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RESEARCH NOTE

Weed management with pre- and post-emergence herbicide under varying tillage systems in chickpea grown after sorghum

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ABSTRACT

An experiment was conducted during 2019–20 at Rani Lakshmi Bai Central Agricultural University (RLBCAU), Jhansi to evaluate the effect of tillage and weed management treatments on weeds and productivity of chickpea grown after sorghum. Major broad-leaved weeds were: *Anagallis arvensis* (48%), *Spergula arvensis* (12.3%), *Medicago denticulata* (8.6%), *Melilotus alba* (8.0%); and narrow-leaved, *Cyperus rotundus* (17.0%) and *Dactyloctenium aegyptium* (2.7%). Adoption of zero tillage (ZT) and ZT+ residue retention increased mean grain yield of chickpea by 10.6 and 21.1%, respectively over the conventional tillage (CT). Pre-emergence application (PE) of pendimethalin 1.0 kg/ha followed by (*fb*) post-emergence application (PoE) of clodinafop-propargyl + Na-acifluorfen 122.5 g/ha at 30 DAS controlled weeds effectively and resulted in 8.6, 19.3 and 43.5% more grain yield than pendimethalin *fb* hand weeding, pendimethalin alone and unweeded check, respectively. It was concluded that clodinafop-propargyl + Na-acifluorfen proved to be a good substitute for hand weeding at 30 DAS but its dose and timing of application need to be further standardized at different locations.

Keywords: Chickpea, Clodinafop-propargyl + Na-acifluorfen, Pendimethalin, Sorghum residue, Weed management, Zero tillage

Chickpea (*Cicer arietinum* L.) also called Bengal gram, is the largest produced food legume in South Asia and in India. The chickpea has a lion's share of 49.3% in the total pulses production of 25.6 million tonnes in India (Gaur 2021). However, the productivity of chickpea is quite low (1.14 t/ha) considering its potential (up to 3 t/ha) with better soil and crop management. Among the factors responsible for low yield are poor crop stand and weed infestation (Sanketh *et al*. 2021). Adopting conventional practices like repeated ploughings to prepare a fine seedbed for germination and establishment exposes the weed seeds from lower soil layers (Chauhan *et al.* 2012). A bold-seeded crop like chickpea does not require fine tilth (Parihar *et al*. 2019). Poor competitive ability of chickpea makes weeds to cause yield losses up to 90% under severe infestation (Mukherjee 2007). Application of pre-emergence herbicide like pendimethalin provides good early season weed control (Singh and Jain, 2017), but the farmers often have to resort to manual weeding in the later stages which is quite costly. Lack of any suitable post-emergence herbicide for controlling weeds, especially the broad-leaved species is a major limitation in chickpea. A mixture of clodinafop-propargyl + Na-acifluorfen is recommended in soybean, and showed promise in chickpea despite some phytotoxicity (Nath *et al*. 2018). The present experiment was planned to evaluate the efficacy of sequential application of pre- and post-emergence herbicide under varying tillage systems on weed control and performance of chickpea grown after sorghum.

The experiment was carried out on sandy clay-loam soil at the research farm of Rani Lakshmi Bai Central Agricultural University (RLBCAU), Jhansi, Uttar Pradesh during 2019-20. Twelve treatment combinations comprised of three tillage practices in main-plots, *viz*. zero tillage (ZT), ZT with residue (ZT+R), conventional tillage (CT), and four weed management treatments in sub-plots, *viz*. pre-emergence application (PE) of pendimethalin 1.0 kg/ha, pendimethalin 1.0 kg/ha PE followed by (*fb*) post-emergence application (PoE) of clodinafop-propargyl + Na-acifluorfen 122.5 g/ha at 30 days after sowing (DAS), pendimethalin 1.0 kg/ha PE *fb* hand weeding at 30 DAS, and unweeded check. A split-plot design with three replications was used. Sowing of chickpea variety "*RVG-202*" was done with happy-seeder on 9 November, 2019 along with basal application of 100 kg DAP/ha. One irrigation was given in mid-January, and the crop was harvested on 5 April, 2020. Crop residue 5 t/ha of the previous sorghum crop was retained on the soil surface in the respective treatments. Glyphosate was applied at 1.2 kg/ha before sowing in ZT plots. Observations on species-wise weed density and biomass were recorded from

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0.25 m^2 area at 30 days interval. Similarly, crop biomass was taken from 0.25 m^2 area, and grain yield at maturity was taken from the net plot area (10 m^2).

Effect on weeds

Predominant weed species at 30 DAS observed in the CT-unweeded control were: *Anagallis arvensis* (48.0%), *Spergula arvensis* (12.3%), *Medicago denticulata* (8.6%), *Melilotus alba* (8.0%) and *Parthenium hysterophorus* (1.8%) among broad-leaved; and *Cyperus rotundus* (17.0%) and *Dactyloctenium aegyptium* (2.7%) among narrow-leaved weeds. Thus, the crop field was dominated by the broad-leaved species (>80%), and *Anagallis arvensis* constituted about half of total weed population. The relative proportion of broad-leaved species at 60 DAS was comparatively lower under ZT+R (76.4%) as compared to ZT alone (81.1%) and CT (84.4%) **(Table 1)**. Tillage checked the infestation of *Cyperus rotundus*, but it regenerated under ZT despite glyphosate application.

Significant variations in total weed density and biomass due to tillage and weed management practices were observed at 30 and 60 DAS (**Table 2**). There was no significant difference in weed density under ZT and ZT+R at 30 DAS, but it was significantly higher under CT at both the stages. Retention of sorghum residue caused decrease in weed density under ZT+R. Repeated ploughings under CT brought the weed seeds to the surface, which were exposed to the light, leading to greater emergence of diverse weed flora as compared to ZT (Chauhan *et al.* 2012).

Application of pendimethalin resulted in weed suppression from the early stages. At 30 DAS, the weed density in the pendimethalin treatments was significantly lower than unweeded check. Application of clodinafop-propargyl *fb* Na-acifluorfen at 30 DAS resulted in efficient control of both broad-leaved and narrow-leaved weeds, resulting in significantly lower weed density and biomass than other treatments. Pendimethalin is primarily a grassy weed killer with limited effect on broad-leaved species (Kaur and Kumar 2016). Accordingly, the broad-leaved weeds which were left uncontrolled with pendimethalin, were very efficiently controlled by clodinafop-propargyl + Na-acifluorfen or hand weeding at 30 DAS. Post-emergence application of clodinafop-propargyl + Na-acifluorfen resulted in significantly lower weed density and biomass at 60 DAS as compared to pendimethalin alone or along with hand weeding. Initial suppression of the few grassy weeds with pendimethalin and later control of broad-leaved weeds with clodinafop-propargyl + Na-acifluorfen resulted in lower crop-weed competition.

Effect on chickpea growth

There was no significant effect of tillage on biomass accumulation of chickpea at 30 DAS, but the biomass at 60 DAS was significantly higher under ZT+R than CT **(Table 2)**. Presence of sorghum residue with ZT had a beneficial effect on dry matter accumulation due to reduced weed pressure and modified hydro-thermal regime (Acharya *et al.* 2018). Similarly, the weed management practices did not have any effect on crop biomass at 30 DAS, but pre-emergence application of pendimethalin *fb* clodinafop propargyl + Na-acifluorfen PoE showed significantly lower biomass at 60 DAS as compared to other pendimethalin-applied treatments. The post-emergence application of clodinafop-propargyl + Na-acifluorfen at 30 DAS resulted in a limited and temporary scorching effect on chickpea foliage, which suppressed the crop growth for about 20 days, and resulted in relatively lower dry matter accumulation at 60 DAS. However, the plants recovered from the phytotoxic effect of clodinafop-propargyl + Na-acifluorfen, and accumulated more plant biomass at 90 DAS, which was at par with pendimethalin PE *fb* hand weeding.

Relationship between the crop and weed biomass showed a significant negative correlation ($Y = -0.30X + 361.6$; $R^2 = 0.95$). There was a decrease of 0.30 g/m^2 crop biomass with unit increase in weed biomass at 60 DAS. This suggests that increased weed biomass production caused a greater suppressing effect on crop dry matter accumulation.

Effect on grain yield

Grain yield of chickpea was significantly more under ZT+R (1.71 t/ha) as compared to CT (1.35 t/ha) and ZT (1.51 t/ha) **(Table 2)**. Retention of sorghum residue had a positive effect on crop growth and yield

Table 1. Relative proportion (%) of different weed species under varying tillage of unweeded check at 60 DAS

Weed species	ZT	ZT + R	CT
Broad-leaved			
Anagallis arvensis	43.5	36.7	49.8
Spergula arvensis	15.7	15.7	13.0
Medicago denticulata	11.7	12.8	8.8
Melilotus alba	4.3	5.1	8.0
Parthenium hysterophorus	2.0	1.6	1.7
Coronopus didymus	2.0	2.6	1.9
Others	1.8	1.8	1.2
Total	81.1	76.4	84.4
Narrow-leaved			
Cyperus rotundus	16.0	20.2	12.6
Dactyloctenium aegyptium	2.9	3.4	2.9
Total	18.9	23.6	15.6

Table 2. Effect of tillage and weed control practices on weeds crop growth, yield and economics of chickpea

Treatment	Weed density (no./m²)		Weed biomass (g/m²)		Crop biomass (g/m²)		Grain yield (t/ha)	Total cost of cultivation (x10³ ₹/ha)	Net returns (x10³ ₹/ha)	Net B:C ratio
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS				
Tillage										
ZT	49.0	65.1	11.1	29.4	24.9	179.8	1.51	26.9	48.7	1.79
ZT+R	45.1	54.5	9.6	21.0	24.3	181.9	1.71	29.4	56.3	1.90
CT	99.9	133.3	26.6	76.0	26.3	172.1	1.35	31.9	35.7	1.10
LSD (p=0.05)	7.1	8.9	1.5	4.5	NS	5.1	0.14	-	-	-
Weed management										
Pendimethalin 1.0 kg/ha PE	46.8	61.1	11.0	27.8	25.1	191.3	1.50	28.8	46.1	1.62
Pendimethalin 1.0 kg/ha PE *fb* clodinafop-propargyl + Na-acifluorfen 122.5 g/ha PoE	46.6	21.3	11.3	10.2	25.4	167.2	1.86	30.2	62.6	2.09
Pendimethalin 1.0 kg/ha PE *fb* HW	46.7	36.4	11.1	14.6	25.1	195.9	1.70	32.1	52.9	1.67
Unweeded control	118.7	218.2	29.6	115.9	26.0	157.3	1.05	26.3	26.0	1.01
LSD (p=0.05)	3.8	6.3	1.0	3.0	NS	3.3	0.04	-	-	-

*PE= Pre-emergence; PoE = Post-emergence; *fb* = followed by

attributes, which led to significantly higher grain yield when compared with other practices. Application of pendimethalin *fb* clodinafop-propargyl + Na-acifluorfen was the best weed management practice with respect to grain yield, followed by pendimethalin *fb* hand weeding. Nath *et al*. (2018) also reported that clodinafop-propargyl + Na-acifluorfen controlled weeds effectively and increased the yield of chickpea despite some phytotoxicity symptoms on crop foliage. Chickpea requires nipping to check vertical growth of plants, and this effect may have also been achieved through application of clodinafop-propargyl + Na-acifluorfen. Interaction revealed that the highest grain yield of chickpea (2.02 t/ha) was obtained under ZT+R with application of clodinafop-propargyl + Na-acifluorfen.

Effect on economics

Among the tillage practices, the cost incurred on CT (31.9 x10³ ₹/ha) was higher compared to ZT and ZT+R. On the other hand, the total cost of cultivation was lower under ZT and ZT+R, besides the cost of residue included under ZT+R **(Table 2)**. Employing manual hand weeding after pendimethalin resulted in increased cost of cultivation compared to the use of pendimethalin PE *fb* clodinafop-propargyl + Na-acifluorfen PoE. Despite the increased cost of cultivation under CT, the net returns, and net B:C ratio (1.10) were lower compared to the better performing treatments ZT+R (1.90) and ZT (1.79). Among the weed management practices, pendimethalin PE *fb* clodinafop-propargyl + Na-acifluorfen PoE recorded more net returns (62.6 x10³ ₹/ha) and net B:C ratio (2.09).

It was concluded that zero-till chickpea can be grown successfully with retention of sorghum residue. Weeds can be effectively controlled with glyphosate application before sowing, pendimethalin 1.0 kg/ha PE *fb* clodinafop-propargyl + Na-acifluorfen 122.5 g/ha PoE.

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RESEARCH NOTE

Weed management in chickpea at South Saurashtra of Gujarat, India

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ABSTRACT

A field experiment was conducted during winter *(Rabi)* season of 2019-20 at Instructional Farm, Department of Agronomy, College of Agriculture, JAU, Junagadh, Gujarat, India, to study the effect of different weed management treatments on weeds, yield attributes and yield of chickpea. The experiment comprised of twelve treatments laid out in randomized block design with three replications. Significantly higher plant height, number of branches / plant, number of pods/plant, seed yield and stover yield, were recorded with pre-emergence application (PE) of pendimethalin 900 g/ha followed by (*fb*) post-emergence application (PoE) of sodium-acifluorfen + clodinafop-propargyl 80 + 165 g/ha ready-mix (RM) at 40 DAS and hand weeding (HW) twice at 20 and 40 days after seeding (DAS) as they effectively minimized the weed biomass and lowered weed index with higher weed control efficiency. The highest net return and B:C ratio were recorded with pendimethalin 900 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl 80 + 165 g/ha (RM) PoE at 40 DAS followed by alachlor 750 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl 80 +165 g/ha (RM) PoE at 40 DAS and HW twice at 20 and 40 DAS.

Keywords: Chickpea, Hand weeding, Herbicides, Sodium-acifluorfen + clodinafop-propargyl, Weed management

Pulses constitute one of the most important components of human diet and major source of protein particularly for the vegetarians. The inherent higher nutritive value and capacity to restore soil productivity, made pulses an important constituent of sustainable cropping systems. Among pulses, chickpea (*Cicer arietinum* L.) holds a prime position in area and production of winter (*Rabi*) pulse crops in India. It is a leguminous crop, belongs to family Fabaceae, subfamily Faboideae and originated from South-West Asia. India ranks first in production of chickpea in the world and contributing about 65% of global chickpea production. Weeds cause crop yield loss by competing for space, nutrients, water and light. Chickpea is a poor competitor with weeds due to its slow growth rate and limited leaf development at early stage of crop growth and establishment (Kumar *et al*. 2014). If weed management is neglected, yield loss may extend up to 75% (Chaudhary *et al*. 2005). The farmers are preferring the use of herbicides for controlling weeds in order to reduce cost of cultivation due to prevailing shortage and high cost of labor. Hence there is a need to evaluate available herbicides for identifying effective herbicides that are economical than the existing cultural weed control methods and previously recommended herbicides for weed management and to obtain higher productivity and profitability of chickpea.

An experiment was conducted, to identify economical and effective weed management option in chickpea (*Cicer arietinum* L.), during winter *(Rabi)* season of the year 2019-20. The soil of the experimental plot was clayey in texture, slightly alkaline in reaction with pH 8.0, EC 0.33 dS/m, medium in available nitrogen (249 kg/ha), high in available phosphorus (30 kg/ha) and high in available potash (283 kg/ha). The experiment was laid out in a randomized block design with twelve treatments replicated thrice. The twelve weed management treatments comprised of pre-emergence application (PE) of pendimethalin 900 g/ha followed by (*fb*) hand weeding (HW) at 40 days after seeding (DAS); alachlor 750 g/ha PE *fb* HW at 40 DAS; HW at 20 DAS *fb* post-emergence application (PoE) of propaquizafop 50 g/ha at 40 DAS; HW at 20 DAS *fb* sodium-acifluorfen + clodinafop-propargyl 80+165 g/ha ready-mix (RM) PoE at 40 DAS; pendimethalin 900 g/ha PE *fb* propaquizafop 50 g/ha PoE at 40 DAS; pendimethalin 900 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl (RM) 80 + 165 g/ha PoE at 40 DAS; alachlor 750 g/ha PE *fb* propaquizafop 50 g/ha PoE at 40 DAS; alachlor 750 g/ha PE *fb* sodium-acifluorfen + clodinafop-

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propargyl (RM) 80 +165 g/ha PoE at 40 DAS; HW at 20 DAS, HW twice at 20 and 40 DAS; weed free and un-weeded check. The pre-emergence applications of herbicides were done one day after sowing and post-emergence application of herbicides was done at 40 DAS using water 375 l/ha. Gram variety *Gujarat Gram-5* was used for sowing with seed rate of 60 kg/ha. The seeds were placed at 4-5 cm depth, keeping inter row spacing of 45 cm and covered with the soil. The crop was uniformly fertilized with 20 kg/ha N and 40 kg/ha P in the form of urea and diammonium phosphate, respectively as a basal application. Gap filling was done at 10 DAS to facilitate optimum plant population by maintaining intra row spacing of 10cm.

Total weed density at harvest was estimated by using an iron quadrat measuring 1.0 square meter, placed randomly in each of the net plot and number of weeds observed within the quadrat were counted and recorded. The weed biomass at harvest was estimated by collecting weeds from net plot area, sun dried and then dry weight of weeds was recorded from respective treatments and expressed as kg/ha. The SPAD meter value was measured from selected five plants in each plot at 35, 55 and 70 DAS by using the chlorophyll meter (Minolta SPAD-502).

Effect on weeds

The dominant weeds in the experimental field were: dicot weeds, *viz*. *Digera arvensis* Forsk, *Launaea nudicaulis* (L.) Hook.f., *Euphorbia hirta* L., *Portulaca oleracea* L., *Amaranthus viridis* L., *Chenopodium album* L., *Physalis minima* L., *Phyllanthus niruri* L., *Parthenium hysterophorus* L. and *Indigofera glandulosa* Roxb. ex Willd., monocot weeds, *viz. Brachiaria* spp., *Echinocloa colona* (L.) Link. *Cynodon dactylon* (L.) Pers. and *Dactyloctenium aegyptium* (L.) Willd. and sedge weed *Cyperus rotundus* L.

The weed biomass, weed index (WI), weed control efficiency (WCE) and herbicidal efficiency index (HEI) were influenced by different treatments (**Table 1**). The lowest weed biomass and WI and higher WCE and HEI were observed with pendimethalin 900 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl 80 + 165 g/ha (RM) PoE at 40 DAS followed by HW twice at 20 and 40 DAS (**Table 1**), among the weed control treatments other than weed free. The lowest weed growth observed with these treatments was due to early season control of weeds by application of pre-emergence herbicides, at later stage by post-emergence herbicides and removal of escaped weeds by hand weeding. The findings are in parallel with results reported by Rupareliya *et al.* (2018).

Chickpea growth and yield parameters

Significantly highest chickpea plant height, no. of branches/plant at 60 DAS and at harvest, highest yield attributes and yield, *viz.* number of pods per

Table 1. Effect of different treatments on weeds and chickpea growth parameters

Treatment	Total weed density at harvest	Weed biomass (kg/ha)	Weed index (%)	Weed control efficiency (%)	Herbicidal efficiency index	Plant height at 60 DAS	Plant height at harvest	No. of branches / plant at 60 DAS	No. of branches plant at 60 DAS
Pendimethalin 900 g/ha PE *fb* HW at 40 DAS	8.9(78.3)	208.33	0.18	82.21	3.95	34.67	36.20	6.00	7.33
Alachlor 750 g/ha PE *fb* HW at 40 DAS	10.5(109.3)	291.67	0.22	75.10	2.47	35.63	36.87	6.67	7.00
HW at 20 DAS *fb* propaquizafop 50 g/ha PoE at 40 DAS	9.7(93.3)	350.00	0.17	70.12	2.37	35.59	36.00	6.67	8.00
HW at 20 DAS *fb* sodium-acifluorfen + clodinafop-propargyl 80+165 g/ha (RM) PoE at 40 DAS	8.8(77.0)	163.33	0.19	86.05	4.85	35.65	36.67	6.33	7.33
Pendimethalin 900 g/ha PE *fb* propaquizafop 50 g/ha PoE at 40 DAS	10.0(99.7)	376.67	0.22	67.85	1.91	35.27	36.33	6.67	7.33
Pendimethalin 900 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl 80 + 165 g/ha (RM) PoE at 40 DAS	7.0(49.0)	91.33	0.08	92.20	11.58	38.16	39.00	7.67	9.67
Alachlor 750 g/ha PE *fb* propaquizafop 50 g/ha PoE at 40 DAS	10.0(99.7)	560.00	0.22	52.20	1.28	35.62	36.00	6.67	7.67
Alachlor 750 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl 80 +165 g/ha (RM) PoE at 40 DAS	10.9(119.0)	343.67	0.15	70.66	2.57	35.85	36.80	6.33	8.33
HW at 20 DAS	11.2(125.7)	581.67	0.31	50.35	-	33.27	35.13	5.67	6.67
HW at 20 and 40 DAS	7.7(59.7)	132.67	0.09	88.67	-	37.20	39.07	7.33	9.33
Weed free	0.7(0.0)	00	00	100.00	-	40.40	41.27	8.33	10.33
Unweeded check	13.1(170.3)	1171.67	0.51	-	-	27.42	27.67	4.33	5.33
LSD(p=0.05)	0.765	67.445	#	#	#	4.26	4.35	1.07	1.11
C.V. %	5.00	11.19	#	#	#	7.11	7.07	9.70	8.40

PE: Pre-emergence; *fb*: Followed by; HW: Hand weeding; DAS: Days after seeding; PoE: Post-emergence

Table 2. Effect of different treatments on SPAD meter readings, chickpea yield attributes, yield and economics

Treatment	SPAD meter reading		Pods/ plant	Seed yield (t/ha)	Stover yield (t/ha)	Gross return (x10³ ₹/ha)	Cost of cultivation (x10³ ₹/ha)	Net return (x10³ ₹/ha)	Benefit Cost ratio
	55 DAS	70 DAS							
Pendimethalin 900 g/ha PE *fb* HW at 40 DAS	63.67	66.33	54.67	2.49	2.96	124.12	38.60	85.52	2.21
Alachlor 750 g/ha PE *fb* HW at 40 DAS	62.67	66.33	52.67	2.37	2.88	117.96	38.32	79.63	2.07
HW at 20 DAS *fb* propaquizafop 50 g/ha PoE at 40 DAS	65.00	74.33	50.00	2.50	3.02	124.74	38.50	86.24	2.24
HW at 20 DAS *fb* sodium-acifluorfen + clodinafop-propargyl 80+165 g/ha (RM) PoE at 40 DAS	54.67	67.00	53.00	2.46	3.01	122.37	37.74	84.63	2.24
Pendimethalin 900 g/ha PE *fb* propaquizafop 50 g/ha PoE at 40 DAS	63.67	66.67	55.00	2.36	2.93	117.82	36.39	81.42	2.23
Pendimethalin 900 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl 80 + 165 g/ha (RM) PoE at 40 DAS	54.00	74.67	68.00	2.79	3.36	138.74	35.92	102.82	2.86
Alachlor 750 g/ha PE *fb* propaquizafop 50 g/ha PoE at 40 DAS	63.33	67.00	51.67	2.37	2.98	118.01	35.83	82.18	2.29
Alachlor 750 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl 80 +165 g/ha (RM) PoE at 40 DAS	53.33	67.33	57.67	2.57	3.03	127.90	35.36	92.54	2.61
HW at 20 DAS	58.33	64.33	51.00	2.08	2.58	103.65	36.44	67.21	1.84
HW at 20 and 40 DAS	67.00	66.67	67.00	2.77	3.34	138.07	40.99	97.08	2.36
Weed free	71.33	76.00	76.00	3.05	3.62	151.78	52.94	98.84	1.86
Unweeded check	54.33	56.00	41.67	1.46	1.72	72.84	32.45	40.39	1.24
LSD (p=0.05)	7.40	8.80	9.05	0.47	0.53	#	#	#	#
C.V. %	7.17	7.67	9.46	11.36	10.52	#	#	#	#

Where, # symbol indicates that these parameters were not statistically analyzed

plant, seed yield and stover yield were observed with pendimethalin 900 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl 80 + 165 g/ha (RM) PoE at 40 DAS and HW twice at 20 and 40 DAS, which were at par with weed free. This could be due to lesser weeds during active crop growth leading to better nutrient availability to crop which helped in luxurious crop growth. Significantly lowest chickpea plant height at 30, 60 DAS and at harvest, no. of branches/plant at 60 DAS and at harvest was documented under unweeded check. These conclusions are similar to those reported by Bankoti *et al.* (2021).

Chickpea phytotoxicity

Slight phytotoxicity in chickpea was observed with the application of sodium acifluorfen + clodinafop-propargyl 80 + 165 g/ha (RM) PoE. Symptoms like chlorosis and epinasty were observed, degree of phytotoxicity on chickpea by checking the apical growth was minimum and crop regained its satisfactory growth within a week as was also observed by Nath *et al.* (2018).

Economics

The highest gross and net returns were obtained under weed free followed by pendimethalin 900 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl 80 + 165 g/ha (RM) PoE at 40 DAS and HW twice at 20 and 40 DAS (**Table 2**). However, maximum B:C ratio was obtained with pendimethalin 900 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl 80 + 165 g/ha (RM) PoE at 40 DAS followed by alachlor 750 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl 80+165 g/ha (RM) PoE at 40 DAS and HW twice at 20 and 40 DAS, respectively due to less cost of herbicides and higher production of yield as reported by Aliveni *et al.* (2016) and Indrajeet *et al.* (2020).

Based on the results it was concluded that effective and economically viable weed management in chickpea under south Saurashtra agro-climatic zone can be achieved by application of pendimethalin 900 g/ha PE *fb* sodium-acifluorfen + clodinafop-propargyl 80 + 165 g/ha (RM) PoE at 40 DAS or by using HW twice at 20 and 40 DAS depending on the availability of labours.

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