Indian Journal of Weed Science

Print ISSN 0253-8040
Online ISSN 0974-8164

Volume – 53 | Number – 4
October – December, 2021

Available Online @ www.indianjournals.com

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

INDIAN JOURNAL OF WEED SCIENCE

Published four times a year by The Indian Society of Weed Science

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Indian Journal of Weed Science (Print ISSN: 0253-8050; Online ISSN: 0974-8164) is an official publication of the Indian Society of Weed Science (ISWS), ICAR-Directorate of Weed Research, Maharajpur, Jabalpur, India 482 004 (+91 9300127442), It contains refereed papers describing the results of research that elucidates the nature of phenomena relating to all aspects of weeds and their control. It is published quarterly, one volume per year, four issues per year beginning in March.

Membership includes online access to Indian Journal of Weed Science and the online ISWS Newsletter. Dues should be sent to Indian Society of Weed Science, ICAR-Directorate of Weed Research, Maharajpur, Jabalpur, M.P., India 482 004. Membership in the society is on a calendar-year basis or on Life time basis. New subscriptions and renewals begin with the first issue of the current volume. Please visit the ISWS subscription page at: http://www.isws.org.in/Membership.aspx; Email: iswsjbp@gmail.com

Indian Journal of Weed Science publishes four times a year in March, June, September, and December.

Annual institutional electronic subscription rates: Indian institutions: Rs. 10,000 and foreign institutions: US $ 300.

Please use the link to access manuscript submissions (http://www. http://www.isws.org.in/IJWSn/Submit_Home.aspx).

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Indian Journal of

Weed Science

Volume 53 | Number 4 | October–December, 2021

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Indian Journal of Weed Science **53**(4): 324–335, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Weed management in finger millet in India- an overview

Adusumilli Narayana Rao*

Consultant Scientist (Weed Science), Hyderabad, Telangana 500033, India

**Email: anraojaya1@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00061.7

Type of article: Review article

Received : 4 September 2021
Revised : 12 December 2021
Accepted : 14 December 2021

KEYWORDS

Agronomic management, Finger millet, Herbicides, Integrated weed management

ABSTRACT

Eleusine coracana (L.) Gaertn (finger millet) is one of the most nutritious and major staple food in some states of India. Finger millet is cultivated by using broadcast seeding, row (drill) seeding, and transplanting. In this review, the weeds associated with finger millet in different parts of India are listed, information on reported weed management options in finger millet is synthesized and future weed management research needs are enumerated. Weeds smother the finger millet resulting in significant reduction in the yield by 5 to 70%. The critical period for weed competition in finger millet is the first 4-6 weeks from planting/seeding. Physical/mechanical methods such as hand weeding at 20 and 30 days after planting (DAP) or passing wheal hoe twice with one manual weeding were found to be equally effective. In majority of the studies, inter-cropping was found helpful in reducing weed population substantially. Pre-emergence application of bensulfuron-methyl + pretilachlor, butachlor, isoproturon and post-emergence application of 2,4-D, chlorimuron-ethyl either alone or in combination with other methods were found effective in managing weeds in finger millet. Future research needs are: continuous monitoring of weeds and their shifts, understanding weed ecology and biology, developing improved mechanical tools and weed competitive cultivars along with location specific cost-effective and eco-friendly weed management strategies.

Introduction

Eleusine coracana (L.) Gaertn (finger millet) is an under-exploited minor millet with several edible and industrial uses (Chandra *et al.* 2016). It has several vernacular names all over the world, but it is known as ragi in India. Finger millet accounts for 12% of the global millet area and is grown in more than 25 countries across eastern Africa and southern Africa, and Asia from the Near East to the Far East. The major producers are India, Nigeria, Niger, Mali, Burkina Faso, Chad and China (Chandra *et al.* 2016). India continued to be the major producer of finger millet with cultivated area of 0.97 million ha and average yields of 1.62 t/ha, during 2019-20 (Tonapi 2020) and is one of the major staple foods of farming communities in some of the Indian states. The major finger millet growing states of India are Karnataka, Uttarakhand, Maharashtra, Tamil Nadu, Odisha, Andhra Pradesh, Gujarat, Jharkhand, West Bengal, Bihar and Chhattisgarh (GOI 2018). Of the total finger millet area and production in India, 13.30% and 20.58% was under irrigation (Shukla *et al.* 2015) mainly in states like Tamil Nadu and Gujarat, respectively . It is commonly grown both as sole crop and as mixed crop or in rotation with pulses and oilseeds. In state like Karnataka, pigeon pea - finger millet cropping system is predominantly followed under rainfed conditions.

Finger millet is cultivated by broadcast seeding (Sarawale *et al.* 2017), row (drill) seeding (Naik *et al.* 2000a, 2001) and transplanting (Naik *et al.* 2000, 2005) methods of establishment. Transplanting finger millet is more suitable and profitable under much delayed sowing conditions (ICAR 2008). Finger millet is grown in different seasons in different parts of the county. As a rainfed crop, during kharif season, it is sown in June-July in all Indian states except in Uttaranchal and Himachal Pradesh at hills of higher altitudes where it is sown in April-May. It is also grown in the winter season (*Rabi*) by planting in September-October in Karnataka, Tamil Nadu and Andhra Pradesh and as a summer irrigated crop by planting in January-February in Karnataka, Tamil Nadu, Andhra Pradesh and Bihar.

The area under finger millet production has become nearly half of what it was in 1955-1956 (DMD 2014) due to several factors including inadequate removal of unwanted weeds (FAO 1996, Sakamma *et al.* 2018). Finger millet has a high yield potential (>10 t/ha under optimum irrigated conditions) and the grain stores very well (http://www.icrisat.org/crop-fingermillet.htm). The current (2019-20) yield is 1.62 t/ha (Tonapi 2020). However, improved finger millet varieties with yield potential of more than 4 t/ha (*L-5* and *GPU-28*) and > 5 t/ha *(ML-365* and *MR-6*) have been developed (DMD 2014). Thus, there is a wide gap in productivity that can be and needs to be narrowed. To realize higher productivity of finger millet, the major constraints limiting finger millet productivity in farmers' fields need to be addressed. Weeds are a major constraint and limit productivity as initial slow growth of the finger millet favours growth of weeds competing for sunlight, nutrient and water in early stages of growth (Pradhan *et al.* 2010, Mishra *et al.* 2018). Weeds associated with finger millet have the ability to adjust to fluctuating edaphic and climatic situations. In order to enhance the productivity, reduce production cost and increase profitability of finger millet farming, complete understanding of associated weeds and adoption of appropriate weed management practices is important. However, an effort to synthesise the published information on weeds and weed management in finger millet is yet to be attempted. Hence, in this review, the weeds associated with finger millet in different parts of India are listed, information on reported weed management options in finger millet is synthesized and future weed management research needs are enumerated.

Finger millet yield loss due to weeds

In unweeded situations, weeds smother the finger millet resulting in significant reduction in the yield by 5 to 70% (Prasad *et al.* 1991, Kumara *et al.* 2007, Rao and Chauhan 2015, Mishra *et al.* 2016, Rama Devi *et al.* 2021) depending on the agro-climatic conditions, associated weed flora and cropping systems adopted. Grain yield of finger millet decreases linearly with increase in weed population (Nanjappa and Hosmani 1985a). Weeds cause an appreciable reduction in density, dry weight and nutrients uptake of finger millet (Naik *et al.* 2000). Weed population and weed biomass of 295/m^2 and 239 g/m^2, were reported to cause 47% reduction in yield in transplanted finger millet, respectively (Bhargavi *et al.* 2016). Hence, it is important to manage weeds during the critical period of crop weed competition to reduce the crop yield losses caused by weeds and improve the conditions favourable to crop.

In addition to direct losses caused by competition, weeds also cause losses indirectly by acting as alternate hosts to diseases. A dense population of weeds creates a good micro-environment for development of blast due to increased humidity around the crop (Berkowitz 1988). The fungus causing blast of finger millet has a wide host range, but the most common alternate hosts are grass weeds such as *Eleusine indica* (L.) Gaertn. *Eleusine africana* (Benth.) Stapf, *Digitaria* spp. *Setaria* spp. and *Dactyloctenium* spp. These serve as primary sources of inoculum (Sreenivasaprasad *et al.* 2004).

Critical period of crop-weed competition

Identifying the critical period of crop weed competition (CPCWC) in crops is one of the first steps in designing a successful integrated weed management (Rao and Nagamani 2010, Mishra 2015, Rao *et al.* 2015). The CPCWC for the finger millet varied from 25-60 days after sowing (DAS) (Yatish *et al.* 2020). In respect of irrigated transplanted finger millet, critical period for weed competition has been identified to be first 4-6 weeks from planting (Nanjappa and Hosmani 1985, Mishra 2015). Under rainfed conditions, finger millet should be kept weed-free during the first 5 weeks to prevent losses in yield (Sundaresh *et al.* 1975, Hedge *et al.* 1983). Grasses were found to be more competitive than sedges or broad-leaved weeds and weeds removed 50% of fertilizer N when weeding was delayed until 65 DAS (Hedge *et al.* 1983). In finger millet/soybean inter-cropping system, 4-5 weeks after sowing was the most critical period of competition (Mohapatra and Haldar 1998).

Weed flora

Eighty-five weed species have been reported to occur in association with the finger millet crop across India. *Cyperus rotundus* L. *Cynodon dactylon* (L.) Pers. *Commelina benghalensis* L. *Ageratum conyzoides* L. *Dactyloctenium aegyptium* (L.) Willd. *Echinochloa colona* (L.) Link, *Digitaria marginata* Stapf, *E. indica*. *Acanthospermum hispidum* DC. *Spilanthes acmella* (L.) Murray, *Eragrostis pilosa* (L.) P. Beauv. *Parthenium hysterophorus* L. *Amaranthus viridis* L. *Alternanthera sessilis (L.)* R. Br. ex DC. *Celosia argentea* L. *Euphorbia hirta* L. *Leucas aspera (Willd.)* Link, *Ocimum canum* Sims *etc*. were the most commonly reported species in the order of decreasing importance (**Table 1**). In a survey

Table 1. Major weeds associated with finger millet in India

Weed species	Ranking	States in which it was reported as a major weed
Cyperus rotundus	1	Andhra Pradesh, Bihar, Chhattisgarh, Gujarat, Orissa, Karnataka, Tamil Nadu, West Bengal, Uttar Pradesh,
Cynodon dactylon	2	Bihar, Chhattisgarh Gujarat, Karnataka, Orissa, Tamil Nadu, Uttar Pradesh
Commelina benghalensis	3	Bihar, Chhattisgarh, Karnataka, Orissa, Uttar Pradesh, West Bengal
Ageratum conyzoides	4	Bihar, Chhattisgarh, Orissa, Karnataka
Echinochloa colona	5	Bihar, Chhattisgarh, Karnataka, Orissa, Uttar Pradesh
Dactyloctenium aegyptium	6	Bihar, Karnataka
Digitaria marginata	7	Andhra Pradesh, Karnataka
Eleusine indica	8	Chhattisgarh, Orissa,
Spilanthes acmella	9	Karnataka
Acanthospermum hispidum	10	Orissa, Karnataka
Eragrostis pilosa	10	Karnataka
Celosia argentea	11	Chhattisgarh, Karnataka, West Bengal
Parthenium hysterophorus	12	Andhra Pradesh, Karnataka
Amaranthus viridis	13	Chhattisgarh, Karnataka
Euphorbia hirta	13	Andhra Pradesh, Chhattisgarh, Karnataka
Ocimum canum	13	Karnataka
Alternanthera sessilis	14	Karnataka
Digitaria sanguinalis (L.) Scop.	14	Chhattisgarh, Orissa, Karnataka
Leucas aspera	14	Karnataka
Sida accuta Burm. f.	15	Karnataka

Based on maximum number of times of its report (Weed species with equal number of times of reporting were given the same number)

on the weed flora of crop fields of North coastal Andhra Pradesh, a total of thirty-five weed species were exclusively recorded in the finger millet crop. Of these, ten species are common including *Sida cordata* (Burm. f.) Borss. Waalk. *Zaleya decandra* (L.) Burm. fil. *Euphorbia indica* Lam. and *Cyanotis cristata* (L.) D. Don. Twenty species were occasional including *Citrullus colocynthis* (L.) Schrader, *Mollugo disticha Ser. Heliotropium curassavicum* L. and *Cyperus pilosus* Vahl. (Gaddeyya and Ratna Kumar 2014). The complete covering of finger millet seedlings with dominant grasses like *D. marginata*, *Portulaca oleracea* L. and *Borreria articularis* (L.f.) F.N. Williams at 30 DAS was reported (UAS 2004). *C. dactylon* was reported to become a difficult to control major weed problem after the second year during a fixed three crop rotation of cotton-sorghum-ragi, raised under zero tillage conditions with chemical weed control (Palaniappan 1988). Thus, weed flora was observed to change in response to management practices.

Weed ecology

Finger millet adapts well in adverse environmental conditions (Gupta *et al.* 2017). Weeds associated with finger millet are also adapted to those unfavourable conditions to compete with finger millet for the limited resources. Hence, it is essential to understand the ecology of weeds associated with finger millet to manage them properly.

Weed dominance was reported to vary with soil fertility (Kandasamy *et al.* 2000, Kumar *et al.* 2000) and irrigation (Sankaran *et al.* 1974). Irrigation at 50% available soil moisture decreased weed populations, compared with irrigation at 60% and 70% (Sankaran *et al.* 1974). Weed density and weed biomass increased significantly up to 40 kg N/ha while relative weed control efficiency and weed index decreased with an increased rate of N (Kumar *et al.* 2000). *Trianthema portulacastrum* L. *Digera arvensis* Forsk. and *C. dactylon*, were the most dominant weed species in fertilized plots, while *Digera arvensis*, *C. dactylon* and *Flaveria australasica* Hook dominated unfertilized plots (Kandasamy *et al.* 2000). The weed ecology in finger millet is yet to be more thoroughly understood for an effective management.

Methods of weed control in finger millet

Non-chemical and chemical methods were found to be effective in managing weeds in finger millet (**Tables 2, 3 and 4**).

Non-chemical methods of weed control: Early weeding was found essential for finger millet and hence first hoeing and weeding within 2 to 3 weeks of sowing and the second a fortnight after was advocated (DAO 2008). Among the non-chemical methods of weed control, physical/mechanical methods such as hand weeding at 20 and 30 days after planting (DAP) or stale seedbed combined with two inter-cultivation or passing wheel hoe twice with one manual weeding were suggested as they were found to be equally effective (Patil *et al.* 2014). Hand weeding and inter-cultivation are the common methods used by the farmers. However, their adoption is normally delayed by farmers. Hence, it is

Table 2. The weed management methods reported effective in drill-seeded finger millet in India

Weed management method	Location, State	Reference
Non chemical		
The conventional tillage (ploughing twice + harrowing once + inter-cultivation twice at 25 and 50 days after sowing (DAS) in Alfisols when compared to minimum and zero tillage practices	Bangalore, Karnataka	Hatti *et al.* 2018
Hand weeding (HW) thrice 20, 40 and 60 DAS	Bangalore, Karnataka	Naik *et al.* 2001, 2001a, 2005
HW twice15 and 30 DAS	Madurai, Tamil Nadu	Boopathi *et al.* 1985a
HW twice 20 and 40 DAS	Almora, Uttarakhand; Bangalore, Karnataka; Berhampur, Orissa; Raipur, Chhattisgarh; Ranchi	Jena and Tripathy 1997, Tuti *et al.* 2016, Pandey *et al.* 2018, IIMR 2021
Hoeing once 15 DAS followed by (*fb*) HW thrice 25,40, 60 DAS	Bhuvaneswar, Orissa	Tosh and Nanda 1983
Hoeing once (30 DAS) *fb* HW once 30 DAS	Bangalore, Karnataka	Reddy *et al.* 1990
Hoeing twice (28 and 41 DAS) (with the improved bent type sweep hoe)	Bangalore, Karnataka	Gowda and Dhananjaya 2000
Hoeing twice by wheel hoe between rows + intra-row manual weeding *fb* HW twice 20 and 40 DAS	Raipur, Chhattisgarh	Kujur *et al.* 2018
Inter-cultivation twice 20 and 40 DAS *fb* HW once 35 DAS	Coimbatore, Tamil Nadu; Tehri Garhwal, Uttar Pradesh	Singh and Arya 1999, Ramamoorthy *et al.* 2002
Inter-cultivation once *fb* HW twice 30 and 45 DAS	Coimbatore, Tamil Nadu	Ramamoorthy *et al.* 2010
Deris indica leaf mulch	Ranchi, Jharkhand	IIMR, 2021
Chemical		
2, 4-D sodium salt 0.75 kg/ha post-emergence application (PoE) 15–20 DAS	Bangalore, Karnataka; Berhampur, Orissa	Jena and Tripathy 1997, Ashok *et al.* 2003, DOA 2008, DMD, 2014
2,4-D 1.0 kg/ha PoE 3-4 weeks after sowing	Ranchi, Jharkhand	Pradhan 1988
2,4-D-sodium salt 1.5 kg/ha PoE	Pandicherry	Subbiah *et al.* 1974
Bensulfuron-methyl (0.6 % G) + pretilachlor (6.0 % G) 0.75 kg/ha (ready-mix) pre-emergence application (PE) (3 DAS)	Bangalore, Karnataka	Kumar 2015, Kumar *et al.* 2015, 2015a
Butachlor 0.75 kg/ha PE (within 3 DAS)	Karnataka (Southern Transition zone, Southern Dry zone, Eastern Dry zone and Central Dry zone.)	DWR 2000
Isoproturon 0.5 kg/ha PE	Jagdalpur, Chhattisgarh; Tehri Garhwal, Uttar Pradesh; Bangalore, Karnataka Coimbatore, Tamil Nadu	Singh and Arya 1999, Ramamoorthy *et al.* 2002, Ashok *et al.* 2003, ICAR 2008, DOA 2008, Pradhan *et al.* 2012, DMD 2014
Isoproturon 0.5 PE *fb* 2, 4-D Na salt 0.5 kg/ha PoE	Raipur, Chhattisgarh	Kujur *et al.* 2018
Neburon 1.0 kg/ha and 2,4-D sodium 1.5 kg/ha PE	Bangalore, Karnataka	Reddy *et al.* 1990
Nitrofen 0.5 kg/ha PE	Pondicherry, India	Subbiah *et al.* 1974
Nitrofen 0.5 kg/ha PE *fb* propanil 2.0 kg/ha PoE	Madurai, Tamil Nadu	Boopathi and Kolandaiswamy 1981, Boopathi *et al.* 1985a
Integrated		
2,4-D amine or sodium salt at 0.5 and 1.5 kg/ha PoE 10 DAS *fb* hoeing and/or HW once 30-35 DAS	Bangalore, Karnataka	Prasad *et al.* 1991
Butachlor 0.5 to 0.75 kg/ha 12 DAS *fb* hoeing once 35 DAS	Bangalore, Karnataka	Naik *et al.* 1999, 2001
Chloramben 1.01 kg/ha (1 DAS) *fb* HW once 25 DAS	Bhuvaneswar, Orissa	Tosh and Nanda 1983
Isoproturon 0.25 kg/ha + metoxuron 0.375 kg/ha PE 1 DAS *fb* HW once 30 DAS	Bangalore, Karnataka	Manjunath and Muniyappa 1992
Isoproturon 0.5 kg/ha PE *fb* 2,4-D Na salt 0.75 kg/ha PoE 15 DAS *fb* inter- cultivation once 30 DAS	Coimbatore, Tamil Nadu	Ramamoorthy *et al.* 2010
Isoproturon 0.5 Kg/ha PE *fb* HW twice 20 and 40 DAS	Jagdalpur (Chhattisgarh)	Pradhan and Singh 2009
Isoproturon 0.50 kg/ha *fb* hoeing up to 35 DAS	Bangalore, Karnataka	Naik *et al.* 2001a
Metoxuron 0.50 kg/ha PE 1 DAS *fb* HW 30 DAS	Bangalore, Karnataka	Manjunath and Muniyappa 1992
Oxyfluorfen 0.25 to 0.5 kg/ha *fb* HW twice 20 and 45 DAS	Jagdalpur, Chhattisgarh	Pradhan *et al.* 2010
Oxadiargyl at 150 to 200 g/ha (within 3 DAS) *fb* one inter-cultivation once at 25-30 DAS	Kolhapur, Nandyal, Ranchi and Ranichauri	IIMR 2021
Bispyribac sodium 15 g/ha (within 15-20 DAS) *fb* inter-cultivation once 35-40 DAS	Kolhapur, Nandyal, Ranchi and Ranichauri	IIMR 2021

Table 3. Weed management practices found effective in transplanted finger millet in India

Weed management method	Location	Reference
Non chemical		
Hand weeding (HW) once between 2 to 3 weeks after transplanting. A second weeding may be done 15 to 20 days after, if necessary.	Orissa	DOA 2008
HW twice 20 and 30 days after planting (DAP)	Bangalore, Karnataka	Patil *et al.* 2014, 2014a; Patil and Reddy 2014
HW twice 15 and 30 DAP	Coimbatore, TN	Ramamoorthy *et al.* 2010
HW twice 20 and 40 DAP	Bangalore, Karnataka Tirupati, Andhra Pradesh	Guruprasanna *et al.* 2004, Kumara *et al.* 2007, Rama Devi *et al.* 2021
Hoeing twice 20 and 35 DAP followed by (*fb*) HW once 45 DAP	Bangalore	Patil *et al.* 2014
Hoeing (wheel) thrice 20, 30 and 40 DAP *fb* HW once 45 DAP	Bangalore	Patil and Reddy 2014
Inter-culture twice *fb* HW once or twice	India	DMD 2014
Stale seed bed technique *fb* inter-cultivation twice at 20 and 35 DAP and it was at par with hand weeding twice at 20 and 30 DAP; passing wheel hoe at 20, 30 and 40 DAP + one HW at 45 DAP	Bangalore	Patil *et al.* 2013
Stale seedbed technique in combination with inter-cultivation twice at 20 and 35 DAP or passing wheel hoe at 20, 30 and 40 DAP with one hand weeding for weed management	Bangalore	Patil *et al.* 2014a
Stale seedbed with inter-cultivation twice at 20 and 35 DAP	Bangalore	Patil *et al.* 2014, Patil and Reddy 2014
Chemical		
Bensulfuron-methyl 60 g + pretilachlor 600 g (6.6% G pre-mix formulation) 1.0 kg/ha pre-emergence application (PE) 2 DAP	Mandya, Karnataka	Banu *et al.* 2016
Butachlor 0.75 kg/ha PE 3DAP	Bangalore, Karnataka	Kumara *et al.* 2007
Butachlor 0.5 to - 0.75 kg/ha 7 to 12 DAP	Bangalore, Karnataka	Naik *et al.* 2000, Naik *et al.* 2000a, 2005, Kumara *et al.* 2014
Butachlor 0.75 kg/ha PE 3 DAP	Bangalore, Karnataka	Prasad *et al.* 2010, Kumara *et al.* 2014
Chlorimuron ethyl 5 and 10 g/ha Early PoE10 DAP	Bangalore, Karnataka	Guruprasanna *et al.* 2004
2, 4-D Na salt 0.75 kg/ha PoE 15 DAP	Bangalore, Karnataka	Kumara *et al.* 2007
Fluchloralin 0.9 kg/ha PE and 2,4-D sodium 0.8 kg/ha PoE	Bangalore, Karnataka	Dhanapal 1987
Nitrofen 0.5 kg/ha PE or 2,4-D 1.5 kg/ha PoE	Coimbatore, Tamil Nadu	Sankaran *et al.* 1974
Nitrofen 0.5 kg/ha 5 DAP *fb* propanil 2.0 kg/ha 20 DAP	Madurai, TN	Boopathi *et al.* 1985
Oxyfluorfen 0.1 kg/ha PE 3 DAP azimsulfuron 20 g/ha PoE 20 DAP	Tirupati, Andhra Pradesh	Bhargavi *et al.* 2016.
Oxyfluorfen 0.1 kg/ha PE *fb* HW once 20 DAP	Tirupati, Andhra Pradesh	Bhargavi *et al.* 2016.
Oxyfluorfen 0.1 kg/ha PE	India; Mandya, Karnataka	Prakash *et al.* 2006, ICAR 2008, DMD 2014
Propanil 2.24 kg/ha PoE	Orissa	Patro and Tosh 1982
Pyrazosulfuron-ethyl 15 g/ha PE 2 DAP	Tirupati, Andhra Pradesh	Rama Devi *et al.* 2021
Pretilachlor 500 g/ha PE 2 DAP	Tirupati, Andhra Pradesh	Rama Devi *et al.* 2021
Penoxsulam 20 g/ha PoE 20 DAP	Tirupati, Andhra Pradesh	Rama Devi *et al.* 2021
Integrated		
Butachlor 0.5 kg/ha12 DAP *fb* earthing-up once 35 DAP	Bangalore, Karnataka	Naik *et al.* 2005
Butachlor 1.0 kg/ha PE *fb* HW once 30 DAP	Coimbatore, TN	Kandasamy *et al.* 2000
Isoproturon or 2,4-D sodium salt 0.75 or 0.5 kg/ha 7 DAP *fb* earthing up once 35 DAP	Ranchi, Bihar; Bangalore, Karnataka	Yadav *et al.* 2005, Naik *et al.* 2000a
Nitrofen 0.5 kg/ha PE 5 DAT *fb* HW once 30 DAS	Madurai, TN	Boopathi *et al.* 1985, Kolandaiswamy 1981, Boopathy *et al.* 1985a
Oxadiargyl 100 g/ha PE 3 DAP *fb* inter-cultivation once 20 DAP	Bapatla, Andhra Pradesh	Prithvi *et al.* 2015
Oxadiazon 0.4 kg/ha PE *fb* HW once 30 DAP	South Konkan.	DWR 2000
Oxadiazon 0.50 kg/ha *fb* HW (30 DAP) HW once 30 DAP	Coimbatore, TN	Ramamoorthy *et al.* 2010
Pendimethalin 0.75 kg/ha PRE *fb* HW once 30 DAP	Coimbatore, TN	Ramamoorthy *et al.* 2010
Pretilachlor 0.45 kg/ha *fb* HW once 30 DAP	Coimbatore, TN	Ramamoorthy *et al.* 2010

essential to create awareness among farmers on the importance of carrying out those operations during critical period of crop weed competition.

Hand weeding: In regions where animal or machine power is not available, the weeding and cultivation operations are usually carried out by hand, manually. This may be done on an individual family or community basis. Hand weeding once to thrice (**Table 2** and **3**) was found to be the best and an efficient method for the weed control giving highest yield and weed control efficiency (Bhushan and Singh 2013, Patil *et al.* 2014a, Patil and Reddy 2014). However, implementation of MGNERGA (Mahatma Gandhi National Rural Employment Guarantee Act) works has led to labour scarcity to the tune of 53% and 30% for agriculture operations like weeding and sowing, respectively, resulting in a decline in area for labour intensive crops like ragi to the extent of 30%, in Chikmagalur districts in central dry zone of Karnataka (Harish *et al.* 2011). The labour non-availability and increasing labour cost are becoming serious limitations for the farming community to adopt the manual method of weed control. Hence, hand weeding may be used for managing weeds when family labour is available on small holdings or as a component of integrated weed management.

Tillage: The role of tillage in conserving soil moisture and its subsequent beneficial effect on crop productivity has long been recognized. Conventional tillage was found superior for finger millet under semiarid Alfisols (Sankar *et al.* 2006). However, conventional tillage had resulted in higher weed density particularly grasses and additional cost than zero tillage (UAS 2004). The combination of wooden ploughing followed by power tiller rotovating or cultivating, with later inter-row cultivation by the improved bent tyne sweep hoe, gave higher yields of dryland finger millet than conventional methods of seedbed preparation by bullock ploughing followed by inter-row cultivation with the local hoe called '*chipkunte'* (Gowda *et al.* 1999). Under rainfed pigeon pea-finger millet system in Alfisols, the infestation of *Borreria articularis*, *Cynodon dactylon* and *C. rotundus* was reduced with conventional tillage (3 ploughings + 3 inter cultivations) when compared to other tillage practices {reduced tillage (2 ploughings + 2 inter cultivations) and minimum tillage (1 ploughing + 1 inter-cultivation)} (Vijaymahantesh *et al.* 2016). Tillage has its influence on weed seed distribution in soil. More weed seeds were distributed in upper 10 cm soil depth in minimum tillage where as in conventional tillage weed seed distribution was more or less uniform in the soil profile (Vijaymahantesh *et al.* 2016, Hatti *et al.* 2018). Exhausting weed seedbank with stale seedbed technique (Patil *et al.* 2014a, Patil and Reddy 2014), under minimum tillage, may be explored as a means of weed management in finger millet.

Inter-cultivation: Traditionally, direct row seeded stands of finger millet are often cultivated by farmers with tined implements drawn by draft animals. This is done twice or thrice at ten-day intervals beginning about three weeks or a month after seeding. Inter-cultivation once or twice followed by hand weeding was found to be effective in managing weeds in finger millet (**Table 2** and **3**). Energy analyses indicated that among different operations of cultivation of irrigated crop of finger millet, weeding and inter-row cultivation used for managing weeds were the most energy intensive operations (Gowda *et al.* 1999). Inter-cultivation results in removing weeds, thinning the stand, particularly in the case of the broadcast one, and mulching the soil. Later the crop is hand-weeded and hand hoed once or twice. The use of improved blade hoe and improved bent type sweep hoe proved superior in conserving soil moisture at flowering and grain filling stages, controlled weeds more effectively and resulted in the highest grain yield, compared to inter-row cultivation using the local hoe (Gowda and Dhananjaya 2000).

Inter-cropping: Inter-cropping, finger millet with legumes such as urd bean (*Vigna mungo* L. Hepper), peanuts (*Arachis hypogea L.*), cowpeas (*Vigna unguiculata* (L.) Walp.) and pigeon pea (*Cajanus cajan* (L.) Huth), is common among farmers as complementarity between crops in resource use is important in low input subsistence farming systems (Chandra *et al.* 2013). Inter-cropping results in highest grain yield/ha (Sidar and Thakur 2017) and less weeds, insects and diseases infestation in the crop (Meena *et al.* 2017). The improved cropping

Table 4. Weed management practices found effective in finger millet based inter-cropping systems

Inter-cropping system	Herbicide/weed management method	Location	Reference
Finger millet inter-cropped with soybeans or mixtures of field bean, niger [*Guizotia abyssinica* (L.f.) Cass.], fodder jowar [*Sorghum bicolor* (L.) Moench] and mustard [*Brassica juncea (L.) Czern.*]	Hand weeding (HW) thrice gave the highest grain/seed yields in all cropping systems Neburon 2. 1.0 kg/ha pre-emergence treatment (PE)	Bangalore, Karnataka	Nanjappa and Hosmani 1986
Finger millet + sorghum (drill-seeded)	2,4-D ethyl-ester1.0.6 kg/ha PE Fluchloralin 0.55 kg/ha post-emergence treatment (PoE) 2,4-D amine 0.3 kg/ha PoE as directed sprays	Bangalore, Karnataka	Mahabaleswara 1987
Finger millet + pigeon pea (drill-seeded)	Conventional tillage (three ploughings -15 to 20 cm deep) *fb* inter-cultivation thrice – first after 30 days after seeding (DAS) and remaining at 15-day intervals) + integrated supply of nitrogen (50% N through urea +25% through FYM+25%N through Glyricidia [*Gliricidia sepium* (Jacq.) Kunth ex Walp.])	Bangalore, Karnataka	Vijaymahantesh *et al.* 2016
Finger millet + horsegram (*Macrotyloma uniflorum* (Lam.) Verdc.) (drill-seeded)	Finger millet–horsegram (2:1 ratio) (inter-row space 30 cm) with HW twice 25 and 40 DAS	Jagdalpur, Chhattisgarh	Pradhan *et al.* 2018

systems include: finger millet + pigeon pea in 8-10: 2 or finger millet + field bean (*Phaseolus vulgaris* L.) in 8: 1 for Karnataka and Tamil Nadu and finger millet + field bean in 6 : 2 row proportion for Bihar; finger millet + soybean (*Glycine max* (L.) Merr.) (9:1 crop mixtures) for Garhwal region of Uttarakhand; finger millet + mothbean (*Vigna acontifolia* L.)/ blackgram [*Vigna mungo* (L.) Hepper] (4:1) for Kolhapur (DMD 2014). In finger millet / blackgram (Chandra *et al.* 2013) and blackgram + finger millet (1:1 or 2:1) (Bhushan and Singh 2013) inter-crops, weed biomass was lower than sole crops. Hand weeding, certain herbicides and inter-cultivation were found to be effective in managing weeds in inter-cropping systems (**Table 4**). A few of the inter-crops do not show the advantage of reducing weed biomass. For example: weed biomass was not significantly affected by inter-crops of finger millet with horse gram [*Macrotyloma uniflorum (Lam.) Verdc.*] or soybeans (Patil *et al.* 1987, Pradhan *et al.* 2018).

Weed control with herbicides

The labour availability is decreasing and the labour wages are increasing making labour use uneconomical in India. Hence, efforts were made to identify appropriate and cost-effective herbicides to control weeds and improve finger millet productivity (Mgonja *et al.* 2013).

Effective herbicides for managing weeds in finger millet: Several herbicides were found effective in managing weeds in finger millet in India (**Table 2** and **3**). Herbicide (butachlor at 0.75 kg/ha) application in finger millet gave similar grain yield to hand weeding twice due to good weed management (Dhanapal *et al.* 2015) and saved weeding cost (Rs. 6810 to 6980/ha) (Prasad *et al.* 2010). Several researchers reported herbicide use to be the most effective and economical method for managing weeds in finger millet (Guruprasanna *et al.* 2004, Ramamoorthy *et al.* 2010, Pradhan *et al.* 2012, Bhargavi *et al.* 2016). Application of 2,4-D reduced the number of broad-leaved weeds, with the exception of *A. conyzoides*, but resulted in higher densities of grasses (*D. marginata*, *D. aegyptium*, *E. pilosa* and *E. colona*) at all stages (Prasad *et al.* 1991). Weed population shifts were also reported in a few instances. For example: continuous application of butachlor in finger millet resulted in considerably lowered grass (*D. marginata* and *E. colona*) density and increased sedge density (Prasad *et al.* 2010). Density of *C. benghalensis* was also found to increase with continuous application of butachlor. Greater efforts are needed to understand the weeds species response to the herbicides used and identify suitable herbicides and combinations to manage weed flora associated with finger millet.

Effect of residual herbicides and persistence

Finger millet is normally raised as succeeding crop in the same field after the harvest of crops like groundnut treated with herbicides. Fluazifop-p-butyl (Kumbar *et al.* 2014) and pendimethalin (Gowda *et al.* 2002) applied to groundnut and fluometuron (Balasubramanian and Sankaran 1976), glyphosate (Jagannathan and Nadanam 1996, Nadanassababady *et al.* 2000) and glufosinate (Nadanassababady *et al.* 2000) applied on cotton did not cause phytotoxicity on succeeding finger millet grown. However, straw yield of finger millet was lower when grown in plots treated with 1.0 kg atrazine/ha in preceding sorghum crop (Jagannathan and Nadanam 1996).

In a long-term study, no residual toxicity was observed due to any of the herbicides applied to the respective crops grown in rotation for over nine years in finger millet (butachlor or 2,4-D)-groundnut (pendimethalin or alachlor) cropping system (Prasad *et al.* 2010). Butachlor persisted in soil up to 21- 30 days in finger millet and the half-life ranged from 11.3 to 15.5 days in red sandy loam soil (Gowda *et al.* 2008). Continuous application of herbicides butachlor (0.75 kg/ha), 2,4-D (0.40 kg/ha) to finger millet did not affect the pH, EC, bulk density organic carbon, phosphorous and potassium contents of soil. Continuous application of herbicides 2,4-D (0.4 to 0.8 kg/ha), butachlor (0.75 to 1.5 kg/ha) in transplanted finger millet did not show herbicide residues in soil, grain, straw and underground water (in case of butachlor only) at 100 to 120 days of herbicide application (Gowda *et al.* 2008).

Herbicide toxicity to finger millet

Phytotoxicity to finger millet was reported due to application of fluchloralin at 1.0 or 1.25 kg/ha PE (Mahabaleswara *et al.* 1987). Simazine or atrazine 0.5 kg/ha PE was slightly toxic to *E. coracana*, even though it was most effective against weeds (Sankaran *et al.* 1974). Butralin, thiobencarb, alachlor, monuron, fluchloralin reduced the finger millet stand substantially within 10 DAS (Tosh and Nanda 1983). It is essential to take necessary care to educate farmers in avoiding the usage of herbicides that cause toxicity to finger millet.

Effect of herbicides on microbial population

The application 2,4-D, neburon, propanil and nitrofen, had a depressive effect on the soil microbial population during first 30 days of herbicide application. However at a later stage, there was built up of population of soil bacteria, fungal, actinomycetes and azotobacter to the original level in soils of finger millet crop (Nanjappa *et al.* 1986). The application of butachlor and 2,4-D Na salt (0.75 kg/ha) in finger millet and butachlor and pendimethalin (1.0 kg/ha) in the succeeding groundnut showed higher microbial biomass in the soil at harvest as compared to hand weeding or unweeded (Kumara *et al.* 2014). Continuous monitoring of the influence of microbial population associated with finger millet grown soil is essential for sustainable soil health management.

Integrated weed management

Integrated weed management (IWM) with combination of herbicides, mechanical and hand weeding methods proved to result in efficient weed control and higher finger millet yields (**Table 2, 3** and **4**). IWM effectively manages weeds, reduces the uptake of nutrients by weeds, thereby making nutrients available to finger millet and reduces the cost on excess nutrients application (Gowda *et al.* 2012). The integration of hand weeding with 2,4-D resulted in higher yields of finger millet (Prasad *et al.* 1991). The stale seedbed technique in combination with inter-cultivation twice at 20 and 35 DAP or passing wheel hoe at 20, 30 and 40 DAP with one hand weeding was found effective and was suggested as a viable alternative to manual weed control (at 20, 30 and 40 DAP) in organic finger millet production (Patil *et al.* 2014a, Patil and Reddy 2014). Considering the increased cost and non-availability of labour, the integrated use of herbicides and mechanical weeding for weed control at critical stages proved to be an appropriate strategy for finger millet (Naik *et al.* 2001a, Yadav *et al.* 2005, Gowda *et al.* 2012, Rao *et al.* 2015).

Economics of weed management

Farmers' decision on the method of weed control depends on the profitability of various options available. Economic evaluation of weed management methods tested in finger millet indicated that the lesser weed density and biomass; higher yields of finger millet and higher B:C ratio were obtained with hand weeding twice (Boopathi *et al.* 1985a), isoproturon 0.50 kg/ha PE (Pradhan *et al.* 2012), chlorimuron-ethyl 5 g/ha (Guruprasanna *et al.* 2004), 0.5 kg/ha nitrofen + 2.0 kg/ha propanil (Boopathi *et al.* 1985a), integration of hand weeding once with 2, 4-D (Prasad *et al.* 1991) or nitrofen (Boopathi *et al.* 1985a) or oxyfluorfen 0.25 kg/ha PE (Pradhan *et al.* 2010), integration of hand weeding twice (20 and 45 DAS) with oxyfluorfen 0.15 to 0.25 kg/ha (Pradhan *et al.* 2010), isoproturon PE at 0.5 kg/ha *fb* 2,4-D Na salt at 0.75 kg/ha PoE 15 DAS and inter-cultivation once on 30 DAS (Ramamoorthy *et al.* 2010); butachlor (0.5 kg/ha) *fb* hoeing once at 35 DAS (Naik *et al.* 2001), oxyflourfen 0.1 kg/ha PE (3 DAT) *fb* azimsulfuron 20 g/ha PoE applied at 20 DAT (Bhargavi *et al.* 2016). However, Tuti *et al.* (2016) recorded the highest B:C ratio (1.39) with manual weeding at 20 DAS alone in rainfed finger millet in Uttarakhand. Farmers in India normally follow hand weeding or inter-cultivation or integration of both as they are most economical to them in their small holdings and as they are not aware of the herbicides available for managing weeds in finger millet. There is an urgent need to create awareness among finger millet farmers in India on the usefulness and economical advantage of integrating herbicides with either hand weeding or inter-cultivation.

Future research

The finger millet is known to be the food of resources poor farming community in the ecologically and socially fragile ecosystems of semi-arid tropical region of India. However, during recent years the importance of finger millet is being realized keeping in view of its nutritional and other values. One of the ways to increase the income of the finger millet farmers is to evolve improved crop management practices including weed management that enables farmer to incur less cultivation expenses and get higher income. Hence, there is an urgent need to increase the research on finger millet to evolve the integrated crop and weed management technologies that are cost-effective, eco-friendly and which suit to the needs of the finger millet farming community in India.

A few of the future areas of research include: i. Farmers need based weed management research; ii. Basic understanding of the biology and ecology of weeds, and assessing effect of climate change on weeds and their management; iii. Improved mechanical tools (*eg:* finger millet crop specific power weeder) development for mechanical management of weeds and integrating as a component of IWM; iv. Evolve improved weed competitive finger millet cultivars; v. Identifying biological control agents in order to integrate with other methods and vi. Developing and scaling up IWM practices for enhancing productivity of finger millet with enhanced resources use efficiency.

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Indian Journal of Weed Science **53**(4): 336–340, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Weed seedbank dynamics under different tillage practices and planting density in organic basmati rice production system

Hasamuddin Hasam[1], Simerjeet Kaur[1]*, Navjyot Kaur[2] and Makhan S. Bhullar[1]

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

[2]*Department of Plant Breeding & Genetics, PAU, Ludhiana, Punjab 141004, India*

**Email: simer@pau.edu*

Article information

DOI: 10.5958/0974-8164.2021.00062.9

Type of article: Research article

Received : 6 June 2021

Revised : 20 October 2021

Accepted : 22 October 2021

KEYWORDS

Basmati rice, Deep tillage, Green manure, Non-chemical weed control, Puddled transplanted rice, Weed, Seedbank

ABSTRACT

There is a growing demand for organically produced food, including basmati rice, worldwide and organic farming is continuously gaining importance. An experiment was conducted with an objective to study weed seedbank and its management with non-chemical weed management approaches including tillage, plant density and green manuring, in organically grown basmati rice. The two-year study was conducted at research farm of Department of Agronomy, Punjab Agricultural University, Ludhiana, India during (rainy) *Kharif* season of 2017 and 2018. Tillage has differential effect on vertical weed seed distribution as the maximum number of seeds of *Dactyloctenium aegyptium* (L.) Willd., *Echinochloa colona (L.) Link, Trianthema portulacastrum* L. and *Cyperus iria* L. in conventional tillage (CT) was observed in upper soil layer of 0-15 cm whereas in deep tillage (DT), most of weed seeds were displaced to deeper layer (15-30 cm). The lowest weed seedbank was observed with green manuring using sunhemp (*Crotalaria juncea* L.) crop raised by sowing seed of at 50 kg/ha before the transplanting of basmati rice and incorporating sunhemp plants into soil at 40 days after seeding it). Integration of differential tillage, green manuring and increased rice plant density resulted in low biomass of *Echinochloa colona* and *Eclipta alba* than weedy check. Rice growth, yield attributes and grain yield were found statistically similar in non-chemical weed management treatments and conventional agriculture treatment.

INTRODUCTION

Basmati rice is unique among other aromatic long grain rice varieties due to its delicious taste, superior aroma and distinct flavor (Prajapati and Patel 2013). Punjab is an important rice producing state and acreages under basmati rice in the state was estimated at 6.50 lakh hectares during 2021. The Green revolution led to many folds increase in rice and wheat production, but it resulted in deteriorating soil health and decreased organic matter content. The high level of chemical inputs is increasing pollution hazard and results in further degradation of soil health. There is need to shift some area under high value crops into organic agriculture system. Organic farming is defined as the production system which avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators and livestock feed additives. Total area under organic certification process (registered under national program for organic production, APEDA) was 4.33 million ha during 2020-21. It comprises 2.66 million ha of crop land and 1.68 million hectares of wild harvest.

Weeds have become an important production constraint in the transplanted rice, in general, and failure to control weeds results in lower crop yields, and the losses may go up to 40% (Maity and Mukherjee 2008; Pandey and Bhandari 2009). The weed competition during early growth period is more damaging for rice (Rao *et al.* 2007) and weed flora emerges in several flushes during the crop growth period and therefore higher rice yields can only be achieved if weeds are controlled earlier. Tillage helps in controlling weeds by burying weed seeds and emerged seedlings by leaving a rough surface to hinder weed seed germination and expose underground parts of perennial weeds leading to their desiccation (Subbulakshmi 2007). Preparatory tillage and interculture or hoeing can be employed to control weeds under organic agriculture system. Deep tillage is mechanical soil profile modifications, which could improve the nutrient availability and affect vertical distribution of weed seeds in soil profile (Schneider *et al.* 2017). Hand weeding is slow, labour intensive and high-drudgery involving weed management method. Moreover, it can only be adopted over small area by organic growers (De Datta and Baltazar 1996). Hand pulling of weeds in standing water or from moist field may be more helpful in reducing drudgery.

The use of green manuring is primarily important in contributions to soil fertility which also play an important role in managing weeds. Green manuring has great potential and is feasible in rice-wheat system in northern India as there is 45-60 days fallow period between wheat harvest and transplanting of rice. Due to vigorous growth of sunhemp (*Crotalaria juncea* L.) plants in initial 30-40 days, it suppressed the emergence and growth of weed plants (Duke 1981). The weed suppression by sunhemp cover crops has been minimally investigated and only recently it has received more attention. As cropping density increased, the area occupied by weeds decreased which decreased the availability of growth resources to weeds, and thereafter crop yield losses decreased (Aminpanah 2014). Specific information on weeds and growth of basmati rice due to variable green manuring levels, tillage and plant density may provide valuable indications in developing integrated weed management approaches in organic agriculture systems. The objectives of this study were to study weed seedbank and its management with non-chemical weed management approaches including tillage, plant density and green manuring in organically grown basmati rice.

MATERIALS AND METHODS

The field experiment was conducted at the research farm, Punjab Agricultural University (PAU), Ludhiana (30°56'02 N latitude, 75°52'33 E longitude) during (rainy) *Kharif* season (July-October) of 2017 and 2018. The soil of the experimental field was sandy loam, medium in organic carbon (0.42%), low in nitrogen (257.7 kg/ha), medium in phosphorus (14.6 kg/ha) and potassium (163.1 kg/ha), with soil pH of 7.1 and electrical conductivity of 0.19 dS/m. This experiment was conducted in randomized complete block design in three replicates with a total of 30 experimental plots of 7.5 × 5.0 m size.

Weed control treatments tested in this study were: conventional tillage (CT) with (+) green manuring with sunhemp sown using seed rate of 50 kg/ha and incorporated in to soil at 45 days after sowing (DAS) *i.e.* one day before puddling operation (GM 50 kg/ha) + unweeded (weeds were allowed to grow for whole crop season); CT + GM 50 kg/ha + weed free (weeds were uprooted as and when these appeared in plot); CT + GM 50 kg kg/ha + 25 % higher rice plant density + one hand pulling; deep tillage (DT) + GM 50 kg/ha + 25% higher plant density + one hand pulling; CT + GM using sunhemp seed rate of 75 kg/ha (GM 75 kg/ha) + 25% higher rice plant density + one hand pulling; DT + GM 75 kg/ha + 25% higher rice plant density + one hand pulling; CT + using sunhemp seed rate of 100 kg/ha (GM 100 kg/ha) + 25% higher rice plant density + one hand pulling; DT + GM 100 kg/ha + 25% higher rice plant density + one hand pulling; DT + GM 100 kg/ha + normal plant density + one hand weeding. One treatment of conventional agriculture was kept which was compared with weed free treatment of organic agriculture system. In conventional agriculture treatment, pesticides (herbicides, insecticides, fungicides) were used for plant protection measures and inorganic fertilizer was added as per the recommendations of PAU.

Laser land leveller was used for field levelling and it was followed by pre-sowing irrigation. The tillage treatments were given before sowing of green manure crop at variable seed rate. In CT treatments, two ploughings with disc plough were followed by planking; while in deep tillage, one ploughing with mould board plough was followed by planking. Thereafter, green manure crop sunhemp was sown with different seed rates (50, 75 and 100 kg/ha) in respective treatments. At 45 days after sowing (DAS), the sunhemp plants were incorporated one day before puddling operation. The field was filled with water and puddling was done with the help of cultivator. Nursery of basmati rice cultivar *Pusa Basmati* 1121 (days to maturity: 145 days) was transplanted at 30 days of sowing in the puddled field. In normal planting density, 33 plants/m^2 were transplanted at spacing of 20 cm × 15 cm. The plant spacing of 20 × 12 cm was adopted for 25% higher plant density (41 plants/m^2). Hand pulling of weeds was done to uproot once at 35 days of transplanting (DAT) as per treatments. Weed free plots in the experiment were kept free from weeds for whole crop season by hand weeding as and when needed. In weedy plot, weeds were allowed to grow for whole crop season. Water was kept standing continuously for two weeks in the crop after transplantation. Afterwards, irrigation was applied two days after the ponded water has infiltrated into the soil. The irrigation was stopped 15 days before crop harvest. In conventional plot, N-P-K fertilizer was applied for meeting the nutrition and plot was kept weed free with use of pre-emergence herbicide (pretilachlor). For the protection of rice crop from stem borer attack, strips of tricho-cards of *Trichogramma japonicum* and *T. chilonis* per acre were stapled at a weekly interval, starting 30 days after transplantation. For protection from leaf folder, mechanical control by passing 30 cm long coir or jute rope forward and then backwards while touching the crop canopy, starting from 30 days after transplanting was done 2-3 times up to flowering phase.

Weed seedbank study was done by taking soil samples from each plot at 0-7.5 cm, 7.5-15 cm and 15-30 cm soil depth with the help of core sampler before performing tillage (CT or DT) and after tillage. Weed seedbank study was also done by taking soil samples at 0-7.5 cm soil depth after incorporation of green manure crop at 45 DAS. To separate weed seeds from the soil, soil samples were washed with a 0.2 mm sieve cloth. In a laboratory under ambient temperature conditions, seed samples were transferred to petri plates lined with wet filter papers. Germination was recorded for weeds at a weekly interval, until no germination occurred in the dishes. Germination tests were performed at 25-30°C temperatures in the lab conditions and sufficient conditions of moisture were maintained in the plates. The data was converted into number of viable seeds/m^2. Weed density and biomass was recorded at 30 days of transplanting (DAT) and at harvest from each plot.

Two representative quadrats were placed randomly in each plot each of 50 × 50 cm and observations were recorded. For weed biomass, weeds were separated out group-wise (grass and broad-leaved weeds). The above ground weed biomass sample was sun dried first and then placed in oven at 65°C for 72 hrs. Plant height was measured from ground level to the base of the panicle from each plot from five randomly selected plants at harvest. Tillers were counted from third row from two spots of 50 cm row length in each plot at maturity of crop and expressed as number of tillers/m^2. To record biomass data of basmati rice crop at harvest, above ground crop biomass was collected from 50 cm length of second row from two places in each plot. The samples were then oven dried at 65°C for 72 hrs for constant dry weight and the dry biomass data were expressed in g/m^2. The yield attributes and grain yield were recorded. The prevailing market prices of inputs and outputs were used for calculating benefit-cost ratio (B:C) under different weed control treatments.

Data were analyzed in SAS version 9.4 (SAS Institute, 2018) using PROC GLM. The data were pooled from 2017 and 2018. The data on weed density, biomass and data on control of weeds were subjected to square root transformation before statistical analysis. The differences between treatment means of weed free treatment of conventional agriculture and organic agriculture system for crop growth, yield attributes and quality were also analysed using CONTRAST procedures in SAS. Differences between means were compared using the least square means (LSMEANS) procedure and Fisher's protected LSD (Least significant difference) post-hoc. Treatment effects were declared significant at p=0.05.

RESULTS AND DISCUSSION

Effect of tillage on weed seedbank

Before tillage, number of seeds of *D. aegyptium, E. colona, T. portulacastrum* and *C. iria* in 0-7.5 cm soil profile were statistically at par in both conventional (CT) and deep tillage (DT) system (**Table 1**). Similarly, at 7.5-15 cm and 15-30 cm soil depth, non-significant differences in number of weed seeds in DT and CT were observed. Further, seedbank was lower in 15-30 cm soil profile as compared to 0-15 cm soil depth. After tillage treatments, significantly more number of seeds was observed in CT than DT in upper soil layer of 0-7.5 cm. Both CT and DT resulted in similar number of weed seeds at 7.5-15 cm soil depth. At 15-30 cm depth, the maximum number of weed seeds was observed in DT which was significantly more than CT.

Effect of green manuring of *Crotalaria juncea* on weed seedbank

Crotalaria juncea grown as green manure accumulated 4.54-4.63 t/ha of biomass at the time of incorporation. Weed seedbank after incorporation of green manure was strongly affected by green manuring treatment (**Table 2**). Number of weed seeds at 0-7.5 cm soil profile was significantly more in plots in which green manuring was not done as compared to green manured plots. With each successive increase in seed rate of green manure crop from 50 kg/ha to 100 kg/ha, there was significant increase in seedbank of *D. aegyptium, E. colona, T. portulacastrum* and *C. iria* in 0-7.5 cm soil profile. More number of weed seeds were observed in green manuring with 100 kg/ha seed rate than 75 kg/ha. This may be due to less weed seed emergence and density in green manure plots sown with 100 kg/ha of seed rate as compared to lower seed rate of green manuring.

Effect of treatments on weeds in basmati rice crop

Weed flora of the experimental field consisted only of *Echinochloa colona* and *Eclipta alba* at 30 DAT and at harvest (**Table 3**). It indicated that seeds of aerobic weeds (*D. aegyptium* and *T. portulacastrum*) could not germinate in puddled fields. Water is an excellent herbicide and inhibit emergence of aerobic weeds (Rao *et al*. 2007). Weed

Table 1. Effect of different weed management treatments on weed seedbank (0-30 cm) after tillage in organically grown basmati rice (mean of 2 years)

Treatment	Weed seed density at soil depths (cm) 0-7.5		7.5-15		15-30	
	Before tillage	After tillage	Before tillage	After tillage	Before tillage	After tillage
D. aegyptium (no./m^2)						
Conventional tillage	219.6a	249.6b	101.2a	76.2a	6.4a	6.4a
Deep tillage	226.5a	94.3a	93.8a	88.5a	5.7a	150.5b
E. colona (no./m^2)						
Conventional tillage	177.2a	215.2b	87.2a	76.0a	8.7a	8.3a
Deep tillage	169.8a	61.5a	62.7a	79.4a	7.2a	91.4b
T. portulacastrum (no./m^2)						
Conventional tillage	90.6a	132.6b	59.2a	76.2b	8.5a	8.7a
Deep tillage	85.2a	40.5a	44.0a	47.1a	8.0a	58.3b
C. iria (no./m^2)						
Conventional tillage	113.8a	151.8b	53.5a	70.5a	5.9a	5.7a
Deep tillage	119.0a	50.2a	45.2	59.6a	5.7a	70.2b

*Mean values in each column not connected by the same letter are significantly different according to Fisher's Protected LSD (p=0.05).

Table 2. Effect of planting density of green manuring using sunhemp (*Crotalaria juncea*) on weed seedbank (mean of two years)

Treatment	Weed seedbank before transplanting of basmati rice (no./m^2) *D. aegyptium*	*E. colona*	*C. iria*	*T. portula-castrum*
Without GM[a]	266.0d	249.4d	246.90d	217.67d
GM using sunhemp seed rate of 50 kg/ha	101.5a	83.3a	74.42a	89.23a
GM using sunhemp seed rate of 75 kg/ha	159.9b	105.9b	129.79b	113.88b
GM using sunhemp seed rate of 100 kg/ha	205.5c	198.2c	189.35c	159.15c

[a]GM- Green manure with sunhemp (*Crotalaria juncea*); *Mean values in each column not connected by the same letter are significantly different according to Fisher's Protected LSD (p= 0.05).

Table 3. Effect of tillage, green manuring and planting density on weeds in basmati rice (mean of two years)

Treatment[a *]	*Echinochloa colona* Weed density (no./m^2) 30 DAT	At harvest	Weed biomass (g/m^2) 30 DAT	At harvest	*Eclipta alba* Weed density (no./m^2) 30 DAT	At harvest	Weed biomass (g/m^2) 30 DAT	At harvest
CT +GM50+UW	2.4 (5)b	3.0 (8)b	2.3 (5)c	3.7 (13)c	3.2 (9)c	2.6 (6)e	3.3 (10)c	3.9 (15)c
CT +GM50+WF	1.0 (0)a	1.0 (0)a	1.0 (0)a	1.0 (0)a	1.0 (0)a	1.0 (0)a	1.0 (0)a	1.0 (0)a
CT +GM50+25% hPD+1HP	2.2 (4)b	2.8 (7)b	2.1 (4)b	2.7 (7)b	2.0 (3)b	1.9 (3)d	2.2 (4)b	2.0 (3)b
DT +GM50+25% hPD+1HP	1.7 (2)b	2.9 (8)b	2.0 (3)b	2.5 (6)b	1.9 (3)b	1.7 (2)cd	2.0 (3)b	2.2 (4)b
CT +GM75+25% hPD+1HP	2.2 (4)b	2.6 (6)b	2.0 (3)b	2.5 (6)b	1.7 (2)b	1.7 (2)cd	2.0 (3)b	2.0 (3)b
DT +GM75+25% hPD+1HP	2.00(3)b	2.7 (7)b	2.0 (3)b	2.6 (6)b	1.8 (3)b	1.4 (1)b	2.0 (3)b	2.2 (4)b
CT +GM100+25% hPD+1HP	2.2 (4)b	2.8 (7)b	1.9 (3)b	2.2 (4)b	1.9 (3)b	1.7 (2)cd	2.0 (3)b	2.0 (3)b
DT+GM100+25% hPD+1HP	2.2 (4)b	2.6 (6)b	2.0 (3)b	2.6 (6)b	1.9 (3)b	1.6 (2)bc	2.0 (3)b	1.7 (2)b
DT+GM100+1HP	1.9 (3)b	2.8 (7)b	1.9 (3)b	2.7 (7)b	1.9 (3)b	1.7 (2)cd	2.0 (3)b	1.9 (3)b
Comparison between organic and chemical weed control treatments								
Conv.+WF	1.0 (0)ns	1.0 (0)ns	1.0 (0)ns	1.0 (0)ns	1.0 (0)ns	1.0 (0)ns	1.0 (0)ns	1.0 (0)ns

[a]Mean values in each column not connected by the same letter are significantly different according to Fisher's Protected LSD. Original data of weed density and biomass was square root transformed and figures within parentheses are means of original values; *CT = Conventional tillage; DP = Deep tillage; GM50 = Green manuring using sunhemp (Crotalaria juncea) seed rate of 50 kg/ha; GM75 = Green manuring using sunhemp (*Crotalaria juncea*) seed rate of 75 kg/ha; GM100 = Green manuring using sunhemp (*Crotalaria juncea*) seed rate of 100 kg/ha; UW = Un weeded; WF = Weed free; hPD = higher rice plant density; HP = Hand pulling of weeds in water inundated field

density was significantly affected by different weed control treatments of organically grown basmati rice. Weed density of *E. colona* was the minimum in weed free treatment and it was significantly lower than other weed control treatments including unweeded at 30 DAT and at harvest. This indicated that different tillage, green manuring and plant density treatments have non-significant effect on grass weed density. The density of *E. alba* was found significantly less under CT or DT with green manuring at 50-100 kg/ha plus 25% higher plant density along with one hand pulling as compared to unweeded check at 30 DAT and at harvest. These results are in agreement with those of Gnanavel and Kathiresan (2002) who reported that green manuring in the preceding season and ploughing in-situ before puddling resulted in reduced weed density in puddled transplanted rice.

Weed biomass at 30 DAT was very less due to less growth of weed. At 30 DAT, weed growth was very less as water was kept ponded in the experimental fields continuously for 15 days of transplanting rice seedlings in puddled fields. Different weed management techniques resulted in differential effect on weed biomass (**Table 3**). The maximum weed biomass of grass (*E. colona*) and broad-leaved (*E. alba*) weeds was reported in unweeded check due to greater weed density. The minimum weed biomass of both *E. colona* and *E. alba* was observed in weed free. All weed management methods including CT or DT with 50-100 kg/ha of green manuring with 25% higher rice plant density and hand pulling resulted in significantly lower biomass of grass and broad-leaved weeds than

Table 4. Effect of tillage, green manuring and planting density on crop growth, yield attributes and yield of basmati rice (mean of two years)

Treatment[a *]	Plant height at harvest (cm)	Tillers at harvest (no./m^2)	Crop biomass at harvest (g/m^2)	Panicle length (cm)	1000 grain weight (g)	Grain yield (t/ha)			B:C
						2017	2018	Pooled	
CT +GM50+UW	83.8a	357a	1491a	25.4a	25.8a	3.079a	3.096a	3.088a	1.534
CT +GM50+WF	87.5a	399a	1621a	26.4a	26.6a	3.181a	3.185a	3.183a	2.316
CT +GM50+25% hPD+1HP	87.0a	389a	1597a	26.2a	25.9a	3.134a	3.146a	3.140a	1.947
DT +GM50+25% hPD+1HP	87.1a	387a	1599a	26.4a	26.2a	3.149a	3.148a	3.149a	1.852
CT +GM75+25% hPD+1HP	87.8a	378a	1601a	26.2a	26.0a	3.145a	3.159a	3.152a	1.893
DT +GM75+25% hPD+1HP	86.6a	390a	1592a	26.2a	26.2a	3.150a	3.164a	3.157a	1.816
CT +GM100+25% hPD+1HP	86.6a	386a	1599a	26.2a	26.3a	3.157a	3.163a	3.160a	1.968
DT+GM100+25% hPD+1HP	86.8a	389a	1607a	26.5a	26.4a	3.149a	3.165a	3.157a	1.935
DT+GM100+1HP	86.6a	389a	1607a	26.5a	26.5a	3.128a	3.143a	3.136a	2.239
Comparison between organic and chemical weed control treatments									
Conv.+WF	89.3ns	437*	1888*	27.5ns	26.9ns	3.502ns	3.566ns	3.534 ns	2.542

[a]Mean values in each column not connected by the same letter are significantly different according to Fisher's Protected LSD ($\sqrt{x+0.5}$); *CT = Conventional tillage; DP = Deep tillage; GM50 = Green manuring using sunhemp (*Crotalaria juncea*) seed rate of 50 kg/ha; GM75 = Green manuring using sunhemp (*Crotalaria juncea*) seed rate of 75 kg/ha; GM100 = Green manuring using sunhemp (*Crotalaria juncea*) seed rate of 100 kg/ha; UW = Un weeded; WF = Weed free; hPD = higher rice plant density; HP = Hand pulling of weeds in water inundated field.

unweeded check. The incorporation of green manure crops by self-decomposition was reported to reduce the weed count and weed dry matter by 60 and 43% as compared to pure crop of rice (Anitha *et al.* 2009).

Effect of treatments on rice growth and yield

The effect of various weed control treatments on plant height was non-significant and resulted in statistically similar plant height at harvest (**Table 4**). Total number of tillers and crop biomass per unit area at harvest was numerically lower in unweeded check but it was statistically similar to rest of cultural weed management practices. This indicated that no improvement in crop parameters such as plant height, number of tillers and crop biomass was observed due to cultural weed control methods in transplanted basmati rice. All cultural weed management practices including differential tillage with higher planting densities and green manuring levels from 50-100 kg/ha resulted in statistically similar yield attributes such as panicle length and thousand grain weight. Panicle length and thousand grain weight was numerically lower in unweeded check but it was statistically similar to rest of cultural weed management practices. The effect of different management methods on the grain yield was statistically non-significant. The weed free plots of CT along with GM 50 kg/ha, and DT along with GM 100 kg/ha along with hand hoeing in basmati rice resulted in greater benefits.

Conclusion

The weed problem in puddled transplanted basmati rice under organic agriculture system may be controlled with green manuring and increasing rice plant density.

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Indian Journal of Weed Science **53**(4): 341–345, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Efficacy of herbicides in managing *Alternanthera sessilis* (L.) R.Br. ex DC. and other weeds for improving the growth and yield of dry direct-seeded rice

Shrikant Chitale* and Nitish Tiwari

Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh 492012, India

**Email: shrikantmadhukarchitale@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00063.0

Type of article: Research article

Received : 29 July 2021
Revised : 25 October 2021
Accepted : 27 October 2021

KEYWORDS

Alternanthera sessilis, Bispyribac-sodium, Penoxsulam + cyhalofop–butyl, Weed control efficiency, Weed management

ABSTRACT

A field study was carried out during (rainy) *Kharif* seasons of 2019 and 2020 at Raipur, Chhattisgarh to study the efficacy of eight herbicide treatments in managing weed community dominated by *Alternanthera sessilis* (L.) R.Br. ex DC. and improving the growth and yield of dry direct-seeded rice. The most dominant weed species was *Alternanthera sessilis* accounting for 70% of the total weed density in weedy check. Other associated weeds were *Echinochloa colona* (L.) Link, *Brachiaria ramosa* (L.) Stapf and *Sporobolus diander* (Retz.) P. Beauv. among grasses and the sedge *Cyperus iria L.* The post-emergence of penoxsulam + cyhalofop–butyl 135 g/ha very effectively controlled the *A. sessilis* and other weeds, produced highest of 5.04 and 4.63 t/ha grain yield and net return of ₹ 71409 and 65563/ha and maximum weed control efficiency among the herbicide-based treatments during 2019 and 2020, respectively. Penoxsulam 22.5 g/ha post-emergence and bispyribac-sodium 25 g/ha post-emergence were also found to be equally effective to it with regards to rice grain yield.

INTRODUCTION

Direct-seeded rice (DSR) is economical and environment friendly crop establishment method with optimal yield potential, when the weed menace is adequately managed (Rao *et al*. 2007). In Chhattisgarh, the area under direct-seeded rice is increasing considerably as higher yields can be attained with lesser cost of cultivation due to the availability of new seeding machinery and proven effective pre-emergence herbicides to manage problematic weeds as the labour availability is becoming scarce and costly for transplanting of rice. Weeds are major constraints hindering adoption of DSR as rice yields are reduced by 35-100% in direct-seeded rice in the absence of proper weed management (Kumar *et al*. 2008) owing to the prevalence of congenial environment during the (rainy) *Kharif* season and the absence of impounding of water to suppress weeds at crop emergence. *Alternanthera sessilis of* Amaranthaceae is one of the world's worst tropical aquatic weeds of South American origin and has invaded all continents except Africa and Europe (Lu *et al*. 2002 and Ye *et al*. 2003). *Alternanthera sessilis* as an invasive aquatic/semi-aquatic perennial weed that rarely sets seeds and sessile and it invades direct-seeded rice too. *Echinochloa colona, Ischaemum rugosum, Cyperus iria, Cyprus difformis, Fimbristylis miliacea* and *Celosia argentea* are very common weeds which cause yield reduction in rice. However, weeds like *Alternanthera* spp. which was not observed earlier in Chhattisgarh area are now dominating the weed flora from last two to three years period and became serious weed of concern causing severe yield reduction. Thus, needs serious attention to evolve methods to manage it. Normally, *Alternanthera sessilis* is a rainy season weed but its presence could be seen even on field bunds, road sides and non-cropped area during *rabi* season too. Therefore, an effective herbicide or a suitable weed management practice to control this weed is essential to avoid rice yield losses due to it. The weed control options available for weed management in rice such as physical control, which is eco-friendly but is tedious and labour intensive and the biological control, by using different bio agents and myco-herbicides, can only be practiced effectively in irrigated lowland condition (Rao *et al.* 2017). Hence, herbicides-based weed management is being considered as the most cost effective and practical method for weed management in direct-seeded rice (Singh *et al.*, 2016). The present study was conducted with an objective to identify the suitable broad-spectrum herbicide for control of diverse weed flora and particularly the dominant *Alternanthera sessilis* in dry directed-seeded rice.

MATERIALS AND METHODS

The present study was carried out during (rainy) *Kharif* season of 2019 and 2020 at all india coordinated research project on weed management, Raipur, Chhattisgarh, India. The soil texture of the experimental field was clayey and neutral (pH 7.1) in reaction with medium fertility having 4.75 g/kg soil OC, low N (201.1 kg/ha), medium available P (14.42 kg/ha) and high available K (328 kg/ha) content. The experiment consisted of 10 treatments replicated 3 times in a randomized block design. The treatments were: pre-emergence application (PE) of pretilachlor 750 g/ha; post-emergence application (PoE) of bispyribac-sodium 25 g/ha, fenoxaprop-p-ethyl 56.25 g/ha PoE; cyhalofop-butyl 80 g/ha PoE; penoxsulam + cyhalofop-butyl (1.02 + 5.1%) (ready-mix) 135 g/ha PoE; penoxsulam 22.5 g/ha PoE; metsulfuron-methyl 20 g/ha PoE; 2,4-D ethyl ester 750 g/ha PoE; weed free by hand weeding thrice at 20, 40 and 60 days after seeding (DAS) and weedy check. The pre-emergence application of pretilachlor was done 3 DAS. The post-emergence application of herbicides was done at 22 days after sowing of rice, except penoxsulam which was applied at 16 DAS. The recommended dose of fertilizers (100:60: 40 N, P and K kg/ha) was used. Nitrogen, phosphorus and potassium were provided to crop by using urea (46 percent N), SSP (16% P) and muriate of potash (60% K), respectively. Half the dose of nitrogen and full dose of phosphorous and potash were applied as basal. The remaining half of nitrogen dose was applied in two split doses, the first split dose applied at active tillering stage and the second split at panicle initiation stage of rice in all the treatments. The test crop rice variety "*Indira Rajeshwari (IGKV R1)*" was directly line sown with a row-to-row distance of 20 cm on 08.07.2019 and 02.07.2020 and harvested on 15.11.2019 and 05.11.2020, respectively. The crop received 975- and 782-mm rainfall during two years.

The data on species wise weed density and biomass were recorded at 60 days after sowing and at harvest of crop with the help of quadrat (0.5 x 0.5 m) at three randomly selected places in each plot and then converted into per square meter. Weeds were cut at ground level, washed with tap water, sun dried and then oven dried at 75^0 C for 48 hours and weighed. Weed control efficiency (WCE) and weed index (%) were calculated by using standard formula suggested by Maity and Mukherjee (2011). The data on various crop growth and yield attributing characters were statistically analyzed as per the standard procedure. Minimum support price (MSP) was used to calculate the economics.

RESULTS AND DISCUSSION

The weed flora of the experimental field consisted of *Echinochloa colona, Brachiaria ramosa and Sporobolus diander* among grasses; *Cyperus iria,* the sedge and *Alternanthera sessilis*, the broad-leaved weed. *Alternanthera sessilis* dominated the weed flora during entire vegetative growth stage. *Brachiaria ramosa and Sporobolus diander* were present during later stages of the crop. The occurrence of other weeds like *Ischaemum rugosum, Cyanotis axillaris,* etc. was uneven with lesser density.

Effect on weed density

Alternanthera sessilis (81.6 and 83.0/m^2) was the predominant weed in weedy check with its density contribution of 74.2 and 71.6% to the total weed density. The pretilachlor 750 g/ha, bispyribac-sodium 25 g/ha and fenoxaprop-p-ethyl 56.25 g/ha and cyhalofop-butyl 80 g/ha could not effectively control *A. sessilis* resulting in higher density of it occurring with those treatments. The lowest density of *A. sessilis* was observed with 2,4-D ethyl-ester 750 g/ha and metsulfuron-methyl 4.0 g/ha during 2019 and 2020. Penoxsulam + cyhalofop-butyl 135 g/ha and penoxsulam 22.5 g/ha also recorded lesser densities of *A. sessilis* during both the years of the study (**Table 1**). Singh *et al.* (2009) observed that penoxsulam PE at 3 DAT was more effective in reducing *A. sessilis* density compared to its early PoE at 10 DAS.

At all the growth stages, among all the treatment the highest weed density of total weeds was recorded under the weedy check and lowest weed density was noticed under the weed free. The lowest total weed density was observed under the application of penoxsulam + cyhalofop-butyl 135 g/ha (14.2 and 19.0/m^2) followed by penoxsulam 22 g/ha and metsulfuron- methyl 4.0 g/ha at 30 DAS, amongst herbicide-based treatments. The highest total weed density was observed with cyhalofop-butyl 80 g/ha (25.5 and 32.0/m^2). At 60 DAS, among the herbicide-based treatments the lowest total weed density was observed with penoxsulam + cyhalofop-butyl 135 g/ha (35.4 and 39.0 /m^2) followed by 2,5-D ethyl-ester 750 g/ha, metsulfuron-methyl 4.0 g/ha and bispyribac-sodium 25 g/ha. At harvest, among the herbicide-based treatments, the lowest total weed density was observed with penoxsulam + cyhalofop-butyl 135 g/ha (34.2 and 35.0 /m^2) followed by metsulfuron-methyl 4.0 g/ha and penoxsulam 22 g/ha. The highest total weed density (82.7 and 87.0 m^2) was observed with cyhalofop-butyl 80 g/ha. Similar observations were made by Yadav *et al.* (2018).

Weed biomass and weed control efficiency

Weed biomass is a better parameter to measure the competition than the weed number (Channappagoudar *et al.* 2013). Reduction in total weed biomass with the application of herbicides is clearly evident by their higher weed control efficiency. Among the herbicides-based treatments, lowest biomass of *A. sessilis* was observed with 2,4-D ethyl-ester 750 g/ha closely followed by penoxsulam 22.5 g/ha and they were at par with the weed free at 30 DAS. The lowest biomass of 12.9 and 14.0 g/m^2 and at harvest 29.1 and 30.2 g/m^2 *A.*

Table1. Density (no./m^2) of *Alternanthera sessilis* and total weeds at 30, 60 days after seeding (DAS) and at harvest as influenced by weed management treatments in dry direct-seeded rice

Treatment	*Alternanthera sessilis*						Total weeds					
	30 DAS		60 DAS		At harvest		30 DAS		60 DAS		At harvest	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Pretilachlor 750 g/ha pre-emergence	3.2 (9.7)	3.4 (11.0)	6.1 (37.0)	6.4 (40.0)	6.1 (36.7)	6.1 (37.0)	4.7 (21.2)	5.1 (25.0)	8.2 (67.05)	8.6 (73.0)	7.8 (60.5)	7.8 (61.0)
Bispyribac-sodium 25 g/ha post-emergence	3.6 (12.1)	3.7 (13.0)	5.92 (34.6)	6.0 (36.0)	6.8 (46.3)	7.0 (48.0)	4.5 (20.0)	5.0 (24.0)	7.3 (52.2)	7.5 (56.0)	8.1 (65.5)	8.3 (69.0)
Fenoxaprop-p-ethyl 56.25 g/ha post-emergence	4.1 (16.0)	4.2 (17.0)	7.61 (57.4)	7.7 (59.0)	7.2 (51.6)	7.3 (53.0)	4.9 (23.8)	5.2 (27.0)	9.7 (94.3)	9.4 (87.0)	8.1 (65.7)	8.4 (70.0)
Cyhalofop-butyl 80 g/ha post-emergence	4.3 (18.0)	4.5 (20.0)	7.54 (56.3)	7.7 (58.0)	7.7 (59.0)	7.8 (60.0)	5.1 (25.5)	5.7 (32.0)	9.1 (83.1)	9.9 (97.0)	9.1 (82.6)	9.4 (87.0)
Penoxsulam + cyhalofop-butyl (ready-mix) 135 g/ha	2.9 (7.9)	3.1 (9.0)	3.87 (14.5)	4.1 (16.0)	4.5 (19.5)	4.1 (16.0)	3.8 (14.2)	4.4 (19.0)	6.0 (35.4)	6.3 (39.0)	5.9 (34.2)	6.0 (35.0)
Penoxsulam 22.5 g/ha post-emergence	2.59 (6.2)	2.92 (8.0)	4.15 (16.7)	4.30 (18.0)	4.58 (20.4)	4.30 (18.0)	4.09 (16.2)	4.53 (20.0)	7.1 (50.3)	7.45 (55.0)	6.44 (41.0)	6.60 (43.0)
Metsulfuron-methyl 4 g/ha early post-emergence	2.01 (3.5)	2.12 (4.0)	3.35 (10.7)	2.35 (5.0)	3.09 (9.04)	2.92 (8.0)	4.24 (17.5)	4.53 (20.0)	6.9 (47.2)	7.11 (50.0)	6.31 (39.3)	6.52 (42.0)
2,4-D ethyl-ester 750 g/ha post-emergence	2.29 (4.7)	2.35 (5.0)	3.58 (12.3)	2.12 (4.0)	3.42 (11.2)	2.74 (7.0)	5.10 (25.5)	5.34 (28.0)	6.6 (43.1)	6.96 (48.0)	7.03 (48.9)	7.31 (53.0)
Weed free	1.58 (2.0)	1.87 (3.0)	1.41 (1.50)	1.58 (2.0)	2.99 (8.45)	3.24 (10.0)	2.12 (4.0)	2.92 (8.0)	1.9 (3.0)	2.74 (7.0)	4.31 (18.1)	4.85 (23.0)
Weedy check	4.36 (18.5)	4.53 (20.0)	7.91 (62.1)	8.09 (65.0)	9.06 (81.6)	9.14 (83.0)	6.12 (37.0)	6.52 (42.0)	9.4 (88.5)	9.77 (95.0)	10.50 (109.8)	10.79 (116.0)

Data in parentheses are original values

Table 2. Weed biomass (g/m^2) of *Alternanthera sessilis* and total weeds at 30, 60 days after seeding (DAS) and at harvest as influenced by weed management treatments in dry direct-seeded rice

Treatment	*Alternanthera sessilis*						Total weeds					
	30 DAS		60 DAS		At harvest		30 DAS		60 DAS		At harvest	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Pretilachlor 750 g/ha pre-emergence	3.7 (12.8)	3.8 (13.7)	6.2 (37.8)	6.3 (39.2)	7.6 (57.9)	7.7 (59.5)	4.7 (22.0)	4.8 (22.7)	8.9 (78.7)	9.0 (80.1)	10.9 (118.4)	11.0 (120.4)
Bispyribac-sodium 25 g/ha post-emergence	4.0 (15.5)	4.2 (17.0)	6.8 (25.1)	5.2 (26.2)	6.9 (47.1)	7.0 (48.7)	5.0 (24.2)	5.2 (26.3)	6.8 (45.5)	6.9 (47.3)	9.3 (86.0)	9.4 (88.2)
Fenoxaprop-p-ethyl 56.25 g/ha post-emergence	4.8 (22.6)	5.0 (24.2)	5.1 (47.2)	7.0 (48.5)	9.3 (85.0)	9.4 (87.0)	5.2 (26.5)	5.3 (27.3)	8.7 (75.1)	8.8 (76.4)	11.2 (125.0)	11.3 (127.1)
Cyhalofop-butyl 80 g/ha post-emergence	4.1 (16.5)	4.3 (18.0)	6.9 (47.7)	7.0 (49.1)	8.9 (78.0)	9.0 (80.0)	5.3 (27.8)	5.4 (29.0)	9.2 (84.0)	9.3 (85.2)	12.2 (149.0)	12.3 (151.3)
Penoxsulam + cyhalofop-butyl (ready-mix) 135 g/ha	1.8 (2.7)	1.8 (2.9)	3.7 (12.9)	3.8 (14.0)	5.3 (27.6)	5.5 (29.4)	4.2 (17.2)	4.3 (18.3)	6.0 (35.2)	6.1 (36.3)	8.1 (65.3)	8.2 (67.0)
Penoxsulam 22.5 g/ha post-emergence	1.8 (2.6)	1.8 (2.8)	3.7 (13.2)	3.9 (14.9)	5.4 (29.1)	5.5 (30.2)	4.7 (21.7)	4.9 (23.0)	7.0 (48.3)	7.1 (50.2)	8.9 (78.0)	8.9 (78.8)
Metsulfuron-methyl 4 g/ha early post-emergence	1.9 (3.3)	2.0 (3.6)	3.8 (13.8)	2.3 (4.6)	5.9 (34.1)	5.1 (25.2)	4.2 (16.8)	4.3 (17.6)	7.8 (60.8)	7.9 (61.9)	10.5 (110.0)	10.6 (112.1)
2,4-D ethyl-ester 750 g/ha post-emergence	1.8 (2.6)	1.8 (2.7)	3.8 (14.2)	2.5 (5.6)	5.5 (30.0)	4.7 (21.5)	4.5 (20.1)	4.7 (21.2)	7.3 (52.3)	7.4 (54.4)	9.8 (95.0)	9.8 (96.4)
Weed free	1.3 (1.3)	1.4 (1.6)	1.5 (1.7)	1.6 (2.1)	2.3 (4.9)	2.6 (6.1)	2.0 (3.5)	2.1 (4.1)	1.7 (2.5)	1.9 (3.1)	2.5 (5.7)	2.6 (6.2)
Weedy check	4.9 (23.5)	5.1 (25.7)	7.0 (49.1)	7.1 (50.4)	9.8 (95.8)	10.0 (98.7)	6.9 (46.7)	7.0 (48.7)	10.8 (115.6)	11.9 (140.2)	14.5 (210.3)	15.5 (238.3)
LSD (p=0.05)	0.4	0.5	0.6	0.6	0.7	0.8	0.6	0.6	0.7	0.9	1.5	1.4

sessilis at 60 DAS was recorded with penoxsulam + cyhalofop-butyl 135 g/ha PoE due to management of both the grassy and non- grassy weeds resulting in maximum weed control efficiency during 2019 and 2020, respectively. It was closely followed by penoxsulam 22.5 g/ha, metsulfuron-methyl 4 g/ha and 2,4-D ethyl ester 750 g/ha. The higher biomass of *Alternanthera sessilis* was recorded with fenoxaprop-p-ethyl 56.25 g/ha and cyhalofop-b-butyl 80 g/ha throughout the growing period as they both could not control the *Alternanthera sessilis.* Similar trend was observed in the total weed biomass at 30 and 60 DAS and at harvest (**Table 2**).

The highest 69.0 and 72.0 % total weed control efficiency (WCE) was achieved with the application of penoxsulam + cyhalofop-butyl 135 g/ha PoE, during 2019 and 2020, respectively, followed by penoxsulam 22.5 g/ha PoE and bispyribac-sodium 25 g/ha PoE at harvest. The highest weed control efficiency was observed with penoxsulam + cyhalofop-butyl (ready-mix) PoE was due to its broad-spectrum effect against diverse weed flora as compared to application of the component herbicides alone. The application of penoxsulam 22.5 g/ha PoE at 16 DAS coincided with the 2-3 leaf stage of weeds at which the weed is most susceptible to the herbicide and thus resulted in greater weed control efficiency. The fenoxaprop-p-ethyl 56.25 g/ha PoE and cyhalofop-butyl 80 g/ha PoE were not effective on *A. sessilis* and showed very less WCE at 60 DAS and at harvest as compared to the other herbicides tested (**Table 3**). The lowest control efficiency of 29.1 and 36.5% was recorded with cyhalofop-butyl 80 g/ha PoE during 2019 and 2020, respectively due to lower percentage reduction in total weed density and biomass as reported earlier by Singh *et al*. (2014). Weed index refers to the reduction in crop yield due to the presence of weeds in comparison to weed-free crop. The unmanaged weeds in weedy check caused the maximum yield loss of 65.0 and 81.1% during 2019 and 2020, respectively when compared to maximum grain yield recorded. Penoxsulam + cyhalofop-butyl 135 g/ha PoE; bispyribac-sodium 25 g/ha PoE and penoxsulam 22.5 g/ha PoE recorded minimum yield loss due to weeds when compared to the rest of the herbicide-based treatments.

Effect on rice grain yield

The highest grain yield of 5.04 and 4.63 t/ha was achieved with the application of penoxsulam + cyhalofop-butyl 135 g/ha PoE which was at par with weed free treatment 5.08 and 4.98 t/ha, the yield during 2019 and 2020, respectively. The bispyribac-sodium 25 g/ha PoE and penoxsulam 22.5 g/ha PoE have also recorded comparable yield to that of penoxsulam+ cyhalofop-butyl 135 g/ha (ready-mix) PoE (**Table 4**). The efficacy of penoxsulam was reported by Mishra *et al*. (2007). The lower weed biomass at 60 DAS and at harvest resulted in higher grain yields due to greater number of tillers with these three herbicidal treatments because of lesser competition with weeds at critical stages of plant growth and lesser removal of nutrients by weeds from soil. The grain yield of rice decreased by 25-28%, if *A. sessilis* was not controlled effectively as observed with pretilachlor 750 g/ha PE, fenoxaprop-p-ethyl 56.25 g/ha PoE and cyhalofop-butyl 80 g/ha PoE as reported earlier also by Bahar and Singh (2004). The grain yield losses due to uncontrolled *A. sessilis* in rice was also reported by Yi (1992) and Zhang *et al*. (2004). The ineffectiveness of fenoxaprop-p-ethyl 60 g/ ha PoE in controlling broad-leaved weeds was reported earlier by Mishra and Singh (2008) who observed a decrease (60%) in dry-

Table 3. Weed control efficiency and weed index as affected by different weed management treatments in dry direct-seeded rice

Treatment	Weed control efficiency (%)								Weed index (%)	
	Alternanthera sessilis				Total weeds					
	60 DAS		At harvest		60 DAS		At harvest			
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Pretilachlor 750 g/ha pre-emergence	23.0	22.2	39.6	39.7	31.9	42.9	43.7	49.5	24.6	41.0
Bispyribac-sodium 25 g/ha post-emergence	48.9	48.0	50.8	50.7	60.6	66.3	59.1	63.0	8.9	14.7
Fenoxaprop-p-ethyl 56.25 g/ha post-emergence	3.9	3.8	11.3	11.9	35.0	45.5	40.6	46.7	26.4	54.0
Cyhalofop-butyl 80 g/ha PoE	2.9	2.6	18.6	18.9	27.3	39.2	29.1	36.5	28.3	59.0
Penoxsulam + cyhalofop-butyl 135 g/ha post-emergence	73.7	72.2	71.2	70.2	69.6	74.1	69.0	72.0	0.8	7.0
Penoxsulam 22.5 g/ha post-emergence	73.1	70.4	69.6	69.4	58.2	64.2	62.9	67.0	8.5	16.9
Metsulfuron-methyl 4 g/ha early post-emergence	71.9	90.9	64.4	74.5	47.4	55.8	47.7	53.0	22.0	28.5
2,4-D ethyl-ester 750 g/ha post-emergence	71.1	88.9	68.7	78.2	54.8	61.2	54.8	59.5	20.5	19.7
Weed free	96.5	95.8	94.9	93.8	97.8	97.8	97.3	97.4	-	-
Weedy check	0	0	0	0	0	0	0	0	65.0	81.1

DAS: Days after seeding

Table 4. Effective tillers, grain yield, net return and B:C ratio as influenced by different weed management treatments in dry direct-seeded rice

Treatment	Effective tillers/m row length		Grain yield (t/ha)		Net return ($x10^3$ `/ha)		B:C ratio	
	2019	2020	2019	2020	2019	2020	2019	2020
Pretilachlor 750 g/ha pre-emergence	52.0	51.0	3.83	2.94	51.93	35.22	4.09	2.8
Bispyribac-sodium 25 g/ha post-emergence	58.3	51.9	4.63	4.25	66.50	59.53	4.82	4.0
Fenoxaprop-p-ethyl 56.25 g/ha post-emergence	53.7	49.3	3.74	2.29	50.17	23.01	4.03	2.2
Cyhalofop-butyl 80 g/ha PoE	50.7	47.6	3.64	2.04	48.62	18.34	3.90	1.9
Penoxsulam + cyhalofop-butyl 135 g/ha post-emergence	60.7	53.9	5.04	4.63	71.41	65.56	4.89	4.2
Penoxsulam 22.5 g/ha post-emergence	58.3	53.7	4.65	4.14	66.65	56.97	4.60	3.8
Metsulfuron-methyl 4 g/ha early post-emergence	57.3	51.4	3.96	3.56	55.20	47.50	4.23	3.5
2,4-D ethyl-ester 750 g/ha post-emergence	57.4	51.7	4.04	4.00	56.40	55.47	4.28	3.9
Weed free	62.3	54.0	5.08	4.98	66.02	64.76	3.13	3.6
Weedy check	23.3	21.1	1.78	0.94	14.37	-0.70	2.02	-1.0
LSD (p=0.05)	3.8	3.5	0.47	0.31	-	-	-	-

seeded rice yield when *A. sessilis* and other weeds competed with rice up to maturity.

The economics

The maximum net return of ₹ 71409 and 65,563/ha and highest B:C of 4.89 and 4.2 was recorded with penoxsulam + cyhalofop-butyl 135 g/ha PoE during 2019 and 2020, respectively followed by bispyribac-sodium 25 g/ha amongst the herbicides. Although the net return obtained with weed free treatment was higher than the most of the herbicides except penoxsulam + cyhalofop-butyl 135 g/ha, weed free has recorded lower benefit: cost ratio as compared to the herbicidal treatments because of the higher wages of labour and cost incurred on labour to keep it weed free used in this treatment.

Based on two years field experimentation, it was concluded that penoxsulam + cyhalofop-butyl (ready-mix) 133 g/ha PoE applied at 22 DAS under saturated moist field conditions appreciably reduced the density of *Alternanthera sessilis* and other weeds and produced significantly higher grain yield of dry direct-seeded rice and net return compared to rest of the treatments.

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Indian Journal of Weed Science **53**(4): 346–352, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Eco-friendly weed management in dry direct-seeded rice under organic production system

Rohini Naganagouda Meti*, Satyanarayana Rao, B.K. Desai, B.G. Koppalkar, Pramod Katti and S.N. Bhat
University Agricultural Sciences, Raichur, Karnataka 584104, India
Email: rohinimeti5080@gmail.com

Article information

DOI: 10.5958/0974-8164.2021.00064.2

Type of article: Research article

Received : 27 July 2021
Revised : 19 November 2021
Accepted : 21 November 2021

KEYWORDS

Dry direct-seeded rice, Eco-friendly weed management, Seed rate, Weed control efficiency, Weed management

ABSTRACT

A field experiment was conducted at Agricultural Research Station, Dhadesugur, University of Agricultural Sciences, Raichur, Karnataka, India during rainy (*Kharif)* seasons of 2017 and 2018 to identify the eco-friendly weed management practice in dry direct-seeded rice under organic production system. The experiment was laid out on fixed site in two consecutive years in a split plot design with two main plot treatments and five sub plots. Along with main and sub-plot treatments, recommended weed management practice as outside uneven control was kept for comparison. The 25% higher rice population with the seed rate of 25 kg/ha along with rice bran at 2 t/ha followed by (*fb*) hand weeding (HW) recorded significantly lower total weed density (36.60, 46.72 and 42.94 g/m^2) and biomass (28.28, 66.95 and 49.40 g/m^2); higher weed control efficiency (62.82, 63.73 and 74.17% at 20, 30 and 50 DAS) and higher grain yield (4.81 t/ha) of dry direct-seeded rice under organic production system and it was at par with 25% higher rice population with the rice seed rate of 25 kg/ha along with one inter-cultivation (IC) and hand weeding.

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food for more than half of world population and is one of the leading cereal crop being grown in many regions of world. Recently, there is trend towards adopting direct-seeded rice (DSR) because of labour and water scarcity (Mallikarjun *et al.* 2014). To overcome these twin problems especially that of human labour involved in nursery preparation and transplanting operations, researchers as well as farmers are looking at mechanical transplanting and direct-seeding options that were developed and adopted widely in Asian countries. The establishment of rice crop through direct-seeding technique is not only simple to use but also has been found effective in sustaining the production of rice. Currently, a keen awareness has sprung on the adoption of organic farming as a remedy to cure the negative impact of modern agriculture. There is an emerging awareness among public on the use of high-quality food materials which are free from chemical toxicants.

The direct-seeded rice is associated with the biggest biological constraint of profuse heterogeneous weeds growth (Rao *et al.* 2007). The success of DSR entirely depends on efficient weed management practices (Rao *et al.* 2007, Rao *et al.* 2015) because uncontrolled weeds in DSR can reduce yields to the tune of 53% to 90% (Bhat *et al.* 2011). Continuous use of the herbicides over a period of time on a same piece of land, leads to ecological imbalances in terms of weed shift and environmental pollution. Hence, emphasis is given for the use of organic resources and non-chemical management practices to maintain the soil quality and environmental health in order to produce food of high-quality (Sangeetha 2006). Organic weed control encourages weed suppression rather than elimination (Gnanasoundari and Somasundaram 2014). This is done by promoting soil health through a combination of biologically based bio-fertilizers, compost and mulch. Proper management through organic methods offer varied benefits over chemical herbicides, including increased biodiversity, improved soil nutrition, soil structure, and protection of ground and surface water (Gnanasoundari and Somasundaram 2014). Therefore, this study was conducted to identify non-chemical weed management treatments for effective weed management and higher rice yield and economic returns in organic dry direct-seeded rice (dry-DSR) system.

MATERIALS AND METHODS

A field experiment was carried out during rainy *(Kharif)* seasons of 2017 and 2018 at Agricultural Research Station, Dhadesugur, University of Agricultural Sciences (UAS), Raichur to identify the ideal weed management practice in organic dry direct-seeded rice production. The soil had 0.46% organic carbon, 286.20 kg/ha nitrogen, 25.40 kg/ha phosphorus and 440.10 kg/ha potassium in medium range available nutrients. The experiment was laid out on fixed site in two consecutive years in split plot design consisted of two main plot treatments, *viz.* normal plant population and 25% higher population. Each main plot was further divided in to five sub plots *i.e.*, weed management practices, *viz*. rice straw 3 t/ha on 3 DAS + HW on 40 days after seeding (DAS); rice bran at 2 t/ha on 3 DAS + hand weeding (HW) on 40 DAS; Azolla inoculation 500 kg/ha at 10 DAS and incorporation at 40 DAS, cono-weeder usage at 10, 20, 30 and 40 DAS; inter-cultivation (IC) with hand drawn hoe at 20 DAS *fb* HW twice at 25 and 50 DAS and unweeded check. Along with main and subplot treatments, recommended weed management practice as outside uneven control was kept for comparison. The experiment was initiated first time and in order to know the extent of yield reduction in organic production system with various treatments including higher seed rate (which is considered as one of the weed control measures in order to have weed suppression effect in organic systems) in comparison with conventional recommended DSR system, the uneven control treatment was included. If the investigation had been under organic field, uneven control treatment would have been eliminated.

The dry seeds of rice variety *GNV-1089* were sown on 19th August 2017 and 1st July 2018 at recommended seed rate. The dry-DSR was grown in organic manner following the package of practices suggested by Organic Farming Research Institute, UAS, Raichur. Weeds observations like weed flora, weed density and biomass were taken at 20, 30 and 50 DAS. The rice grain from each net plot was cleaned, sun dried and weight at 14% moisture content and the grain yield was expressed in t/ha. The straw yield was expressed in t/ha. The data were statistically analysed by the analysis of variance method as suggested by Gomez and Gomez (1984). The critical differences were worked out at 5% probability level and the values are furnished.

RESULTS AND DISCUSSION

Weed flora

The predominant weed flora observed in the experimental field included grasses like, *Chloris barbata*, *Cynadon dactylon*, *Dactyloctenium aegyptium*, *Echinochloa colonum*, *Elusine indica* and *Panicum repens*. Among broad-leaved weeds, *Ageratum conyzoides, Celosia argentia, Commelina benghalensis*, *Parthenium hysterophorus*, *Phyllanthus niruri*, *Portulaca oleraceae*, *Tridax procumbens* and the sedge *Cyperus rotundus* were noticed. Among the weed species, the density of *Cyperus rotundus, Cynodon dactylon, Echinochloa colonum*, *Ageratum conyzoides*, *Commelina benghalensis* and *Portulaca oleraceae* were more than other weed species indicating their dominance and competitiveness with the dry direct-seeded organic rice.

Total weed density

Significantly lower total weed density was recorded with 25% higher rice population with the seed rate of 25 kg/ha (59.27, 80.28 and 84.25 /m^2, respectively on pooled basis) than normal population with the seed rate of 20 kg/ha (72.08, 104.3 and 100.3 /m^2, respectively on pooled basis) at 20, 30 and 50 DAS (**Table 1**). The rice crop had a competitive advantage over weeds at higher population due to earlier closer of canopy and thus reducing total weed density and growth (Chauhan *et al.* 2011 and Ahmed *et al.* 2014).

Among weed management practices, significantly lower total weed density was recorded with one IC *fb* HW twice (44.01, 41.24 and 43.60/m^2 at 20, 30 and 50 DAS, respectively, on pooled basis) but it was on par with rice bran at 2 t/ha *fb* HW (41.80, 58.49 and 47.59/m^2 at 20, 30 and 50 DAS, respectively on pooled basis). Significantly higher total weed density was recorded in unweeded check (139.5, 194.1 and 224.1/m^2 at 20, 30 and 50 DAS, respectively on pooled basis) which might be due to the control of weeds at the germination phase by rice bran and significant reduction at later stages as late germinating weeds were controlled by one hand weeding at 40 DAS. The suppressive effect of rice bran application to soil surface on weed population was considered to be associated with a decline in redox potential and dissolved oxygen concentration as reported by Kim *et al.* (2001) and Maeda *et al.* (2003).

Among various interactions, at 20 DAS 25% higher rice population with the seed rate of 25 kg/ha along with one IC and HW twice recorded significantly lower total weed density (33.99/m^2 on pooled basis) but it was at par with 25% higher rice population with the seed rate of 25 kg/ha along with rice bran at 2 t/ha + HW (36.60 m^{-2} on pooled basis) this might be due to effective weed control right from emerging stage of rice crop, while normal population with the seed rate of 20 kg/ha with unweeded check recorded significantly higher total weed density (146.3/m^2 on pooled basis) among all other treatment combinations. At 30 and 50 DAS, 25% higher rice population with the seed rate of 25 kg/ha along with one IC *fb* two HW recorded significantly lower total weed density (30.34 and 34.92/m^2, respectively on pooled basis) but it was at par with 25 higher rice population with the seed rate of 25 kg/ha along with rice bran at 2 t/ha *fb* HW (46.72 and 42.94/m^2, respectively on pooled basis), while normal population with the seed rate of 20 kg/ha with unweeded check recorded significantly higher total weed density (209.9 and 233.3/m^2, respectively on pooled basis) among all other treatment combinations except with 25% higher population with the seed rate of 25 kg/ha with unweeded check (178.4 and 214.9/m^2, respectively on pooled basis).

Interestingly, population levels in combination with weed management practices recorded significantly higher total weed density over uneven control with recommended weed management practice (19.90, 13.39 and 12.94/m^2 at 20, 30 and 50 DAS, respectively on pooled basis).

Table 1. Total weeds density and weeds biomass at 20, 30 and 50 days after seeding (DAS) as influenced by weed management treatments in direct-seeded rice under organic production system (pooled data 2017 and 2018)

Treatment	Total weeds density (no./m^2)			Weed biomass (g/m^2)		
	20 DAS	30 DAS	50 DAS	20 DAS	30 DAS	50 DAS
Rice plant population level (P)						
Normal rice plant population with recommended seed rate (20 kg/ha) – (P_1)	8.37(72.1)	9.96(104.3)	9.63(100.3)	7.63(58.0)	10.21(110.9)	9.36(92.1)
Higher rice plant population with 25% higher recommended seed rate (25 kg/ha) – (P_2)	7.52(59.3)	8.63(80.3)	8.71(84.2)	6.55(43.6)	9.52(98.0)	8.55(78.6)
LSD (p=0.05)	0.47	1.51	0.45	0.20	4.44	0.54
Weed management treatment (W)						
Rice straw at 3 t/ha on 3 DAS *fb* HW once on 40 DAS – (W_1)	7.09(49.6)	8.81(77.3)	7.58(57.0)	6.53(42.1)	9.33(86.5)	7.93(62.0)
Rice bran at 2 t/ha on 3 DAS *fb* HW once on 40 DAS – (W_2)	6.68(44.0)	7.67(58.5)	6.96(47.6)	6.11(36.8)	8.49(71.5)	7.39(53.8)
Azolla inoculation at 500 kg/ha on 10 DAS and incorporation at 40 DAS – (W_3)	8.25(67.0)	10.61(112.9)	11.08(122.0)	8.08(64.3)	12.43(159.7)	9.23(84.7)
Cono-weeder at 10, 20, 30 and 40 DAS – (W_4)	7.27(52.1)	8.38(69.6)	7.75(59.4)	6.96(48.0)	9.40(88.2)	8.07(64.6)
One inter-cultivation (IC) at 20 DAS fb two HW twice at 25 and 50 DAS – (W_5)	6.51(41.8)	6.44(41.2)	6.65(43.6)	5.90(34.4)	5.78(32.7)	6.90(47.1)
Unweeded check – (W_6)	11.85(139.5)	13.88(194.1)	15.00(224.1)	8.95(79.0)	13.74(188.1)	14.18(200.1)
LSD (p=0.05)	0.26	1.31	0.55	0.34	2.76	0.91
Interaction (P X W)						
P_1W_1	7.56(56.4)	9.58(90.9)	8.03(64.0)	7.12(50.0)	9.80(95.1)	8.26(67.3)
P_1W_2	7.23(51.4)	8.43(70.3)	7.30(52.2)	6.81(45.4)	8.74(76.1)	7.69(58.1)
P_1W_3	8.46(70.5)	11.03(122.9)	11.52(131.9)	8.30(67.9)	12.94(169.1)	9.51(90.2)
P_1W_4	7.70(58.2)	8.97(79.5)	8.31(68.1)	7.72(58.6)	9.89(96.9)	8.51(71.8)
P_1W_5	7.11(49.6)	7.29(52.1)	7.30(52.3)	6.70(43.8)	6.14(36.8)	7.66(57.7)
P_1W_6	12.14(146.3)	14.49(209.9)	15.30(233.3)	9.11(82.1)	13.86(191.5)	14.45(207.8)
P_2W_1	6.62(42.8)	8.04(63.7)	7.14(49.9)	5.94(34.3)	8.85(77.9)	7.60(56.8)
P_2W_2	6.13(36.6)	6.91(46.7)	6.63(42.9)	5.41(28.3)	8.24(66.9)	7.10(49.4)
P_2W_3	8.04(63.6)	10.19(102.8)	10.63(112.1)	7.85(60.7)	11.93(150.4)	8.95(79.2)
P_2W_4	6.85(45.9)	7.79(59.6)	7.19(50.7)	6.20(37.5)	8.91(79.5)	7.63(57.3)
P_2W_5	5.92(34.0)	5.60(30.3)	5.99(34.9)	5.10(25.0)	5.41(28.6)	6.13(36.6)
P_2W_6	11.56(132.7)	13.26(178.4)	14.69(214.9)	8.78(76.0)	13.62(184.7)	13.91(192.4)
LSD (p=0.05)	0.30	1.50	0.64	0.39	3.17	1.04
Pendimethalin - 0.677 kg/ha pre-emergence application (PE) *fb* one HW at 30DAS UC	4.57(19.9)	3.87(13.4)	3.73(12.9)	3.94(14.5)	4.54(19.6)	2.72(6.4)
LSD(p=0.05)	0.32	1.47	0.60	0.36	3.29	0.96

Figures in the parentheses indicate the original value and the data subjected for transformation using square root of $(\sqrt{x+1})$, where X is weed count

Total weed biomass

Significantly lower total weed biomass was recorded with 25% higher rice population with 25 kg/ha rice seed rate (43.62, 98.00 and 78.64 g/m^2 at 20, 30 and 50 DAS, respectively on pooled basis) than normal population with the seed rate of 20 kg/ha (57.96, 110.9 and 92.15 g/m^2 at 20, 30 and 50 DAS, respectively on pooled basis) (**Table 1**) which might be due to the minimum number of total weeds with lesser biomass in the cropping period in one IC *fb* two HW plot. These results are in close conformity to the findings of Kathiresan and Manoharan (2002) and Moorthy and Saha (2005).

Among weed management practices, significantly lower total weed biomass at 20 and 50 DAS was recorded with one IC and two HW (34.41 and 47.14 g/m^2 at 20 and 50 DAS, respectively on pooled basis) but it was at par with rice bran at 2 t/ha + HW (36.82 and 53.77 g/m^2, respectively on pooled basis) might be due to the efficient weed control and lesser weed population as compared to other treatments (Bavaji and Somasundaram 2017). Significantly higher total weed biomass was recorded with unweeded check (79.05 and 200.1 g/m^2 at 20 and 50 DAS, respectively on pooled basis). At 30 DAS, significantly lower total weed biomass was recorded with one IC *fb* HW twice (32.67 g/m^2 on pooled basis) and it was on par with rice bran at 2 t/ha + HW (71.51 g/m^2 on pooled basis), while unweeded check recorded significantly higher total weed dry weight (188.1 g/m^2 on pooled basis) among all other weed management practices except with azolla incorporation (159.7 g/m^2 on pooled basis).

Among interaction effects, at 20 and 50 DAS, higher rice plant population with 25% higher population with the rice seed rate of 25 kg/ha along with one IC *fb* HW twice recorded significantly lower total weed biomass (24.97 and 36.62 g/m^2, respectively on pooled basis) and it was at par with 25% higher rice population with the seed rate of 25 kg/ha with rice bran at 2 t/ha + (28.28 and 49.40 g/m^2 at 20 and 50 DAS, respectively on pooled basis), while normal population with the seed rate of 20 kg/ha with unweeded check recorded significantly higher total weed dry weight (82.07 and 207.8 g/m^2 at 20 and 50 DAS, respectively on pooled basis) among all other treatment combinations except with 25% higher population with the seed rate of 25 kg/ha with unweeded check (76.04 and 192.4 g/m^2 at 20 and 50 DAS, respectively on pooled basis) because of effective weed control right from emerging stage of rice crop thus, resulted in obtaining the lower weed dry weight. At 30 DAS, 25% higher rice population with the seed rate of 25 kg/ha with one IC *fb* HW twice recorded significantly lower total weed biomass (28.56 g/m^2 on pooled basis) but it was at par with normal population with the seed rate of 20 kg/ha with one IC and two HW (36.77 g/m^2 on pooled basis) and 25% higher population with the seed rate of 25 kg/ha with rice bran at 2 t/ha + HW (66.95 g/m^2 on pooled basis), while normal population with the seed rate of 20 kg/ha with unweeded check recorded significantly higher total biomass (191.5 g/m^2 on pooled basis) among all other treatment combinations except with 25% higher population with the seed rate of 25 kg/ha with unweeded check (184.7 g/m^2 on pooled basis), normal population with the seed rate of 20 kg/ha with azolla incorporation (169.1 g/m^2 on pooled basis) and 25% higher population with the seed rate of 25 kg/ha with azolla incorporation (150.4 g/m^2 on pooled basis).

Interestingly, population levels in combination with weed management practices recorded significantly higher total weed biomass over uneven control with recommended weed management practice (14.54, 19.64 and 6.38 g/m^2 at 20, 30 and 50 DAS, respectively on pooled basis).

Weed control efficiency

Higher weed control efficiency was recorded in 25% higher rice population with the seed rate of 25 kg/ha along at 20 DAS (42.63% on pooled basis), 30 DAS (46.97% on pooled basis) and at 50 DAS (59.09% on pooled basis). Normal population with the seed rate of 20 kg/ha along recorded lower weed control efficiency at 20 DAS (29.26% on pooled basis), 30 DAS (42.19% on pooled basis) and at 50 DAS (55.23% on pooled basis) (**Table 2**).

One IC *fb* two HW gained higher weed control efficiency at 20 DAS (56.77% on pooled basis), 30 DAS (82.69% on pooled basis) and at 50 DAS (76.39% on pooled basis). It was followed by rice bran at 2 t/ha + HW (53.68, 62.12 and 72.95%, respectively on pooled basis) due to reduction of weed biomass by reducing the weed density in these treatments resulted in higher WCE as reported by Dutta and Bandyopadhyaya (2003).

At 20 and 50 DAS, 25% higher rice population with the seed rate of 25 kg/ha along with one IC *fb* HW twice recorded lower weed control efficiency (67.16 and 80.88%, respectively on pooled basis). It was followed by 25% higher rice population with the seed rate of 25 kg/ha along with rice bran at 2 t/ha + HW (62.82 and 74.17%, respectively on pooled basis). At 30 DAS, 25% higher rice population with the seed rate of 25 kg/ha along with one IC and two

HW recorded lower weed control efficiency (84.58% on pooled basis). It was followed by normal population with the seed rate of 20 kg/ha along with one IC and two HW (80.80% on pooled basis) and 25% higher rice population with the seed rate of 25 kg/ha along with rice bran at 2 t/ha + HW (63.73% on pooled basis). Higher population played favourable role in reducing the weed density and growth of varying weed fauna, added to that application of manual, mechanical or organic treatments further improved the suppressive effect on weeds there by increasing the weed control efficiency.

Uneven control with recommended weed management practice recorded higher weed control efficiency at 20 DAS (82.23% on pooled basis), 30 DAS (89.75% on pooled basis) and at 50 DAS (96.88% on pooled basis) than all other treatment combinations during both the years of study.

Rice grain and straw yield

Among the population levels, 25% higher rice population with the seed rate of 25 kg/ha recorded significantly higher rice grain (4.10 t/ha) and straw yield (4.90 t/ha) as compared to normal population with the seed rate of 20 kg/ha (**Table 3**). Normally, the grain and straw yield per plant decreases with increase in plant population but the grain and straw yield per unit area increases with increase in plant population. Decrease in yield per plant will be compensated by increased plant population and the reverse was true with lower plant population as observed by Kaur and Singh (2014). This implies that increased crop density had strong and consistent negative effects on weed and positive effects on grain and straw yield. Higher grain and straw yield with higher seed rate was also reported by Rajneesh *et al.* (2017).

With respect to weed management practices significantly higher grain (4.73 t/ha) and straw yield (5.44 t/ha) was recorded with one IC *fb* two HW and the next best treatment was application of rice bran at 2 t/ha + HW (4.69 and 5.38 t/ha grain and straw yield respectively), which was in conformity with the findings of Kato *et al.* (2010). Rice bran application

Table 2. Weed control efficiency (%) at 20, 30 and 50 days after seeding (DAS) as influenced by weed management treatments in direct-seeded rice under organic production system (pooled data 2017 and 2018)

Treatment	Weed control efficiency (%)		
	20 DAS	30 DAS	50 DAS
Rice plant population level (P)			
Normal rice plant population with recommended seed rate (20 kg/ha) – (P_1)	29.26	42.19	55.23
Higher rice plant population with 25% higher recommended seed rate (25 kg/ha) – (P_2)	42.63	46.97	59.04
Weed management treatment (W)			
Rice straw at 3 t/ha on 3 DAS *fb* HW once on 40 DAS – (W_1)	47.11	54.12	68.79
Rice bran at 2 t/ha on 3 DAS *fb* HW once on 40 DAS – (W_2)	53.68	62.12	72.95
Azolla inoculation at 500 kg/ha on 10 DAS and incorporation at 40 DAS – (W_3)	18.57	15.30	57.21
Cono-weeder at 10, 20, 30 and 40 DAS – (W_4)	39.54	53.25	67.47
One inter-cultivation (IC) at 20 DAS fb two HW twice at 25 and 50 DAS – (W_5)	56.77	82.69	76.39
Unweeded check – (W_6)	0.00	0.00	0.00
Interaction (P X W)			
P_1W_1	39.29	50.32	67.16
P_1W_2	44.54	60.51	71.73
P_1W_3	16.92	12.10	55.78
P_1W_4	28.42	49.40	64.80
P_1W_5	46.38	80.80	71.90
P_1W_6	0.00	0.00	0.00
P_2W_1	54.93	57.92	70.42
P_2W_2	62.82	63.73	74.17
P_2W_3	20.23	18.51	58.64
P_2W_4	50.66	57.11	70.13
P_2W_5	67.16	84.58	80.88
P_2W_6	0.00	0.00	0.00
Pendimethalin - 0.677 kg/ha pre-emergence application (PE) *fb* one HW at 30DAS UC	82.23	89.75	96.88

Figures in the parentheses indicate the original value and the data subjected for transformation using square root of $(\sqrt{x+1})$, where X is weed count significantly increased both spikelet number per panicle and panicle number, leading to substantial increase in total spikelet number per unit area grain and straw yield compared to unweeded control as reported by Gnanasoundari and Somasundaram (2014). Significantly lower grain (2.22 t/ha) and straw yields (2.86 t/ha) were recorded in unweeded check due to increased weed competition for resources such as space, light, nutrients.

A significant interaction between population levels and weed management practices showed that a treatment combination of 25% higher rice population with the seed rate of 25 kg/ha along with one IC *fb* two HW gave the highest rice grain (4.91 t/ha) and straw yield (5.56 t/ha) which was significantly superior to all the treatment combinations except with 25% higher population with the seed rate of 25 kg/ha along with rice bran at 2 t/ha + HW (4.81 and 5.47 t/ha grain and straw yield, respectively). These results clearly showed that under organic rice cultivation, 25% higher rice population with the seed rate of 25 kg/ha with a combination of weed management practice helped in controlling weeds resulting in significantly less density and dry matter accumulation of weeds, which led to better nutrient uptake and least crop weed competition under these treatment combinations.

The higher grain (5.10 t/ha) and straw yield (5.80 t/ha) with uneven control than weed management treatment combinations was due to application of nutrients to soil pool through recommended chemical fertilizer with FYM and chemical and cultural weed management practices.

Economics

Economic analysis clearly showed that significantly higher net returns (₹ 39,153/ ha) and B:C ratio (1.89) were noticed with the 25% higher rice

Table 3. Rice grain yield, straw yield and economics as influenced by weed management treatments in direct-seeded rice under organic production system (pooled data 2017 and 2018)

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)	B:C ratio (`/ha)
Rice plant population level (P)					
Normal rice plant population with recommended seed rate (20 kg/ha) – (P_1)	3.94	4.73	79.48	35.97	1.83
Higher rice plant population with 25% higher recommended seed rate (25 kg/ha) – (P_2)	4.10	4.90	82.83	39.15	1.89
LSD (p=0.05)	0.08	0.86	1.56	1.56	0.04
Weed management treatment (W)					
Rice straw at 3 t/ha on 3 DAS *fb* HW once on 40 DAS – (W_1)	4.34	5.35	87.79	46.94	2.15
Rice bran at 2 t/ha on 3 DAS *fb* HW once on 40 DAS – (W_2)	4.69	5.38	94.55	41.72	1.79
Azolla inoculation at 500 kg/ha on 10 DAS and incorporation at 40 DAS – (W_3)	3.77	4.58	76.17	27.18	1.55
Cono-weeder at 10, 20, 30 and 40 DAS – (W_4)	4.36	5.31	88.06	46.75	2.13
One inter-cultivation (IC) at 20 DAS fb two HW twice at 25 and 50 DAS – (W_5)	4.73	5.44	95.42	53.66	2.28
Unweeded check – (W_6)	2.22	2.85	44.95	9.14	1.26
LSD (p=0.05)	0.12	0.08	2.37	2.37	0.06
Interaction (P X W)					
P_1W_1	4.26	5.24	86.03	45.26	2.11
P_1W_2	4.57	5.29	92.21	39.46	1.75
P_1W_3	3.71	4.56	75.02	26.11	1.53
P_1W_4	4.32	5.17	87.13	45.91	2.11
P_1W_5	4.56	5.31	91.99	50.32	2.21
P_1W_6	2.20	2.83	44.50	8.78	1.25
P_2W_1	4.43	5.46	89.56	48.61	2.19
P_2W_2	4.81	5.47	96.89	43.97	1.83
P_2W_3	3.83	4.60	77.33	28.25	1.58
P_2W_4	4.40	5.45	88.98	47.59	2.15
P_2W_5	4.91	5.56	98.84	57.00	2.36
P_2W_6	2.24	2.88	45.40	9.50	1.26
LSD (p=0.05)	0.14	0.09	-	2.72	NS
Pendimethalin - 0.677 kg/ha pre-emergence application (PE) *fb* one HW at 30DAS UC	5.10	5.80	102.82	62.60	2.56
LSD (p=0.05)	0.17	0.09	-	3.08	0.08

population with the seed rate of 25 kg/ha over normal population with the seed rate of 20 kg/ha (₹ 35,974 / ha and 1.83) (**Table 3**). Kaur and Singh (2014) also reported lower net returns with reduced seed rate of 20 kg/ha in direct-seeded rice.

Economic analysis clearly showed that significantly higher net returns (₹ 53,658 /ha) and B:C ratio (2.28) were noticed with one IC *fb* HW twice. Significantly lower net returns (₹ 9,140 /ha) and B: C ratio (1.26) were noticed with unweeded check. Rice bran at 2 t/ha + HW though gave higher grain yield, but as the cost of cultivation was more, net returns and B:C ratio were reduced compared to one IC *fb* two HW. This was in accordance with the findings of Bavaji and Somasundaram (2017).

Significantly higher net returns (₹ 56,996 /ha) and B: C ratio (2.36) were noticed 25% higher rice population with the seed rate of 25 kg/ha with one IC *fb* HW twice. Significantly lower net returns (₹ 8,776 /ha) and B: C ratio (1.25) were noticed with normal population with the seed rate of 20 kg/ha with unweeded check.

Interestingly, recommended weed management practice had significantly higher net returns (₹ 62,603 /ha on pooled basis) and B:C ration (2.56) than any of the population levels and weed management practice combinations.

Conclusion

In organic dry-DSR production system, 25% higher rice population with the seed rate of 25 kg/ha along with rice bran at 2 t/ha + HW at 40 DAS would be the viable technique as it resulted in achieving comparable and better weed control efficiency and economic yields as recorded in 25% higher rice population with the seed rate of 25 kg/ha with one IC at 20 DAS *fb* two HW at 25 and 50 DAS.

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Indian Journal of Weed Science **53**(4): 353–357, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Nitrogen and weed management treatments effect on productivity of aerobic rice

E. Subramanian*, A. Sathishkumar and P. Rajesh[1]

Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu 625 104, India

[1]Department of Crop Management, RVSAC, Thanjavur, Tamil Nadu 613 402, India

**Email: esubramanian@tnau.ac.in*

Article information

DOI: 10.5958/0974-8164.2021.00065.4

Type of article: Research article

Received : 3 July 2021
Revised : 8 October 2021
Accepted : 12 October 2021

KEYWORDS

2,4-D Na salt, Aerobic rice, Herbicide, Nitrogen, Pendimethalin, Mechanical weeding, Productivity, Weed management

ABSTRACT

A field experiment was conducted to study the effect of three nitrogen levels and weed management practices on grain yield of aerobic rice at Tamil Nadu Rice Research Institute, Aduthurai during *Kharif* seasons of 2014 and 2015. The main plot treatments comprised of three nitrogen levels (75, 100 and 125 kg/ha N) and sub-plot treatments consisted five weed management treatments, *viz.* rice + *Sesbania* (dhaincha) (1:1) + pendimethalin pre-emergence application (PE) at 1.0 kg/ha followed by (*fb*) one hand weeding at 60 days after sowing (DAS); pendimethalin 1.0 kg/ha PE *fb* mechanical weeding twice at 20 and 40 DAS; rice + *Sesbania* (dhaincha) (1:1) + pendimethalin 1.0 kg/ha PE *fb* 2,4 D Na salt 0.8 kg/ha post-emergence application (PoE); mechanical weeding twice at 20 and 40 DAS and un-weeded control. The Rice + Dhaincha (1:1) + pendimethalin PE *fb* 2,4 D Na salt PoE recorded the lowest weed density at 20 DAS. At 40 and 60 DAS, pendimethalin PE *fb* mechanical weeding twice at 20 and 40 DAS recorded lower weed density and biomass during both the years. Among the N levels, application of N at 125 kg/ha resulted in maximum rice plant height, number of tillers/m^2, number of panicles/m^2, panicle weight and grain yield, during both the years. Pendimethalin PE *fb* mechanical weeding twice at 20 and 40 DAS resulted in higher rice plant height, number of tillers/m^2, number of panicles/m^2, panicle weight and grain yield. Application of N at 125 kg/ha along with pendimethalin PE *fb* mechanical weeding twice at 20 and 40 DAS may be used for effective weed management and higher productivity of aerobic rice.

INTRODUCTION

Water scarcity is becoming severe in many rice (*Oryza sativa* L.) growing areas in the world. Many water saving technologies have been developed to cope with water scarcity in lowland rice areas, such as alternate wetting and drying and continuous soil saturation (Zhang *et al.* 2009). A new technology that responds to more severe water shortages is the aerobic rice system, in which rice is grown in well-drained, non-puddled, and non-saturated soils without standing water (Bouman *et al.* 2005). Aerobic rice systems can reduce water use in rice production system as much as 50% in clay soils (Subramanian *et al.* 2008). Nevertheless, direct-seeded aerobic rice is subject to more severe weed infestation than transplanted lowland rice, because in aerobic rice systems weeds germinate simultaneously with rice, and there is no water layer to suppress weed growth. (Rao *et al.* 2017, Karthika *et al.* 2019). Weeds are the major constraints in aerobic rice to wide adoption of aerobic rice as they cause yield loss to an extent of 50 % to 100% (Parthiban *et al.* 2013). The critical period of crop weed competition in direct-seeded rice occurs between 15 to 45 days after sowing. Hence, the timely weed management is essential to improve the productivity of direct-seeded rice. Due to increased crop-weed competition in direct-seeded condition; adoption of single weed management methods does not give fruitful results. In such conditions integrated weed management offers most practical and cost-effective means of reducing weed competition to obtain higher economic returns with minimum yield loss (Rao and Nagamani 2010).

Nitrogen is a key nutrient which regulates the growth and development of plants and plays a significant role in the competitive balance between weeds and crops. Optimum dose of nitrogen fertilization plays a vital role in growth and development and grain formation as a result of higher yield of rice plant. Excessive nitrogen fertilization encourages excessive vegetative growth which makes the plant susceptible to insect, pest and diseases, which ultimately reduces yield whereas less than optimum rate affects both yield and quality of rice to remarkable extent. Hence, it is essential to find out the optimum rate of nitrogen application for efficient utilization of this resource by rice plants and attain higher rice grain yield. Therefore, this study was conducted to quantify the effect of varying levels of nitrogen fertilizer and weed management treatments on the crop and weed growth and yield of aerobic rice.

MATERIALS AND METHODS

Field experiments were conducted at Tamil Nadu Rice Research Institute, Aduthurai during *Kharif* (rainy) seasons of 2014 and 2015 with an objective to identify optimal nitrogen rate and effective weed management method for economically attaining optimum rice grain yield and higher net return. Experiment was laid out in split plot design with three replications. The main plot treatments comprised of three nitrogen levels (75, 100 and 125 kg/ha N) and sub-plot treatments consisted of five weed management treatments, *viz*. rice + dhaincha (*Sesbania aculeata* L.) (1:1) intercrop + pre-emergence application (PE) of pendimethalin 1.0 kg/ ha followed by (*fb*) one hand weeding (HW) at 60 days after seeding (DAS); pendimethalin 1.0 kg/ha PE *fb* mechanical weeding twice at 20 and 40 DAS; rice + dhaincha (1:1) + pendimethalin PE *fb* post-emergence application (PoE) of 2,4 D Na salt 0.8 kg/ ha; mechanical weeding twice at 20 and 40 DAS and un-weeded control. The field was thoroughly prepared by using tractor drawn disc plough, cultivator and rotavator. The soil of the experimental field was clay loam in texture and moderately drained. The initial soil status was low in available nitrogen, high in available phosphorus and medium in available potassium. The rice variety '*ADT 45*' seeds were soaked in water for 12 hours and incubated for 10 hours. Sprouted seeds were line sown at 20 x 10 cm spacing. Irrigation was given immediately after sowing and life irrigation was given on third day after sowing. Subsequent irrigation was given based on need of the crop or once in 4-5 days to maintain the aerobic condition. Rice and dhaincha were sown simultaneously on the same day in between two rows of rice dhaincha was sown as additive series following 1:1 ratio for rice and dhaincha. For the intercrop dhaincha, the seed rate adopted was 20 kg/ ha. The row-to-row spacing was 20 cm between rice with one row of dhaincha in the middle. Intercropped dhaincha was incorporated in-situ at 35 DAS using cono weeder. Mechanical weeding was done by cono weeder at 20 and 40 DAS as per the treatment schedule. Pre-emergence application of pendimethalin was done on 3 DAS and 2,4-D Na salt PoE was done on 25 DAS. The herbicides were sprayed uniformly with knapsack sprayer fitted with flat fan nozzle calibrated to deliver 500 liters/ha water volume. The application of nitrogen was done as per treatment which was applied in three splits (50% as basal, 25% N at active tillering and 25% N at panicle initiation stage). The fertilizers were applied in the form of urea (46% N), super phosphate (16% P) and muriate of potash (60% K). The phosphorous and potassium fertilizers were applied as basal. The data on yield attributes and yield of rice were recorded at the time of harvesting. The density of grasses, sedges and broad-leaved weeds was calculated by placing the quadrat (0.25/m^2 area) four times randomly and the density was expressed in no./m^2. Weed species within the area of quadrat were counted and collected and air dried in hot air oven maintained at 70 to 75ºC temperature for recording weed dry weight (weed biomass). The data obtained from the field experiment were subjected to statistical scrutiny. Wherever the treatment differences were significant, F test and critical differences were worked out at 5% probability level and the values were furnished.

RESULTS AND DISCUSSION

Effect on weeds

The weed flora of the experimental field consisted of mainly: *Echinochloa colona*, *Cynodon dactylon* and *Dactyloctenium aegyptium* amongst grasses (55.7%), *Cyperus rotundus* and *Cyperus iria* amongst sedges (17.8 per cent) and *Eclipta alba, Ammania baccifera, Ludwigia parviflora, Bergia capensis, Sphaeranthus indicus, Trianthema portulacastrum, Phyllanthus amarus* and *Boerhavia diffusa* amongst broad-leaved weeds (26.5%). Nitrogen application and weed management practices exerted pronounced impact on weed density at all the stages. Weed management treatments influenced the density (**Table 1**) and biomass (**Figure 1**) of weeds (at 60 DAS) during both the seasons. Nitrogen application did not have significant influence on the weed density during early stage. Among the N levels, application of N at 125 kg/ ha resulted in higher weed density at 40 and 60 DAS during both the years indicating that N application had greater influence on the weed density at later stages (Subramanian *et al.* 2005).

The rice + dhaincha (1:1) + pendimethalin PE *fb* 2,4 D Na salt recorded the lower weed density at 20 DAS which might be due to inherent capability of the chemical to affect the cell division, cell growth and hindering the germination of weeds (Bhargaw *et al.* 2018). This might be also due to *Sesbania* intercropping which might have suppressed the weed infestation due to faster canopy cover. At 40 and 60 DAS, pendimethalin PE *fb* mechanical weeding twice recorded lower density of weeds during 2014 and 2015 and it was followed by rice + dhaincha (1:1) + pendimethalin PE *fb* 2,4-D Na salt PoE and mechanical weeding twice at 20 and 40 DAS at 60 DAS in terms of reduced weed density. This might be due to the fact that pendimethalin PE controls the complex weed flora at initial stages and 2,4- D PoE was effective against broad-leaved weeds and the weeds emerged at later stages were removed by mechanical weeding. Hence, in aerobic rice cultivation integration of the herbicide application with mechanical weeding at later stage, preferably at 40 DAS is essential to remove the unmanaged weeds and to reduce the weed competition against rice.

The observed significantly lower weed biomass, at all crop growth periods, was due to efficient control of the weeds by weed management treatments tested. The highest weed biomass was registered under un-weeded control during both the years. Similar to weed density, the weed biomass was also lesser with pendimethalin PE *fb* mechanical weeding twice at 20 and 40 DAS and mechanical weeding twice at 20 and 40 DAS. Intercropping of *Sesbania* in rice appreciably enhanced the weed smothering efficiency (WSE), weed control efficiency (WCE) at 60 DAS and weed index (WI). Rice + dhaincha (1:1) + pendimethalin PE *fb* 2,4 D Na salt registered the maximum WSE at 40 DAS, weed control efficiency (WCE) at 60 DAS and weed index

Table 1. Effect of nitrogen and weed management treatments on weed density (no./m^2) in aerobic rice during *Kharif* 2014 and 2015

Treatment	Year	20 DAS				40 DAS				60 DAS			
		75 kg/ha N	100 kg/ha N	125 kg/ha N	Mean	75 kg/ha N	100 kg/ha N	125 kg/ha N	Mean	75 kg/ha N	100 kg/ha N	125 kg/ha N	Mean
Rice + dhaincha (1:1) + pendimethalin PE *fb* one HW at 60 DAS	2014	5.28 (27.33)	5.76 (32.67)	5.64 (31.33)	5.56 (30.44)	3.94 (14.99)	4.18 (16.99)	4.26 (17.67)	4.13 (16.55)	4.26 (17.67)	3.94 (14.99)	4.18 (16.99)	4.13 (16.55)
	2015	4.53 (19.99)	4.85 (23.00)	4.81 (22.67)	4.73 (21.89)	3.49 (11.67)	3.58 (12.34)	3.72 (13.33)	3.60 (12.45)	3.98 (15.33)	3.72 (13.33)	3.89 (14.67)	3.87 (14.44)
Pendimethalin PE *fb* mechanical weeding twice at 20 and 40 DAS	2014	5.61 (30.99)	5.21 (26.67)	5.49 (29.67)	5.44 (29.11)	3.49 (11.67)	3.67 (12.99)	3.81 (13.99)	3.66 (12.88)	2.44 (11.33)	4.06 (15.99)	3.85 (14.33)	3.79 (13.88)
	2015	4.64 (21.00)	4.49 (19.66)	4.56 (20.33)	4.56 (20.33)	3.14 (9.33)	3.29 (10.33)	3.44 (11.33)	3.29 (10.33)	3.34 (10.67)	3.81 (14.00)	3.63 (12.67)	3.60 (12.45)
Rice + dhaincha (1:1) + pendimethalin PE fb 2,4-D Na PoE	2014	4.98 (24.33)	5.70 (31.99)	4.81 (22.67)	5.18 (26.33)	4.67 (21.33)	4.53 (19.99)	4.78 (22.33)	4.66 (21.22)	4.56 (20.33)	4.85 (22.99)	4.92 (23.67)	4.78 (22.33)
	2015	4.30 (18.00)	4.71 (21.66)	4.10 (16.34)	4.38 (18.67)	4.02 (15.67)	3.85 (14.33)	4.26 (17.67)	4.05 (15.89)	4.34 (18.33)	4.56 (20.33)	4.71 (21.67)	4.54 (20.11)
Mechanical weeding twice at 20 and40 DAS	2014	5.90 (34.33)	6.07 (36.33)	6.26 (38.67)	6.08 (36.44)	4.34 (18.33)	3.98 (15.33)	4.95 (23.99)	4.44 (19.22)	3.76 (13.67)	4.02 (15.67)	4.49 (19.67)	4.10 (16.34)
	2015	5.49 (29.67)	5.58 (30.67)	5.64 (31.33)	5.57 (30.56)	3.76 (13.67)	3.54 (12.00)	4.34 (18.33)	3.89 (14.67)	3.52 (12.33)	3.76 (13.66)	4.14 (16.67)	3.84 (14.22)
Un-weeded control	2014	5.96 (34.99)	6.47 (41.33)	6.44 (40.99)	6.29 (39.10)	6.62 (43.33)	7.11 (49.99)	7.15 (50.67)	6.96 (48.00)	7.43 (54.67)	7.24 (51.99)	7.47 (55.33)	7.38 (54.00)
	2015	5.52 (30.00)	5.59 (35.33)	5.85 (33.67)	5.79 (33.00)	5.96 (35.00)	6.39 (40.33)	6.84 (46.34)	6.41 (40.56)	6.92 (47.33)	6.62 (43.33)	7.08 (49.67)	6.88 (46.78)
Mean	2014	5.56 (30.39)	5.86 (33.80)	5.76 (32.67)		4.74 (21.93)	4.85 (23.05)	5.12 (25.73)		4.90 (23.53)	4.98 (24.33)	5.15 (26.00)	
	2015	4.92 (23.73)	5.15 (26.06)	5.04 (24.87)		4.19 (17.07)	4.29 (17.87)	4.68 (21.40)		4.62 (20.80)	4.63 (20.93)	4.85 (23.07)	
		N	W	N at W	W at N	N	W	N at W	W at N	N	W	N at W	W at N
LSD (p=0.05)	2014	0.32	0.25	0.42	0.44	0.35	0.28	0.46	0.49	0.44	0.41	0.52	0.55
	2015	0.35	0.26	0.39	0.41	0.31	0.25	0.42	0.45	0.41	0.32	0.45	0.48

Figures in the parentheses are original values which were subjected to square root $\sqrt{x+0.5}$ transformation; DAS: Days after seeding; PE: Pre-emergence; PoE: Post-emergence

Table 2. Effect of weed management treatments on weed smothering efficiency (WSE), weed control efficiency (WCE) and weed index (WI) in aerobic rice during *Kharif* season of 2014 and 2015

Treatment	WSE (%)		WCE (%)		WI	
	2014	2015	2014	2015	2014	2015
Rice + dhaincha (1:1) + pendimethalin PE *fb* weed management one HW at 60 DAS	87.0	88.0	88.7	89.4	0.74	0.75
Pendimethalin PE *fb* mechanical weeding twice at 20 and 40 DAS	85.8	86.6	93.3	94.0	0.83	0.80
Rice + dhaincha (1:1) pendimethalin PE *fb* 2,4 D Na salt PoE	89.0	89.5	88.8	87.2	0.68	0.71
Mechanical weeding twice at 20 and 40 DAS	84.0	84.0	91.1	93.6	0.76	0.78
Un-weeded control		-	-	-	-	-

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

Table 3. Rice growth and yield under varying nitrogen and weed management treatments in aerobic rice during *Kharif* season of 2014 and 2015

Treatment	Plant height (cm)		Tillers/m^2		Panicles/m^2		Panicle weight (g)		Grain yield t/ha	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Nitrogen level										
75 kg/ha	85.4	80.2	455	402	241	238	2.06	2.16	2.88	2.68
100 kg/ha	93.6	91.3	506	489	265	262	2.26	2.32	3.25	2.86
125 kg/ha	108.4	95.6	524	505	281	271	2.42	2.48	3.46	3.14
LSD (p=0.05)	1.8	2.5	24.2	18	16	21	0.13	0.15	0.26	0.25
Weed management										
Rice: dhaincha (1:1) + pendimethalin PE *fb* one HW (60 DAS)	86.67	83.33	484	438	303	269	2.63	2.59	3.74	3.23
Pendimethalin PE *fb* mechanical weeding twice at 20 and 40 DAS	92.00	90.67	514	465	368	308	2.83	2.96	4.74	4.09
Rice: dhaincha (1:1) + pendimethalin PE *fb* 2,4-D Na salt	83.89	80.52	468	421	253	247	2.20	2.31	3.04	2.78
Mechanical weeding twice at 20 and 40 DAS	89.73	85.48	505	453	324	275	2.69	2.68	4.12	3.56
Un-weeded control	68.43	66.67	389	317	108	112	0.81	0.91	0.98	0.80
LSD (p=0.05)	1.5	2.4	20.2	16.8	14	19	0.12	0.14	0.18	0.21

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

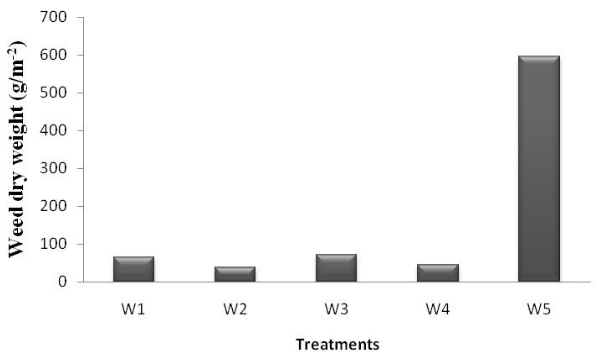

Figure 1. Weed biomass as influenced by weed management treatments at 60 DAS during *Kharif* season (pooled mean for two years)

W_1- Rice + Dhaincha (1:1) + pendimethalin PE *fb* weed management one HW at 60 DAS, W_2- pendimethalin PE *fb* mechanical weeding twice at 20 and 40 DAS, W_3- rice + dhaincha (1:1) pendimethalin PE *fb* 2,4 D Na salt PoE, W_4- mechanical weeding twice at 20 and 40 DAS and W_5- un-weeded control

(WI) during 2014 and 2015 (**Table 2**). It might be due to effective ground cover by dhaincha which decreased the availability of sunlight to the late emerging weed seeds inhibiting their germination and growth (Chauhan and Mahajan 2014; Bommayasamy *et al.* 2018).

Effect on rice growth and yield attributes

Nitrogen dosage rates and weed management treatments produced significant variation in the rice growth as well as yield attributes (**Table 3**). Among the tested N levels, N at 125 kg/ha caused maximum plant height, number of tillers/m^2, number of panicles/m^2 and panicle weight during both the years indicating the aerobic rice greater responsiveness to the applied N up to the rate of 125 kg/ha. Application of nitrogen promoted rice growth due to higher availability of nitrogen to the rice plants leading to its higher uptake and translocation to the different part of the rice plant (Jain *et al.* 2018), which suppressed the negative competitive effect of weeds on rice. Application of nitrogen at 125 kg/ha recorded higher yield (3.46 and 3.14 t/ha in 2014 and 2015, respectively) and it was followed by nitrogen at 100 kg/ha. Significant increase in grain yield could be attributed to N application which might have improved the N, P and K uptake by crop plant resulting in better growth and yield attributes (Mohana Keerthi *et al.* 2018). The lowest yield was recorded with application of nitrogen at 75 kg/ha.

Among the weed management methods, pendimethalin PE followed by mechanical weeding twice at 20 and 40 DAS resulted in greater rice plant

Table 4. Economic impact of varying nitrogen and weed management treatments in aerobic rice during *Kharif* season of 2014 and 2015

Treatment	Cost of cultivation (x10^3 `/ha)		Gross returns (x10^3 `/ha)		B:C ratio	
	2014	2015	2014	2015	2014	2015
Nitrogen level						
75 kg/ha	48.50	49.20	56.16	52.26	1.16	1.06
100 kg/ha	49.10	49.85	63.37	55.77	1.29	1.12
125 kg/ha	49.80	50.35	67.47	61.23	1.35	1.22
Weed management						
Rice + dhaincha (1:1) + pendimethalin PE *fb* hand weeding once at 60 DAS	49.50	50.25	72.93	62.98	1.47	1.25
Pendimethalin PE *fb* mechanical weeding twice at 20 and 40 DAS	50.25	51.20	92.43	79.75	1.84	1.56
Rice + dhaincha (1:1) pendimethalin PE *fb* 2,4 D Na salt PoE	47.15	48.20	59.28	54.21	1.26	1.12
Mechanical weeding twice at 20 and40 DAS	49.85	50.75	80.34	69.42	1.61	1.37
Un-weeded control	44.50	45.20	19.11	15.60	0.43	0.35

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

height, number of tillers/m^2, number of panicles/m^2 and panicle weight. This might be attributed to efficient and timely weed management which reduced the weed density and biomass leading to higher weed control efficiency during early stage of crop growth and ultimately resulted in improved rice yield attributes and increased grain yield. Whereas, lower grain and straw yield were found in un-weeded control owing to severe crop-weed competition which resulted in the reduction of growth and yield components of aerobic rice.

Application of nitrogen at 125 kg/ha with pendimethalin PE *fb* two mechanical weeding twice at 20 and 40 DAS was found to be the best treatment combination for effective weed management and higher yield of aerobic rice.

Economics

Application of nitrogen at 125 kg/ha recorded higher gross returns and B:C ratio followed by nitrogen at 100 kg/ha (**Table 4**). Among the weed management treatments, pendimethalin PE *fb* mechanical weeding twice at 20 and 40 DAS was found to be the most economical combination for higher gross returns and B:C ratio.

It was concluded that application of 125 kg N/ha and pendimethalin PE followed by mechanical weeding twice at 20 and 40 DAS is preferable option for achieving better weed management and higher economical productivity in aerobic rice cultivation.

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Indian Journal of Weed Science **53**(4): 358–362, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Sequential application of pre- and post-emergence herbicides for the control of weeds in transplanted rice at Hirakud command areas of Odisha

S. Mohapatra*, S.K. Tripathy and A.K. Mohanty

Regional Research and Technology Transfer Station, Orissa University of Agriculture and Technology, Chiplima, Sambalpur, Odisha 768025, India

**Email: sanjukta.mohapatra34@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00066.6

Type of article: Research article

Received : 4 June 2020
Revised : 28 September 2021
Accepted : 30 September 2021

KEYWORDS

Bispyribac-sodium, Pretilachlor + bensulfuron (ready-mix), Transplanted rice, Sequential application, Weed control efficiency, Weed management

ABSTRACT

A field experiment was conducted during rainy *(Kharif)* seasons of 2018 and 2019 to assess the efficacy of the sequential application of pre- and post-emergence herbicides for managing complex weed flora in transplanted rice at Hirakud command areas of Odisha. The weed free maintained by hand weeding twice recorded the highest values of growth parameters and rice grain yield (6.4 t/ha). The weeds in weedy check caused 50% rice grain yield reduction. The sequential application of pre-emergence herbicide (PE) pretilachlor + bensulfuron-methyl (ready-mix) 660 g/ha followed by (*fb*) post-emergence application (PoE) of bispyribac-sodium 25 g/ha recorded the highest weed control efficiency (93%), rice grain yield (6.1 t/ha), net return (₹ 63720 /ha) and benefit cost ratio (2.4) with 72.8% reduction in weed biomass and 24.6% yield advantages over recommended practice of pendimethalin 1000 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE.

INTRODUCTION

In India, rice (*Oryza sativa* L.) is grown in an area of 43.8 million ha, with a production of 116.4 million tons, and productivity of 2.7 t/ha in 2020 - 2021 (GOI 2021). In Odisha, area under rice crop is 3.86 million ha with a production of 7.7 million tons and productivity of 2.0 t/ha in 2018-2019 (RBI 2020). The advent of capital intensive technology like high yielding varieties tailored to respond to external inputs like fertilizers, irrigation and new intensive cropping systems aggravated the problem of weeds (Yaduraju and Mishra 2002). Weed infestation has been established as one of the important factors responsible for lower productivity in Odisha, as the weed flora under transplanted conditions cause a yield reduction up to 45% (Manhas *et al.* 2012).

Herbicide use is an effective method of selective and economical control of weeds immediately after rice transplanting for giving rice an advantageous initial vigorous growth and competitive superiority. Several pre- and post-emergence herbicides were identified for effective control of weeds in transplanted rice (Rajkhowa *et al.* 2006, Rao *et al.* 2017). Thus, the sequential application of pre- followed by post-emergence application of broad-spectrum herbicides was found essential for season-long effective weed control as it also helps in avoiding shifts toward problematic weed species or evolution of herbicide-resistant weed biotypes (Chauhan 2012). Adjusting the time of application, reducing the dose of the herbicide or use of herbicide in sequence can improve selectivity and adequate weed control in transplanted rice (Mallikarjun *et al.* 2014). The cultivation of two rice crops during a year in the same field in the command areas creates congenial environment for weed growth. Under such situations, the pre-emergence herbicide works up to 20 days after transplanting (DAT) and after application of 1st top dressing of fertilizer, the second flush of weeds emerge in the field which needs to be controlled. Thus the use of sequential application of pre-emergence herbicides followed by post-emergence herbicides could be more effective in managing the weed menace. With this background, the present study was undertaken.

MATERIALS AND METHODS

A field experiment was conducted during rainy *(Kharif)* seasons of 2018 and 2019 at the Regional Research and Technology Transfer Station, Chiplima of Orissa University of Agriculture and Technology under West Central Table Land Zone Odisha, India. The soil of experimental field was clay loam with porosity 39.28%, infiltration rate 0.26 cm/hr, water holding capacity 25.56% on weight basis, field capacity 19.7% on weight basis, permanent wilting point 10%, acidic (pH 5.65), low in organic carbon content (0.47%) and available N, P and K content were 242, 9.2 and 155 kg/ha, respectively. The experiment was laid out in randomized block design with 3 replications. The individual plot size was 6.1 x 2.4 m. Sixteen weed control treatments were tested (Table 1). Pre-emergence application of herbicides was done by broadcasting the herbicide mixed with 25 kg sand/ha at 3 DAT and the post-emergence application of bispyribac-sodium was done by spraying it at 20 DAT with knapsack sprayer fitted with flat fan nozzle using 375 liters water per hectare. A thin film of water was maintained in the field at the time of application of herbicides. The land was prepared by giving two ploughings each followed by planking with the help of a tractor – drawn cultivator. The puddling was done at the time of transplanting. Rice variety '*Hasant'* was transplanted in July and harvested in November during each of the year. Two rice seedlings per hill were transplanted at 20 × 15 cm spacing. A common fertilizer dose of 80, 40 and 40 kg of N, P and K/ha, respectively was applied to the crop. Full dose of P and K and half dose of N were applied as basal and remaining N was top-dressed in 2 equal splits, at maximum tillering and panicle-initiation stages of the crop.

Weed density (no./m^2), weed biomass (g/m^2) were measured by randomly placing at two places the 0.25 m^2 quadrat at 50 DAT. Weeds were separated in to three broad categories of grass, sedge and broad-leaved weeds (BLW) before drying. The weed samples collected from quadrats were kept at 85^0C for 16 hour in hot air oven and dry weight of the weeds (biomass) was measured (Klingman 1971). Weed density data was analyzed after subjecting to square root transformation. Weed control efficiency was also calculated on the basis of weed biomass using formula suggested by Mani *et al.* (1973).

$$\text{Weed control efficiency} = \frac{(WDc - WDt)}{WDc} \times 100$$

Where, WDc is the biomass (g) of weeds in weedy plots, WDt is the biomass (g) of weeds in treated plots

Data on rice plant height and yield attributes like tillers/m^2, panicle length, grains/panicle, 1000 grain weight and grain yield of rice were recorded at harvest. Economics was computed using the prevailing market prices for inputs and outputs such as rice grain (₹ 17500/t), rice straw (₹ 800/t), manual labour (₹ 280/day), pretilachlor + bensulfuron 6.6 GR (₹ 982/4 kg), pyrazosulfuron +pretilachlor 6.15 GR (₹ 795/4 kg), butachlor + penoxsulam 41 SE (₹ 800/1l), oxadiargyl 80 WP (₹ 190/35 g), pretilachlor 50 EC (₹ 300/1l.), butachlor 50 EC (₹ 200/l), pendimethalin 30 EC (₹ 477/1l), bispyribac-sodium 10 EC (₹ 835/100 ml). All data were subjected to analysis of variance as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect on weeds

Major weed species infesting the field were: *Echinocloa crus-galli* (L.) Beauv., *Echinocloa colona* (L.) Link., *Paspalum distichum* L., *Cyperus iria* L., *Cyperus difformis* L., *Fimbristylis miliacea* (L.) Vahl; *Scirpus acutus Muehl. ex Bigelow., Marsilia quadrifolia* L., *Ammania baccifera* L., *Alternanthera sessilis* (L.) R.Br. ex DC., and *Ludwigia parviflora* L. On an average of two years, the total weed density of 104.5/m^2 (average of two years) was observed in weedy plots at 50 DAT among which grass, sedge and broad-leaved weeds constituted 16.3, 43.1 and 40.7%, respectively (**Table 1**)

All the weed control treatments significantly reduced the density and biomass of grasses, sedges, BLW and total weeds as compared to weedy check (**Table 1 and 2**). Two hand weeding at 20 and 40 DAT provided weed free condition with 100% weed control. The pretilachlor + bensulfuron (ready-mix) PE showed lower weed biomass (8.8 g/m^2), which was at par with pretilachlor + pyrazosulfuron (ready-mix) PE (10.3 g/m^2) compared with other pre-emergence herbicides. The pretilachlor + bensulfuron (ready mix) caused a reduction of 35.7 and 72.8% in weed biomass (**Table 2**) when compared to pretilachlor PE and weedy check, respectively. Similar observations were made by Teja *et al.* (2015). Likewise, pretilachlor + pyrazosulfuron PE reduced weed biomass by 24.8 and 68.2% compared to commonly used pretilachlor and weedy check, respectively.

The sequential application of PE *fb* PoE was proved to be more effective in managing grass, sedge and broad-leaved weeds density, biomass and total weed density and biomass (**Table 1** and **2**). Maximum weed biomass reduction (93.2%) was observed with the sequential application of pretilachlor + bensulfuron (ready-mix) PE *fb* bispyribac-sodium PoE in comparison to weedy check due to effective control of all grasses, sedges and BLWs population at all growth stages as observed earlier by Maity and Mukherjee (2008), Sunil *et al.* (2010) and Bhat *et al.* *(*2017).

The highest weed control efficiency (WCE) at 50 DAT was recorded with pretilachlor + bensulfuron

PE *fb* bispyribac-sodium PoE (93%) followed by pretilachlor + pyrazosulfuron PE (92%) (**Table 2**). The application of pre-emergence herbicide alone showed poor weed control efficiency (48-75%). Similar results were reported by Sanodiya and Singh (2017).

Effect on rice

Pooled mean data of both years showed that sequential application of pre- and post-emergence herbicides resulted in greater rice plant height, more-number of tillers/m^2, maximum numbers of effective tillers and more grains/panicle when compared with the application of pre-emergence herbicides alone and weedy check. (**Table 3**).

The pooled mean data of both years showed that the highest grain yield of 6.4 t/ha was recorded with the weed free treatment with hand weeding twice. Among the herbicide treated plots, the sequential application of pretilachlor + bensulfuron PE *fb* bispyribac-sodium PoE with the grain yield of 6.1 t/ha followed by pretilachlor + pyrazosulfuron (ready-mix) PE *fb* bispyribac- sodium PoE with 6.0 t/ha were statistically comparable with that obtained with weed free plot (**Table 3**). This may be due to their broad spectrum weed control for a longer period resulting in minimum crop-weed competition and better growth and development of the crop. These results are in conformity with the findings of Walia *et al.* (2009), Bhat *et al.* (2017), Dhanapal *et al.* (2018) and Mahajan and Timsina (2011). The rice yield was reduced by 26.2-28.5%, without application of post-emergence herbicide. Walia *et al.* (2008) opined that it is difficult to raise weed-free rice with the application of only one herbicide. The season long uncontrolled weed growth reduced the yield of transplanted rice to an extent of 50% in weedy check in comparison to weed free plot.

The correlation and regression analysis revealed negative correlation between weed biomass and grain yield (R^2 = -0.81) and every unit increase in weed biomass, the grain yield of rice was expected to fall by 0.09 t/ha.

Table 1. Effect of weed control treatments on weed density at 50 days after transplanting (DAT) in transplanted rice

Treatment	Weed density (no./m^2) at 50 DAT											
	2018				2019				Mean			
	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total
Pretilachlor + bensulfuron 660 g/ha as PE	3.6 (12.0)	3.2 (9.0)	3.2 (9.0)	5.6 (30.0)	3.2 (9.0)	2.8 (7.0)	2.8 (7.0)	4.9 (23.0)	3.4 (10.5)	3.0 (8.0)	3.0 (8.0)	5.2 (26.5)
Pretilachlor + pyrazosulfuron 615 g/ha PE	3.7 (13.0)	3.7 (13.0)	3.3 (10.0)	6.1 (36.0)	3.3 (10.0)	3.0 (8.0)	3.0 (8.0)	5.2 (26.0)	3.5 (11.5)	3.2 (10.5)	3.2 (9.0)	5.7 (31.0)
Butachlor + penoxsulam 820 g/ha PE	4.1 (16.0)	4.7 (21.0)	2.8 (7.0)	6.7 (44.0)	3.6 (12.0)	3.6 (12.0)	2.6 (6.0)	5.6 (30.0)	3.9 (14.0)	2.7 (16.5)	2.7 (6.5)	6.2 (37.0)
Oxadiargyl 90 g/ha PE	3.7 (13.0)	5.1 (25.0)	2.8 (7.0)	6.8 (45.0)	3.5 (11.0)	3.9 (14.0)	2.6 (6.0)	5.7 (31.0)	3.6 (12.0)	2.7 (19.5)	2.7 (6.5)	6.2 (38.0)
Pretilachlor 750 g/ha PE	3.6 (12.0)	3.7 (13.0)	4.8 (22.0)	6.9 (47.0)	3.6 (12.0)	3.5 (11.0)	3.5 (11.0)	5.9 (34.0)	3.6 (12.0)	4.2 (12.0)	4.2 (16.5)	6.4 (40.5)
Butachlor 1500 g/ha PE	3.9 (14.0)	5.4 (28.0)	4.0 (15.0)	7.6 (57.0)	3.5 (11.0)	3.9 (14.0)	3.7 (13.0)	6.2 (38.0)	3.7 (12.5)	3.9 (21.0)	3.9 (14.0)	7.0 (47.5)
Pendimethalin 1000 g/ha PE	3.7 (13.0)	4.8 (22.0)	5.4 (28.0)	8.0 (63.0)	3.3 (10.0)	4.1 (16.0)	4.0 (15.0)	6.5 (41.0)	3.5 (11.5)	4.7 (19.0)	4.7 (21.5)	7.3 (52.0)
Pretilachlor + bensulfuron-methyl 660 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	1.4 (1.0)	1.4 (1.0)	1.5 (1.3)	1.7 (2.0)	3.0 (8.0)	1.9 (3.3)	1.9 (3.3)	2.6 (8.7)	2.3 (4.5)	1.8 (2.2)	1.8 (2.3)	2.2 (5.3)
Pretilachlor + pyrazosulfuron 615 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	2.4 (5.0)	1.4 (1.0)	1.7 (2.0)	3.0 (8.0)	3.6 (12.0)	2.6 (6.0)	2.8 (7.0)	5.1 (25.0)	3.1 (8.5)	2.3 (3.5)	2.3 (4.5)	4.2 (16.5)
Butachlor + penoxsulam 820 g/ha *fb* bispyribac-sodium 25 g/ha PoE	2.0 (3.0)	2.2 (4.0)	1.4 (1.0)	3.0 (8.0)	3.6 (12.0)	3.7 (13.0)	2.6 (6.0)	5.7 (31.0)	2.9 (7.5)	2.1 (8.5)	2.1 (3.5)	4.5 (19.5)
Oxadiargyl 90 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	2.0 (3.0)	2.4 (5.0)	1.4 (1.0)	3.2 (9.0)	3.3 (10.0)	3.7 (13.0)	2.8 (7.0)	5.6 (30.0)	2.7 (6.5)	2.2 (9.0)	2.2 (4.0)	4.5 (19.5)
Pretilachlor 750 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	2.2 (4.0)	2.2 (4.0)	3.0 (8.0)	4.1 (16.0)	3.2 (9.0)	3.2 (9.0)	3.5 (11.0)	5.5 (29.0)	2.7 (6.5)	3.2 (6.5)	3.2 (9.5)	4.8 (22.5)
Butachlor 1500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	2.8 (7.0)	2.6 (6.0)	3.0 (8.0)	4.7 (21.0)	3.0 (8.0)	3.3 (10.0)	3.3 (10.0)	5.4 (28.0)	2.9 (7.5)	3.0 (8.0)	3.2 (9.0)	5.0 (24.5)
Pendimethalin 1000 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	2.0 (3.0)	2.8 (7.0)	3.3 (10.0)	4.6 (20.0)	3.2 (9.0)	3.5 (11.0)	3.5 (11.0)	5.7 (31.0)	2.6 (6.0)	3.2 (9.0)	3.4 (10.5)	5.1 (25.5)
Weed free by hand weeding twice	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Weedy check	4.5 (19.0)	7.4 (54.0)	6.9 (47.0)	11.0 (120.0)	4.0 (15.0)	6.1 (36.0)	6.2 (38.0)	9.5 (89.0)	4.2 (17.0)	6.6 (45.0)	6.6 (42.5)	10.3 (104.5)
LSD (p=0.05)	0.3	0.2	0.3	0.3	0.1	0.4	0.4	0.9	0.1	0.3	0.3	0.6

Square root ($\sqrt{x+1}$) transformed values, values in the parentheses are original values

Table 2. Effect of weed control treatments on weed biomass and weed control efficiency (WCE) at 50 days after transplanting (DAT) in transplanted rice

Treatment	Weed biomass (g/m^2) at 50 DAT														
	2018				2019				Mean				WCE (%)		
	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total	2018	2019	Mean
Pretilachlor + bensulfuron-methyl 660 g/ha as PE	2.4 (4.9)	2.0 (2.9)	2.0 (2.9)	3.4 (10.7)	1.9 (2.8)	1.7 (2.0)	1.7 (2.0)	2.8 (6.8)	2.2 (3.8)	1.9 (2.5)	1.9 (2.5)	3.1 (8.8)	75	75	75
Pretilachlor + pyrazosulfuron 615 g/ha PE	2.5 (5.3)	2.3 (4.2)	2.0 (3.2)	3.7 (12.7)	2.1 (3.3)	1.8 (2.3)	1.8 (2.3)	3.0 (7.9)	2.3 (4.3)	2.0 (3.2)	1.9 (2.8)	3.4 (10.3)	70	71	71
Butachlor + penoxsulam 820g/ha PE	2.8 (6.6)	2.8 (6.8)	1.8 (2.3)	4.1 (15.6)	2.3 (4.3)	2.1 (3.4)	1.6 (1.7)	3.2 (9.4)	2.5 (5.4)	2.5 (5.1)	1.7 (2.0)	3.7 (12.5)	64	66	65
Oxadiargyl 90 g/ha PE	2.6 (6.0)	3.0 (8.1)	1.8 (2.3)	4.2 (16.3)	2.2 (3.7)	2.2 (4.0)	1.6 (1.7)	3.2 (9.4)	2.4 (4.8)	2.6 (6.0)	1.7 (2.0)	3.7 (12.9)	62	66	64
Pretilachlor 750 g/ha PE	2.5 (5.4)	2.3 (4.2)	2.8 (7.1)	4.2 (16.7)	2.3 (4.3)	2.0 (3.1)	2.0 (3.1)	3.4 (10.6)	2.4 (4.9)	2.2 (3.7)	2.5 (5.1)	3.8 (13.7)	61	61	61
Butachlor 1500 g/ha PE	2.7 (6.5)	3.2 (9.0)	2.4 (4.8)	4.6 (20.4)	2.3 (4.2)	2.2 (4.0)	2.2 (3.7)	3.6 (11.9)	2.5 (5.4)	2.7 (6.5)	2.3 (4.3)	4.1 (16.2)	52	56	54
Pendimethalin 1000 g/ha PE	2.7 (6.2)	2.8 (7.1)	3.2 (9.0)	4.8 (22.3)	2.4 (5.0)	2.4 (4.6)	2.3 (4.3)	3.9 (13.9)	2.6 (5.6)	2.6 (5.8)	2.8 (6.7)	4.4 (18.1)	48	49	48
Pretilachlor + bensulfuron-methyl 660 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	1.2 (0.5)	1.1 (0.3)	1.3 (0.6)	1.6 (1.5)	1.4 (1.1)	1.4 (0.9)	1.4 (0.9)	2.0 (2.9)	1.3 (0.8)	1.3 (0.6)	1.3 (0.8)	1.8 (2.2)	96	89	93
Pretilachlor + pyrazosulfuron 615 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	1.5 (1.2)	1.1 (0.3)	1.3 (0.6)	1.8 (2.2)	1.6 (1.6)	1.3 (0.7)	1.3 (0.8)	2.0 (3.0)	1.5 (1.4)	1.2 (0.5)	1.3 (0.7)	1.9 (2.6)	95	89	92
Butachlor + penoxsulam 820 g/ha *fb* bispyribac-sodium 25 g/ha PoE	1.3 (0.7)	1.5 (1.3)	1.1 (0.3)	1.8 (2.3)	1.6 (1.6)	1.6 (1.5)	1.3 (0.7)	2.2 (3.8)	1.5 (1.1)	1.5 (1.4)	1.2 (0.5)	2.0 (3.0)	95	86	90
Oxadiargyl 90 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	1.3 (0.8)	1.6 (1.6)	1.1 (0.3)	1.9 (2.7)	1.5 (1.4)	1.6 (1.5)	1.3 (0.8)	2.2 (3.6)	1.4 (1.1)	1.6 (1.5)	1.2 (0.6)	2.0 (3.2)	94	87	90
Pretilachlor 750 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	1.7 (1.9)	1.5 (1.3)	1.9 (2.6)	2.6 (5.8)	1.7 (2.0)	1.4 (1.0)	1.5 (1.3)	2.3 (4.3)	1.7 (2.0)	1.5 (1.2)	1.7 (1.9)	2.5 (5.1)	86	84	85
Butachlor 1500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	2.0 (3.1)	2.0 (3.2)	2.0 (3.2)	3.3 (9.6)	1.8 (2.1)	1.6 (1.7)	1.6 (1.6)	2.5 (5.4)	1.9 (2.6)	1.9 (2.5)	1.8 (2.4)	2.9 (7.5)	78	80	79
Pendimethalin 1000 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	1.6 (1.7)	2.5 (5.2)	2.0 (3.2)	3.3 (10.1)	1.8 (2.4)	1.7 (2.1)	1.6 (1.6)	2.7 (6.0)	1.7 (2.0)	2.1 (3.6)	1.8 (2.4)	3.0 (8.1)	76	78	77
Weed free by hand weeding twice	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	100	100	100
Weedy check	3.3 (10.2)	4.3 (17.4)	4.0 (15.2)	6.6 (42.8)	2.7 (6.2)	3.4 (10.3)	3.5 (10.9)	5.3 (27.3)	3.0 (8.2)	3.9 (13.9)	3.7 (13.0)	5.8 (32.4)	0	0	0
LSD (p=0.05)	0.1	0.04	0.04	0.02	0.02	0.03	0.04	0.03	0.03	0.03	0.03	0.4	-	-	-

Square root ($\sqrt{x+1}$) transformed values, values in the parentheses are original values

Table 3. Effect of weed control treatments on yield attributes, yield and economics of transplanted rice (mean data of 2 years)

Treatment	Plant height (cm)	Panicle length (cm)	Tillers/ m^2	Grains/ panicle	1000 grain wt. (g)	Grain yield (t/ha)			Straw yield (t/ha)	Cost ($x10^3$ `/ha)	Net returns ($x10^3$ `/ha)	B:C ratio
						2018	2019	Mean				
Pretilachlor + bensulfuron 660 g/ha as PE	108	25	306	141	22.9	4.2	4.8	4.5	5.3	46.01	32.68	1.7
Pretilachlor + pyrazosulfuron 615 g/ha PE	107	25	302	141	22.5	4.2	4.6	4.4	5.1	45.53	28.76	1.6
Butachlor + penoxsulam 820 g/ha PE	106	24	289	140	21.9	4.1	4.5	4.3	4.7	45.55	29.49	1.7
Oxadiargyl 90 g/ha PE	105	24	283	138	21.9	3.7	4.3	4	4.6	45.37	22.52	1.5
Pretilachlor 750 g/ha PE	104	24	265	132	21.6	3.2	4.2	3.7	4.4	44.25	17.77	1.4
Butachlor 1500 g/ha PE	104	24	258	127	21.5	3.4	3.8	3.6	4.3	44.12	12.75	1.3
Pendimethalin 1000 g/ha PE	103	24	248	125	21.3	3.6	3.4	3.5	4.2	45.12	13.19	1.3
Pretilachlor + bensulfuron-methyl 660 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	118	26	418	164	23.6	6.2	6.0	6.1	6.6	48.09	63.72	2.4
Pretilachlor + pyrazosulfuron 615 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	114	25	379	161	23.5	6.2	5.8	6.0	6.5	47.62	62.34	2.4
Butachlor + penoxsulam 820 g/ha *fb* bispyribac-sodium 25 g/ha PoE	113	25	373	160	23.2	5.9	5.7	5.8	6.4	47.63	58.68	2.2
Oxadiargyl 90 g/ha PE *fb* bispyribac-sodium25 g/ha PoE	112	25	358	151	23.4	5.3	5.5	5.4	6.2	47.45	51.04	2.2
Pretilachlor 750 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	112	25	347	150	22.9	5.1	5.3	5.2	6.2	47.45	41.63	1.9
Butachlor 1500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	109	25	326	149	22.7	4.5	5.1	4.8	5.5	46.21	39.05	1.9
Pendimethalin 1000 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	109	24	319	141	22.5	4.2	5	4.6	5.4	47.21	31.47	1.7
Weed free by hand weeding twice	120	26	454	170	24	6.6	6.2	6.4	6.9	58.65	56.64	2
Weedy check	102	23	238	122	21.2	3.1	3.3	3.2	3	43.55	5.86	1.1
LSD (p=0.05)	9.7	NS	39.7	6.6	NS	0.7	0.5	0.7	1.2	-	0.03	0.4

Economics

All weed control treatments provided significantly higher return and B: C ratio compared to weedy check (**Table 3**). The net return was reduced by 9.7 times due to weeds (₹ 5860/ha) as compared to weed free (₹ 56640/ha). The sequential application of herbicides proved superior to herbicides pre-emergence application alone. The highest net return (₹ 63720/ha) was obtained with sequential application of pretilachlor + bensulfuron PE *fb* bispyribac-sodium PoE with benefit: cost ratio of 2.4. The hand weeding twice effectively controlled weeds and resulted in higher yields but it's B: C ratio was lower due to higher cost of cultivation (₹ 58600/ha) on account of higher human labour use as reported by Dhanapal *et al.* (2018).

The pre-emergence application of pretilachlor 6% + bensulfuron-methyl 0.6% GR at 660 g/ha *fb* post-emergence application of bispyribac-sodium 25 g/ha at 20 DAT gave effective control of all types of weeds, higher rice yield (6.1 t/ha), net return (₹ 63700 /ha) and benefit cost ratio (2.4).

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Indian Journal of Weed Science **53**(4): 363–366, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Reduction of soil weed seedbank with increased yield in dry direct-seeded rice through weed management

P. Nagarjun*, G.N. Dhanapal, M.T. Sanjay, S.B. Yogananda and R. Muthuraju[1]

Department of Agronomy, University of Agricultural Sciences, GKVK, Bengaluru, Karnataka 560065, India

[1]Department of Agriculture Microbiology, GKVK, Bengaluru, Karnataka 560065, India

**Email: nagarjunp009@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00067.8

Type of article: Research article

Received : 24 September 2020

Revised : 10 July 2021

Accepted : 12 July 2021

KEYWORDS

Direct-seeded rice, Rice herbicides, Weed seedbank, Weed seed emergence

ABSTRACT

Rice cultivation always have a significant role in food and livelihood security. The predictions of increasing water deficiency under a changing climate and overcoming labor shortages in agriculture have brought a change in rice cultivation from conventionally flooded transplanting to direct-seeded rice (DSR) but weeds are the major production constrain in direct-seeded rice. Keeping these facts in view a field study was conducted during rainy season *(Kharif)*, 2016 and 2017 at the Main Research Station, Hebbal, Bengaluru, India to study the effect of different weed management treatments in dry direct-seeded rice (upland condition) on growth, yield and soil weed seedbank as measured by emergence of weed seedlings. Among various weed management treatments, hand weeding at 20, 40 and 60 DAS recorded significantly highest paddy grain and straw yield in hand weeding at 20, 40 and 60 DAS (5.50 and 7.22 t/ha, respectively) and found at par with application of bensulfuron-methyl + pretilachlor as pre-emergence *fb* bispyribac-sodium (5.39 and 7.16 t/ha, respectively). Weedy check recorded significantly lowest yield (1.40 and 2.32 t/ha, respectively). At different intervals significantly the lowest weed seedlings emergence was noticed from the soils collected from different depths in hand weeded plots during both the years. Among various herbicide combinations, pre-emergence application of bensulfuron-methyl + pretilachlor followed by bispyribac-sodium recorded the lowest weed seedbank, as measured by germination of weed seeds and weed seedling emergence, followed by bensulfuron-methyl + pretilachlor and triafamone + ethoxysulfuron. Significantly the highest weed seedbank was noticed from soil collected from weedy check.

INTRODUCTION

Rice production systems are enduring numerous changes and one of such changes is modification from transplanted rice to direct seeding. Direct-seeding of rice (DSR) is increasing rapidly in Asia as the farmers seek high productivity and profitability to offset increasing costs and shortage of farm labour (Pandey and Valesco 2002, Rao *et al.* 2007, 2017). Conventionally, paddy is established by transplanting seedlings in puddled soils, which demands a huge amount of water and labour. The way of direct-seeding evades the transplanting and puddling operations. The major restriction in the effective cultivation of DSR in tropical countries is heavy infestation of weeds which often results in reduction in grain yield from 50-91% (Rao *et al.* 2007).

Soil weed seedbanks are reserves of viable seeds present in the soil and on its surface. Seedbanks consist of both recent and older seed shed in, and dispersed into a locality. This reserve of propagules is the source of local diversity, and is essential for the continuing existence of the flora in that locality (Jack 1999). The weed seedbank is the principal source of annual weeds in the field crops. Size and composition of the seedbank as well as above ground weed flora reflect the past and present weed, crop, and soil management strategies (Roberts and Neilson 1981). Reducing the size of weed seedbank has been a long-term goal of any weed management strategies, particularly in continuously cultivated fields (Schweizer and Zimdahl 1984). Unless reducing the weed seedbank in the soil the effort made managing the weeds will be a time being process. Keeping these facts in view, an experiment was planned and conducted with an objective to assess the effect of different weed management practices on yield of direct seeded rice and soil seedbank by measuring the weed seedling emergence from the soil collected after the harvest of the dry-DSR.

MATERIALS AND METHODS

The field experiment was conducted during *Kharif*, 2016 and 2017 at the Main Research Station, Hebbal, Bengaluru. The soil type was sandy loam with a pH of 6.8, with organic carbon of 0.55%. The experiment consisted 12 treatments, *viz.* bensulfuron methyl + pretilachlor *fb* triafamone + ethoxysulfuron (RM) (60 + 600 /60 g/ha), oxadiargyl *fb* triafamone + ethoxysulfuron (RM) (100/60 g/ha), pendimethalin *fb* triafamone + ethoxysulfuron (RM) (1000/60 g/ha), pyrazosulfuron-ethyl *fb* triafamone + ethoxysulfuron (RM) (20/60 g/ha), bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (60 + 600/25 g/ha), oxadiargyl *fb* bispyribac-sodium (100/25 g/ha), pendimethalin* *fb* bispyribac-sodium (1000/25 g/ha), pyrazosulfuron -ethyl *fb* bispyribac-sodium (20/25 g/ha), pendimethalin *fb* penoxsulam + cyhalofop-butyl (RM) (1000 /135 g/ha), three mechanical weedings (20, 40, 60 DAS), hand weedings (20, 40, 60 DAS) and weedy check were tested in a randomized block design with three replications. Rice variety MAS 946 was sown at a inter row spacing of 30 cm and seeds were placed closely. The crop was fertilized with 100 kg N, 50 kg P and 50 kg K/ha. These treatment combinations were replicated thrice in a randomized complete block design (RCBD). The pre-emergence and post–emergence herbicides were applied using spray volume of 750 liters/ha and 500 liters/ha, respectively with Knap-sack sprayer having WFN nozzle. Plants in the net plot area were harvested and threshed separately in each plot and grains were separated, dried under sun and the grain yield per plot was recorded after cleaning. From this yield per plot was computed and converted as ton per hectare.

Species wise weed density (number/m^2) were recorded at rice harvest at two spots per plot. The weeds present were counted categorizing them as sedge, grasses and broad leaf weeds and expressed as number m^{-2} and averaged over two random spots per plot. At 60 days after sowing growth parameters, *viz.*, plant height (cm), leaf area (cm^2 per meter row length), total dry weight (g) and at harvest, the data on rice yield, straw yield were collected.

The weed seed distribution at different depths in the soils of the experimental site was studied in pot culture experiments. Soil samples were collected from the experimental site after harvest of dry DSR. The soil samples were taken at two different depths *i.e*., 0-10 and 10-20 cm and dried under shade. One kg of soil from each depth was weighed and kept in the plastic tray containing holes at bottom side in all the four corners and replicated thrice to study the emerged weeds present in the soil. The trays were watered manually as and when needed to maintain adequate moisture. After germination, the weed seedlings were identified, counted and removed and again soil was thoroughly stirred and watered regularly for another flush of weeds. The cycle of operation was repeated till all the weed seeds were exhausted. Data averaged over three replications and two spots per replication after harvesting of paddy crop in both the years. The data collected was statistically analyzed using the standard procedure and the results were tested at five per cent level of significance (Gomez and Gomez 1984). The critical difference was used to compare treatment means.

RESULTS AND DISCUSSION

Weed flora

The major weeds associated with dry direct-seeded rice at harvest during 2016 and 2017 were *Cyperus rotundus* (sedge), *Cynodon dactylon, Chloris barbata, Digitaria marginata, Echinolchloa colona, Eleusine indica* (among grasses) (**Table 1**). Whereas, among broad-leaf weeds, major weeds were *Commelina benghalensis, Alternanthera sessilis, Ageratum conyzoides, Acanthospermum hispida, Emilia sonchifolia, Lagascea mollis, Euphorbia geniculata, Euphorbia hirta, Borreria hispida, Phyllanthus niruri* and *Tridax procumbens*. Predominant category of weed was broad-leaved followed by grasses and sedges. Among the weed species, the densities of *Cyperus rotundus, Cynodon dactylon, Digitaria, marginata, Ageratum conyzoides, Commelina benghalensis* and *Alternanthera sessilis* were more than other weed species. Indicating their dominance and competitiveness with the dry direct-seeded rice (**Table 1**). The emergence of different weed species is mainly attributed to different weed management treatments, initial soil weed seedbank, difference in tillage intensity during land preparation, earlier cropping system, weather parameters during crop growth, favorable soil environment, *etc*. Similar results were observed by Yogananda *et al.* (2017).

Growth parameters and yield

The data pertaining to growth parameters and yield of dry direct-seeded rice were significantly influenced by different weed management practices.is presented in the **Table 2**.

At 60 days after sowing hand weeding at 20, 40 and 60 days after sowing as recorded significantly highest plant height (36.85 cm), leaf area (1096.07 cm^2 per meter row length) and total dry weight (51.41 g) compared to all the treatments and it was found statistically at par with application of bensulfuron-methyl + pretilachlor *fb* bispyribac-

Table 1. Effect of different weed manag ement practices on major weed species' density (no./m²) in dry direct-seeded rice (pooled data of two years)

Treatment	Sedges		Grasses						Broad-leaf weeds										Total weeds
	Cr	Total	Cd	Da	Dm	Ec	Clb	Total	Alt	Bh	Cv	Cb	Ac	Ah	Spa	Eg	Eh	Total	
Bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfuron	7.0	7.0	5.4	3.7	3.0	2.3	0.0	15.3	7.0	4.4	3.0	0.0	2.0	1.0	0.4	1.7	0.4	22.7	45.0
Oxadiargyl *fb* triafamone + ethoxysulfuron	16.3	16.3	8.7	6.3	8.7	5.7	3.4	34.7	13.7	8.0	7.4	5.7	7.0	1.7	7.7	4.0	2.7	84.4	135.4
Pendimethalin *fb* triafamone + ethoxysulfuron	17.7	17.7	11.0	9.0	10.7	6.7	6.0	45.0	8.4	11.4	8.7	7.4	7.4	7.4	6.0	6.3	2.3	104.4	167.0
Pyrazosulfuron-ethyl *fb* triafamone + ethoxysulfuron	16.7	16.7	9.7	7.4	8.3	8.0	3.3	39.7	10.3	10.7	7.7	8.0	8.7	7.0	6.7	6.0	2.0	89.0	145.4
Bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium	6.4	6.4	6.0	2.0	2.7	1.7	0.7	14.4	6.4	3.0	3.0	1.0	0.7	2.4	1.0	1.0	0.7	20.7	41.4
Oxadiargyl *fb* bispyribac-sodium	11.4	11.4	9.0	4.0	5.7	5.0	2.0	28.7	11.4	7.0	4.0	4.3	7.0	2.0	6.4	2.3	2.0	61.7	101.7
Pendimethalin* *fb* bispyribac-sodium	14.7	14.7	9.7	8.0	7.3	1.3	2.3	29.7	12.0	6.0	4.7	4.3	4.4	1.7	6.0	2.4	0.4	59.3	103.7
Pyrazosulfuron-ethyl *fb* bispyribac-sodium	11.0	11.0	10.0	4.0	3.7	4.3	1.4	25.7	8.7	6.4	2.0	6.7	1.4	3.0	2.4	1.7	3.0	43.0	79.7
Pendimethalin* *fb* penoxsulam + cyhalofop-butyl	20.0	20.0	10.7	10.4	9.0	5.7	2.7	42.4	9.0	14.3	6.7	6.4	6.0	7.3	6.4	4.7	5.0	104.0	166.3
Mechanical weedings	17.7	17.7	8.4	8.4	8.4	7.7	4.0	38.4	11.3	12.0	11.0	8.0	12.0	5.4	4.7	4.3	3.0	106.0	162.0
Hand weedings	5.7	5.7	5.7	2.7	2.3	2.0	0.4	13.0	6.0	3.3	2.0	1.0	1.0	0.0	1.0	0.4	0.4	19.4	38.0
Weedy check	20.4	20.4	12.7	11.0	16.7	8.0	8.7	60.0	8.7	12.0	11.0	10.4	8.7	10.7	8.7	9.0	7.0	130.0	210.3

Data averaged over three replications and two spots per replication; Sedge: Cr- *Cyperus rotundus,* Grasses: Cd-*Cynodon dactylon*, Da – *Dactyolacteium aegptium,* Ec - *Echinochloa colona,* Clb-*Chloris barbata;* Broad-leaf weeds: Alt-*Alternanthera sessilis*, Bh- *Borreria hispida*, Cv-*Cleome viscosa,* Cb - *Commelina benghalensis*, Es-*Emilia sonchifolia*, Eg - *Euphorbia –geniculata,* Lm-*Lagascea mollis*, Sa-*Spilanthes acmella*, Eh-*Euphorbia hirta,* Ah- *Acanthospermum hispida* Pn – *Phyllanthus niruri;* *The Total of grasses and broad leaf weeds includes values of other minor weeds also which are not mentioned in total; *Pendimethalin (38.7% CS), RM: Ready Mix, *fb*: Followed by

Table 2. Effect of different weed management practices in dry direct-seeded rice on growth parameters and yield (pooled data of two years)

Treatment	Plant height (cm)	Leaf area (cm² per meter row length)	Total dry weight (g)	Grain yield (t/ha)			Straw yield (t/ha)			Harvest index
				2016	2017	Pooled	2016	2017	Pooled	
Bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfuron	35.89	1068.86	49.39	4.95	5.63	5.29	6.86	7.20	7.03	0.43
Oxadiargyl *fb* triafamone + ethoxysulfuron	30.36	901.89	37.83	4.11	4.68	4.39	6.06	6.21	6.14	0.42
Pendimethalin *fb* triafamone + ethoxysulfuron	28.73	849.96	35.99	3.89	4.42	4.15	6.01	6.16	6.09	0.41
Pyrazosulfuron-ethyl *fb* triafamone + ethoxysulfuron	29.70	883.04	36.78	4.04	4.60	4.32	6.08	6.23	6.15	0.41
Bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium	36.46	1082.29	50.14	5.04	5.73	5.39	7.07	7.25	7.16	0.43
Oxadiargyl *fb* bispyribac sodium	31.63	946.03	44.33	4.15	4.69	4.42	6.04	6.19	6.11	0.42
Pendimethalin *fb* bispyribac sodium	30.60	911.51	41.53	4.16	4.70	4.43	6.04	6.19	6.11	0.42
Pyrazosulfuron ethyl *fb* bispyribac sodium	31.85	947.14	46.58	4.21	4.75	4.48	6.13	6.28	6.20	0.42
Pendimethalin *fb* penoxsulam + cyhalofop-butyl	27.93	830.52	33.15	3.90	4.41	4.15	6.06	6.21	6.13	0.40
Mechanical weedings	30.04	894.27	36.36	4.11	4.64	4.38	6.11	6.26	6.19	0.41
Hand weeding	36.85	1096.07	51.41	5.17	5.84	5.50	7.13	7.31	7.22	0.43
Weedy check	26.29	763.69	29.93	1.31	1.49	1.40	2.29	2.35	2.32	0.38
LSD(p=0.05)	2.79	85.71	3.64	0.59	0.65	0.62	0.96	0.99	0.97	NS

NS- Non-significant; RM: Ready Mix, *fb*: Followed by

sodium, (36.46 cm, 1082.29 cm² per meter row length, and 50.14 g, respectively) and bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfuron (35.89 cm, 1068.86 cm² per meter row length and 49.39 g, respectively). Among the various weed management treatments hand weeding at 20, 40 and 60 days after sowing as recorded significantly highest grain (5.50 t/ha) and straw yield (7.22 t/ha) compared to all the treatments. But, it was statistically at par with pre-emergence application of bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium, (5.39 and 7.16 t/ha, respectively) and bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfuron (5.29 and 7.03 t/ha, respectively). It is primarily due to effective management of weeds, which lead to enhance the growth and yield parameters of dry direct-seeded rice. These results were found in conformity with Singh *et al.* (2016) and Yogananda *et al*. (2017). Whereas, significantly lowest gain yield (1.40 t/ha) and straw yield (2.32 t/ha) was noticed in weedy check due to sever completion by weeds, which affected the growth, nutrient uptake and yield parameters of the crop drastically.

Table 3. Effect of different weed management practices in dry direct-seeded rice on seedling emergence of different categories of weed seeds in soil collected from 0-10 and 10-20 cm depth (pooled data of two years)

Treatment	Total weed seeds (no./kg of soil)							
	0-10 cm soil depth				10-20 cm soil depth			
	Sedges	Grasses	BLW	Total	Sedges	Grasses	BLW	Total
Bensulfuron methyl + pretilachlor *fb* triafamone + ethoxysulfuron	1.18(0.4)	1.89(2.6)	1.78(2.2)	2.47(5.1)	1.22(0.5)	2.04(3.2)	1.96(2.9)	2.75(6.6)
Oxadiargyl *fb* triafamone + ethoxysulfuron	1.56(1.4)	2.45(5.1)	2.48(5.2)	3.55(11.7)	1.76(2.1)	2.65(6.1)	2.72(6.4)	3.95(14.6)
Pendimethalin *fb* triafamone + ethoxysulfuron	1.71(1.9)	2.49(5.2)	2.84(7.1)	3.90(14.2)	1.87(2.5)	2.79(6.8)	2.98(7.9)	4.27(17.2)
Pyrazosulfuron-ethyl *fb* triafamone + ethoxysulfuron	1.63(1.7)	2.36(4.6)	2.68(6.2)	3.66(12.4)	1.88(2.5)	2.64(6.0)	2.87(7.3)	4.10(15.8)
Bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium	1.15(0.3)	1.78(2.2)	1.65(1.7)	2.28(4.2)	1.20(0.4)	1.99(2.9)	1.90(2.7)	2.65(6.1)
Oxadiargyl *fb* bispyribac-sodium	1.47(1.2)	2.18(3.8)	2.29(4.3)	3.19(9.2)	1.78(2.2)	2.39(4.7)	2.41(4.9)	3.57(11.8)
Pendimethalin* *fb* bispyribac-sodium	1.56(1.4)	2.32(4.4)	2.47(5.1)	3.46(10.9)	1.79(2.2)	2.51(5.3)	2.67(6.2)	3.84(13.7)
Pyrazosulfuron ethyl *fb* bispyribac-sodium	1.47(1.2)	2.20(3.9)	2.21(3.9)	3.15(8.9)	1.73(2.0)	2.40(4.8)	2.38(4.7)	3.53(11.4)
Pendimethalin* *fb* penoxsulam + cyhalofop-butyl	1.77(2.2)	2.65(6.1)	2.95(7.7)	4.12(15.9)	1.92(2.7)	2.97(7.8)	3.09(8.6)	4.48(19.1)
Mechanical weedings	1.73(2.0)	2.45(5.1)	2.68(6.2)	3.77(13.3)	1.88(2.6)	2.75(6.7)	2.81(6.9)	4.13(16.1)
Hand weedings	1.15(0.3)	1.61(1.6)	1.60(1.6)	2.12(3.5)	1.20(0.4)	1.88(2.6)	1.83(2.4)	2.53(5.4)
Weedy check	1.90(2.6)	2.89(7.4)	3.16(9.0)	4.47(19.0)	2.13(3.6)	3.23(9.4)	3.25(9.6)	4.85(22.6)
LSD (p=0.05)	0.14	0.27	0.16	0.22	0.16	0.24	0.18	0.22

Data within the parentheses are original values; Transformed values - # = log $\sqrt{x+2}$, + = square root of $(\sqrt{x+1})$. BLW = Broad -leaved weeds , RM: Ready Mix, *fb*: Followed by

Soil weed seedbank

The hand weeding at 20, 40 and 60 DAS in dry-DSR has resulted in lower number of weeds (0.3, 1.6, 1.6 and 3.5; and 0.4, 2.4, 2.6 and 5.4 number of sedges, grasses, broad-leaved weeds seed and total weeds seed/kg soil, respectively) at 0-10 and 10-20 cm depth of soil. It was statistically at par with PE of bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium (0.3, 2.2, 1.6 and 3.5; and 0.4, 2.6, 2.4 and 5.4 number of sedges, grasses, broad-leaved weeds seed and total weeds seed/kg soil, respectively at 0-10 and 10-20 cm depth of soil). and application bensulfuron-methyl + pretilachlor as PE *fb* triafamone + ethoxysulfuron (0.4, 2.6, 2.2 and 5.1; and 0.5, 3.2, 2.9 and 6.6 number of sedges, grasses, broad-leaved weeds seed and total weeds seed/kg soil, respectively at 0-10 and 10-20 cm depth of soil). The weedy check recorded significantly the highest no. of weeds seeds, 2.6, 7.4, 9.0 and 19.0; 3.6, 9.4, 9.6 and 22.6 number of sedges, grasses, broad-leaved weeds seeds and total weeds seeds/kg soil, respectively at 0-10 cm and 10-20 cm depth **(Table 3)**.

The significant reduction in weed flora during the crop growth stages arrested the vegetative and reproductive emergence of weeds in the soil this reflected on reducing the weed seedbank in the soil to a greater extent. In unweeded control treatment, the uncontrolled growth of weeds in the field lead to increased weed seed production and seed rain in the soil, thus recorded higher number of weeds/kg of soil. Hawaldar (2011) also reported the similar results in maize crop weed seedbank studies.

In this study, the pre-emergence application of bensulfuron-methyl + pretilachlor *fb* bispyribac-sodium recorded higher growth, yield and was found to be the best herbicide combination for effective reduction of weed flora and also weed seedbank in dry direct-seeded rice.

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Indian Journal of Weed Science 53(4): 367–373, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Effect of different fertiliser levels and herbicide treatments on weeds and wheat

Sarita*, Ishwar Singh[1], M.L. Mehriya[2], U.N. Shukla, Manoj Kumar, H.P. Parewa[3] and P.R. Raiger

College of Agriculture, Agriculture University, Jodhpur, Rajasthan 342304, India

[1]Directorate of Extension Education, Agriculture University, Jodhpur, Rajasthan 342304, India

[2]Agricultural Research Station, Mandor, Jodhpur 342304 Rajasthan, India

[3]College of Agriculture, Sumerpur, Pali, Rajasthan 306902, India

**Email: saritachoudhary739@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00068.X

Type of article: Research article

Received : 26 July 2021
Revised : 21 October 2021
Accepted : 23 October 2021

KEYWORDS

Clodinafop-propargyl, Metsulfuron-ethyl, Economics, Fertiliser management, Ready-mix herbicide, Weed management, Wheat

ABSTRACT

A field experiment was conducted during (winter) *Rabi* seasons of 2018-19 and 2019-20 at College of Agriculture, Jodhpur, Rajasthan with an objective to assess the effect of three fertiliser levels and seven weed management treatments on weeds and wheat to maximise productivity and profitability of wheat (*Triticum aestivum* L.) by effective and economical weed management. The total weed density was not influenced by increase in fertiliser rate. Significantly minimum weed biomass was recorded with the application of 75% of recommended dose of fertilisers (RDF) (90-30 kg N-P/ha). The 100% RDF (120-40 kg N-P/ha) application recorded significantly higher weed biomass, wheat growth indices (wheat growth rate, leaf area index net assimilation rate), grain, straw and biological yield than75% RDF and was at par with 125% RDF (150-50 kg N-P/ha). The post-emergence application (PoE) of clodinafop-propargyl 15% + metsulfuron-methyl 1% (ready-mix) 64 g/ha and sulfosulfuron 75% + metsulfuron-methyl 5% (ready-mix) 32 g/ha resulted in higher weed control efficiency, lower weed index with higher value of crop resistance index (CRI) and herbicide efficiency index (HEI). The use of 100% RDF with clodinafop-propargyl + metsulfuron-ethyl (ready-mix) 64 g/ha PoE recorded higher net returns and maximum B:C ratio.

INTRODUCTION

Wheat is the 2nd staple food crop, next to rice, in India with acreage and production of 30.60 Mha and 107.18 mt, respectively (GOI 2021). In Rajasthan, it is cultivated on 3.50 Mha area with production of 13.88 MT and productivity of 3971 kg/ha (Commissionerate of Agriculture 2021). Weeds are major constraints in wheat production and they reduce productivity by 42.8% (Singh and Singh 2004) due to competition and allelopathy. Weeds cause 17–30% losses in wheat annually (Bisen *et al.* 2006). Thus, the weeds management is a basic requirement for higher production in the wheat production system. Hand weeding which is very effective but it is not only laborious and insufficient but also expensive and accounts for about 25% of total labor force used which amounts to about 900–1200-man hours/ha (Nadeem *et al.* 2008, Nag and Dutt 1979). The manual weeding is not feasible in narrow row crops. Thus, herbicides usage is most commonly used, reliable, quick, more effective, time and labour-saving method (Kumar 2009) for managing weeds in wheat. Due to complexity and diversity of weed flora, more than one herbicide is required either in sequence or as mixture for weed management. Weed management is likely to become more complex due to increase in their invasiveness, herbicides resistance in weeds, weed shifts and their residue hazards under changing climate (Barman *et al.* 2014). Selective herbicides control limited weed species but may not be useful on complex of weed flora. There is ample scope for controlling weeds by application of post-emergence herbicides mixtures.

Alfisols of Western Rajasthan are deficient in nitrogen and phosphorus nutrients and farmers supply these nutrients in the form of fertilizers for normal growth and development of plants. Nitrogen is the important nutrient and its deficiency often limits crop production. Weed density, diversity index and community structure of farmland are significantly affected by soil nutrient content. Manipulation of crop fertilization is a promising cultural practice to reduce weed interference in crops so that nutrient uptake by crops can be maximized and increase the competitive ability of crops against weeds. Fertilizer usage increases crop yield and it is associated with simultaneous increase in the weeds growth with enhanced uptake of nitrogen, phosphorus and potash by weeds compared to wheat crop. Thus, weed management is critical for optimal wheat yield to enable crop to use applied nutrient resources. The efficacy of herbicides on weeds is influenced by several variables, including weed biology, weed ecology, soil fertility, soil moisture and selected nutrients usage. Thus, the present study was conducted to identify effective and economically viable dosage rates of fertilizers and herbicides for managing weeds and enhancing the productivity of wheat.

MATERIALS AND METHODS

The field experiment was carried out during two consecutive *Rabi* (winter) seasons of 2018-19 and 2019-20 at the Instructional Farm, College of Agriculture-Jodhpur, Rajasthan, India. Geographically, it is located between 26° 15' N to 26° 45' North latitude and 73° 00' E to 73° 29' East longitude at an altitude of 231 meters above mean sea level. This region falls under agro-climatic zone Ia (Arid Western Plains Zone) of Rajasthan. The average annual rainfall is about 367 mm and bulk of it (85 to 90 %) is received from June to September (rainy season) by the South-West monsoon. The mean daily maximum and minimum temperatures varied between 20 to 28.8 °C and 10.1 to 20.0 °C, respectively in 2018-19 and the corresponding values in the year 2019-20 were 15 to 25.9 °C and 5.4 to 18.0 °C during the crop growing seasons. The soil of the experimental fields was loamy sand in texture, slightly alkaline in soil reaction, low in organic carbon (0.12 to 0.14%), low available nitrogen (174 to175 kg/ha), medium available phosphorus (20.3 to 21.0 kg/ha), high in available potassium (324 to 325 kg/ha). Wheat variety '*GW 11*' was sown at a row to row spacing of 22.5 cm using 100 kg seeds/ha on 20 November 2018 and 18 November 2019.

The experiment was laid out using split plot design with three replications. The treatments comprised of three levels of fertiliser application in main plots viz., 75% of recommended dose of fertiliser (RDF) (90-30 kg N-P/ha), 100% of RDF (120-40 kg N-P/ha) and 125% of RDF (150-50 kg N-P/ha)] and seven different weed management treatments in sub plots *viz*., post-emergence application (PoE) of trisulfuron 15 g/ha at 35 days after seeding (DAS), sulfosulfuron 75% + metsulfuron-methyl 5% (ready-mix) 32 g/ha PoE at 35 DAS, clodinafop-propargyl 15% + metsulfuron-methyl 1% (ready-mix) 64 g/ha PoE at 35 DAS, carfentrazon 20 g/ha PoE at 35 DAS, metsulfuron-methyl 4 g/ha PoE at 35 DAS, weedy check and weed free. Fertiliser rates were applied using DAP and urea as a source of P and N. Half of N and full dose of P were applied as basal dose at the time of sowing. Remaining quantity of N was applied as top dressing in standing crop through urea in two equal split doses at the time of first and second irrigation. All the tested herbicides were applied at 35 DAS using flat fan nozzle & foot sprayer with spray volume of 600 litres of water per hectare. Weed free plots were weeded regularly to keep them weed free throughout the crop period.

The observations on total weed density (number/m^2) and weed dry weight (weed biomass) (g/m^2) was recorded under each treatment with the help of 0.25 m^2 quadrat and presented as per m^2. Data on total weed density and biomass were transformed using ($\sqrt{(x+0.5)}$ for comparison of treatments. Weed control efficiency (WCE), weed index (WI), herbicide efficiency index and (HEI) crop resistance index (CRI), leaf area index (LAI), crop growth rate (CGR) and net assimilation ratio (NAR) was calculated by using the standard formulae. The experimental data recorded in various observations were statistically analysed in accordance with the 'Analysis of Variance' technique as described by Panse and Sukhatme (1985). The least significant difference (LSD) was calculated for the comparison among treatments where ever the variance ratio (F test) was found significant at 5% level of probability. To elucidate the nature and magnitude of treatments effects, summary tables along with LSD (p=0.05) were prepared.

RESULTS AND DISCUSSION

Effect on weed density and biomass

Weed flora of the experimental field consisted of *Chenopodium murale, Chenopodium album, Rumex dentatus, Asphodelus tenuifolius, Melilotus alba, Melilotus indica, Fumaria parviflora, Cynodon dactylon, Launaea asplenifolia* and *Cyperus rotundus* during both the years of experimentation. The broad-leaved weeds were more dominant than grassy and sedge weeds.

The total weed density recorded (**Table 1**) at 35 and 50 DAS was not affected significantly by fertiliser levels during both the years. Application of 75% RDF resulted in significantly lower weed biomass at 50 DAS (16.01 and12.33 g/m^2). The increase fertiliser rates up to 125% significantly increased weed biomass at 50 DAS during both the years. An increase in weed biomass of 18.18 and 23.79% in the first year and 12.58 and 29.11% in second year was observed at 50 DAS with 125% RDF when compared to 100% and 75% RDF, respectively. This increase in weed biomass with increasing fertiliser dose might be attributed to better growth environment due to ample availability of nutrients both for weeds and wheat as reported by Chauhan *et al.* (2017) and Gupta *et al.* (2019). Balasubramanian and Palaniappan (2004) observed that additional fertilizer application may benefit weeds to a higher extent than crop because nutrient absorption is faster and higher in weeds than in crop plants.

All herbicidal treatments significantly reduced weed density and biomass compared with weedy check plot (control) which recorded maximum weed density and biomass (**Table 1**). Among herbicides, clodinafop-propargyl + metsulfuron-methyl (ready-mix) at 64 g/ha PoE proved most effective in lowering weed density 8.89 and 5.22/m^2 and biomass at 50 DAS 7.94 and 6.16 g/m^2 during 2018 and 2019, respectively. It remained at par with sulfosulfuron + metsulfuron-methyl (ready-mix) 32 g/ha PoE. The metsulfuron-methyl 4 g/ha PoE was next best in minimising weed biomass. A significant reduction in weed density (95.46 and 96.91% in first and second season, respectively) and biomass (85.91 and 85.76% in first and second season, respectively) was observed with clodinafop-propargyl + metsulfuron-methyl (ready-mix) 64 g/ha PoE, over weedy check. Metsulfuron-methyl was effective in managing weeds of wheat due to greater dominance of broad-leaved weeds in the experimental field. The use of broad-spectrum herbicidal combinations was proven more effective as it gave complete control of weeds associated with wheat as reported earlier by Singh *et al.* (2015) and Bharat *et al.* (2012).

Effect on weed indices

The highest weed control efficiency (**Table 2**) was achieved by clodinafop-propargyl + metsulfuron-methyl (ready-mix) 64 g/ha PoE (90.37%) during first season while in second season it was recorded with sulfosulfuron + metsulfuron-methyl (ready-mix) PoE 32 g/ha (92.47%). Similar reports were made by Kumar *et al.* (2012); Malik *et al.* (2013) and Raj *et al.* (2020).

The lowest weed index of 1.40 and 2.40% were recorded by application of clodinafop-propargyl + metsulfuron-methyl (ready-mix) 64 g/ha PoE whereas the second lowest weed index of 7.15 and 3.08% was recorded with sulfosulfuron + metsulfuron-methyl (ready-mix) 32 g/ha PoE during 2018 and 2019, respectively. Weed index is an ideal framework to depict yield loss caused by weed infestation in comparison with weed free plots (Suria *et al.* 2011) and a minimum value of weed index means high herbicide efficiency resulting higher yield of wheat. The clodinafop-propargyl + metsulfuron-methyl (ready-mix) PoE 64 g/ha produced highest

Table 1. Effect of fertilizer rates and weed management treatments on total weed density and biomass

Treatment	Total weed density (no./m^2)				Total weed biomass (g/m^2)			
	Before spray (35 DAS)		After spray (50 DAS)		Before spray (35 DAS)		After spray (50 DAS)	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Fertiliser level (N:P) kg/ha								
75% recommended dose of fertilisers (RDF) (90:30)	10.44(125)	10.25(120)	6.05(56.1)	5.38(45.9)	3.61(14.1)	3.31(11.7)	3.60(16.0)	3.17(12.3)
100% RDF (120:40)	10.70(131)	10.19(119)	6.20(56.6)	5.65(50.2)	4.22(19.4)	3.56(13.6)	3.71 (16.8)	3.41(14.1)
125% RDF (150:50)	10.97(137)	10.41(124)	6.22(59.5)	5.59(48.2)	4.28(20.1)	3.65(14.4)	3.96(19.8)	3.61(15.9)
LSD (p=0.05)	NS	NS	NS	NS	0.272	0.202	0.177	0.199
Weed management								
Trisulfuron 15 g/ha 35 DAS	12.47(155)	11.84(140)	11.06(123)	9.71(94.9)	4.64(21.3)	3.90(14.8)	5.09(25.6)	4.75(22.4)
Sulfosulfuron + metsulfuron-methyl 32 g/ha at 35 DAS	11.94(147)	12.13(143)	2.83(7.6)	2.30(4.9)	4.72(22.2)	3.94(15.2)	2.95(8.2)	2.53(6.0)
Clodinafop-propargyl + metsulfuron-methyl 64 g/ha at 35 DAS	12.23(150)	11.76(138)	3.04(8.9)	2.38(5.2)	4.50(20.1)	3.70(13.2)	2.90(7.9)	2.57(6.2)
Carfentrazon 20 g/ha at 35 DAS	12.71(161)	12.10(147)	6.63(43.6)	7.09(50.0)	4.73(22.1)	4.16(17)	3.77(13.8)	3.64(12.8)
Metsulfuron-methyl 4 g/ha at 35 DAS	12.45(155)	11.76(138)	4.84(23.0)	3.60(12.6)	4.37(18.8)	4.06(16.1)	3.36 (10.8)	2.95(8.2)
Weedy check	12.20(149)	11.86(141)	13.99(196)	12.99(169)	4.58(20.6)	4.09(16.3)	7.53(56.4)	6.61(43.3)
Weed free	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71(0)	0.71 (0)
LSD (p=0.05)	0.647	0.629	0.266	0.347	0.264	0.208	0.164	0.195

*Original values given in parentheses was subjected to square root transformation ($\sqrt{(x+0.5)}$) before analysis; DAS: days after seeding

HEI (0.228 and 0.215) (**Table 2**) in both the study seasons. These results corroborate the findings of Khaliq *et al.* (2011). A higher HEI value indicates greater efficiency of the weed management treatment. Maximum crop resistance index at harvest was also recorded with clodinafop-propargyl + metsulfuron-methyl (ready-mix) 64 g/ha PoE closely followed by sulfosulfuron + metsulfuron-methyl (ready-mix) 32 g/ha PoE and metsulfuron-methyl 4 g/ha PoE.

Effect on wheat growth indices

The CGR, LAI and NAR are the important growth parameters influencing yield which are dependent not only on the genotype but also on the environmental and fertility management practices. Different levels of fertility and herbicidal treatments depicted a positive influence on wheat growth analysis parameters, *viz*., CGR, LAI, and NAR (**Table 3**). The maximum values of these growth indices were recorded with the 125% fertility level followed by 100% RDF. The significantly higher value of CGR at 35-50 DAS (23.74 and 23.58 g/m^2/day) and at 50-75 DAS (16.66 and 17.49 g/m^2/day) was recorded in case of 100% RDF over 75% RDF. Application of 125% RDF registered highest LAI *i.e.,* 4.08 and 4.57 which were on par with 100% RDF. These findings were in close agreement with the finding of Shukla and Warsi (2002); Laghari *et al.* (2010); Chatterjee *et al.* (2016). Sharma *et al.* (2012) and Parewa *et al.* (2018) also reported that higher fertility levels, adequate supply of nutrients favoured the nutrient uptake and nutrient utilization towards protein which favoured vertical and lateral growth of the crop plants and ultimately increased the area of leaves, as evident from significant increase in leaf area index with increasing fertility levels.

Among herbicides, the maximum crop growth rate between 35-50 and 50-75 DAS was recorded with application of clodinafop-propargyl + metsulfuron-methyl PoE 64 g/ha (22.29 and 16.40 g/m^2/day) and it was at par with metsulfuron-methyl 4 g/ha PoE (21.45 and 19.35 g/m^2/day) and

Table 2. Effect of weed management treatments on weed control efficiency, weed index, herbicide efficiency index and crop resistance index

Treatment	Weed control efficiency (%)		Weed index (%)		Herbicide efficiency index		Crop resistance index at harvest	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Trisulfuron 15 g/ha at 35 days after seeding (DAS)	67.44	70.63	24.98	22.56	0.098	0.113	3.72	4.12
Sulfosulfuron + metsulfuron-methyl 32 g/ha at 35 DAS	89.92	92.47	7.15	3.08	0.198	0.204	14.76	19.79
Clodinafop-propargyl + metsulfuron-methyl 64 g/ha at 35 DAS	90.37	92.28	1.40	2.40	0.228	0.215	15.44	19.86
Carfentrazon 20 g/ha at 35 DAS	85.12	84.56	20.05	18.18	0.143	0.145	8.65	8.05
Metsulfuron-methyl 4 g/ha at 35 DAS	87.37	88.75	10.34	9.03	0.202	0.203	10.40	11.83
Weedy check	0.00	0.00	33.84	32.53	0.000	0.000	1.00	1.00
Weed free	100.00	100.00	0.00	0.00	0.237	0.224	0.00	0.00

Table 3. Effect of fertiliser levels and weed management treatments on crop growth rate, leaf area index and net assimilation rate

Treatment	CGR (g/m^2/day)				LAI		NAR (g/m^2 leaf area/day)	
	35-50 DAS		50-75 DAS		75 DAS		50-75 DAS	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Fertiliser levels (N:P) kg/ha								
75% recommended dose of fertilisers (RDF) (90:30)	10.27	9.56	9.55	10.08	3.19	3.67	4.05	3.55
100% RDF (120:40)	23.74	23.58	16.66	17.49	3.79	4.22	5.84	5.29
125% RDF (150:50)	24.69	24.75	16.83	17.66	4.08	4.57	5.72	5.04
LSD (p=0.05)	2.273	2.242	5.903	5.733	0.45	0.42	2.405	1.795
Weed management								
Trisulfuron 15 g/ha at 35 days after seeding (DAS)	17.82	17.56	11.15	12.04	3.62	4.05	4.39	3.88
Sulfosulfuron + metsulfuron-methyl 32 g/ha at 35 DAS	21.43	21.47	16.10	16.49	3.88	4.36	5.52	4.81
Clodinafop-propargyl + metsulfuron-methyl 64 g/ha at 35 DAS	22.29	23.02	16.40	16.59	3.79	4.32	5.70	4.90
Carfentrazon 20 g/ha at 35 DAS	18.74	18.51	14.46	15.21	3.60	4.21	5.36	4.65
Metsulfuron-methyl 4 g/ha at 35 DAS	19.35	19.32	15.96	16.02	3.91	4.30	5.30	4.67
Weedy check	13.68	13.09	9.16	10.74	2.87	3.40	4.57	4.33
Weed free	23.65	22.13	17.19	18.45	4.12	4.47	5.57	5.23
LSD (p=0.05)	3.392	3.627	4.565	4.358	0.37	0.45	1.794	1.540

sulfosulfuron + metsulfuron-methyl (ready-mix) 32 g/ha PoE (21.43 and 19.33 g/m^2/day) during 2018-19 (**Table 3**). Similar pattern of CGR was observed during second season of study. The maximum LAI (4.12 and 4.47) was obtained under weed free treatment during both the seasons (**Table 3**). Among herbicidal treatments, highest leaf area index was recorded with metsulfuron-methyl 4 g/ha (3.91) in 2018 and with sulfosulfuron + metsulfuron-methyl (ready-mix) 32 g/ha (4.36) in 2019. These results were closely in conformity with previous study of Kumar *et al*. (2018). Application of clodinafop-propargyl + metsulfuron-methyl (ready-mix) PoE 64 g/ha resulted in highest NAR however, it was at par with all other treatments except metsulfuron-methyl at 4 g/ha and weedy check during first year. During second year, all herbicides were on par to each other. Our results were in closed conformity with the findings of Meena *et al*. (2019) and Mishra *et al*. (2016).

Effect on wheat grain, straw and biological yield

Application of 125% RDF gave significantly higher grain yield and it was at par with 100% RDF, during both the years (**Table 4**). The increasing RDF from 75-100% resulted in significant improvement in grain yield by 23.5 and 18.6%, respectively during first and second season. The increase in fertiliser level from 100-125% RDF did not influence the grain yield. The straw yield increased significantly upto100% RDF during first season and upto125% during second season The application of 100% RDF resulted in higher straw yield by 21.2% over 75% RDF during 2018-19. In second season, 14.2 and 25.20%, increase in straw yield was observed with increased fertiliser dose from 75-100% RDF and 100-125%, respectively. An increase in total biomass of 16.4 and 24.9% in first and second season, respectively was recorded when the fertiliser rate was increased from 75% RDF to 125% RDF. There was no significant difference in harvest index among all fertility levels during both seasons. Adequate availability of nitrogen and phosphorus in soil at the time of tillering might have resulted in higher numbers of tillers. The higher yield attributes might also be due to better availability of nitrogen resulting faster translocation of photosynthates from leaves to sink site *i.e.* spike and grain via stem. (White and Veneklaas 2012). Similar observations of higher grain yield with increased fertiliser dose were made by Samimi and Thomas (2016); Chauhan *et al.* (2017); Jat *et al.* (2013) and Nadeem *et al.* (2016).

The clodinafop-propargyl + metsulfuron-methyl (ready-mix) 64 g/ha PoE gave grain yield that was at par with weed free check and sulfosulfuron + metsulfuron-methyl (ready-mix) 32 g/ha PoE during first year. In second year, clodinafop-propargyl + metsulfuron-methyl (ready-mix) 64 g/ ha PoE was at par with sulfosulfuron + metsulfuron-methyl (ready-mix) 32 g/ha PoE (4.32 t/ha) and metsulfuron-methyl (ready-mix) 4 g/ha PoE (4.13 t/ha). Significantly negative correlation (r = - 0.812 and - 0.828) was observed between grain yield and weed biomass at 50 DAS (**Figure 1**).

Economic analysis

Higher net returns were recorded with 100% RDF (₹ 69,775/ha) and B:C ratio (2.67) during first

Table 4. Effect of fertiliser levels and weed management treatments on wheat grain, straw and biological yield and harvest index

Treatment	Wheat grain yield (t/ha)		Wheat straw yield (t/ha)		Biological yield (t/ha)		Harvest index (%)	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Fertiliser level (N:P) kg/ha								
75% recommended dose of fertilisers (RDF) (90:30)	3.29	3.46	4.18	4.35	7.47	7.82	44.01	44.23
100% RDF (120:40)	4.06	4.11	5.07	4.97	9.13	9.08	44.41	45.22
125% RDF (150:50)	3.93	4.31	4.77	5.45	8.70	9.76	45.14	44.04
LSD (p=0.05)	0.41	0.40	0.52	0.47	0.92	0.48	NS	NS
Weed management								
Trisulfuron 15 g/ha at 35 days after seeding (DAS)	3.27	3.52	4.17	4.40	7.44	7.91	43.95	44.42
Sulfosulfuron + metsulfuron-methyl 32 g/ha at 35 DAS	4.06	4.32	4.98	5.41	9.04	9.73	44.87	44.34
Clodinafop-propargyl + metsulfuron-methyl 64 g/ha at 35 DAS	4.32	4.43	5.26	5.50	9.58	9.94	45.00	44.52
Carfentrazon 20 g/ha at 35 DAS	3.49	3.72	4.42	4.65	7.91	8.37	44.15	44.37
Metsulfuron-methyl 4 g/ha at 35 DAS	3.92	4.13	4.84	5.05	8.75	9.18	44.77	44.94
Weedy check	2.89	3.06	3.67	3.92	6.56	6.98	44.06	43.87
Weed free	4.37	4.54	5.38	5.55	9.74	10.09	44.82	45.03
LSD (p=0.05)	0.34	0.36	0.38	0.39	0.67	0.67	NS	NS

Table 5. Effect of fertiliser levels and weed management treatments on economics of wheat

Treatment	Net returns (x10^3 `/ha)		B:C ratio	
	2018-19	2019-20	2018-19	2019-20
Fertiliser level (N:P) kg/ha				
75% recommended dose of fertilisers (RDF) (90:30)	49.89	57.19	2.22	2.42
100% RDF (120:40)	69.78	73.50	2.67	2.78
125% RDF (150:50)	64.53	79.78	2.52	2.90
LSD (p=0.05)	11.20	7.70	0.27	0.19
Weed management	0.00	0.00		
Trisulfuron 15 g/ha at 35 days after seeding (DAS)	50.63	59.71	2.27	2.52
Sulfosulfuron + metsulfuron-methyl 32 g/ha at 35 DAS	70.08	81.51	2.71	3.01
Clodinafop-propargyl + metsulfuron-methyl 64 g/ha at 35 DAS	76.96	84.36	2.88	3.08
Carfentrazon 20 g/ha at 35 DAS	56.27	65.15	2.40	2.64
Metsulfuron-methyl 4 g/ha at 35 DAS	67.58	76.52	2.70	2.94
Weedy check	40.96	48.14	2.05	2.25
Weed free	67.33	75.69	2.29	2.46
LSD (p=0.05)	8.56	9.12	0.20	0.22

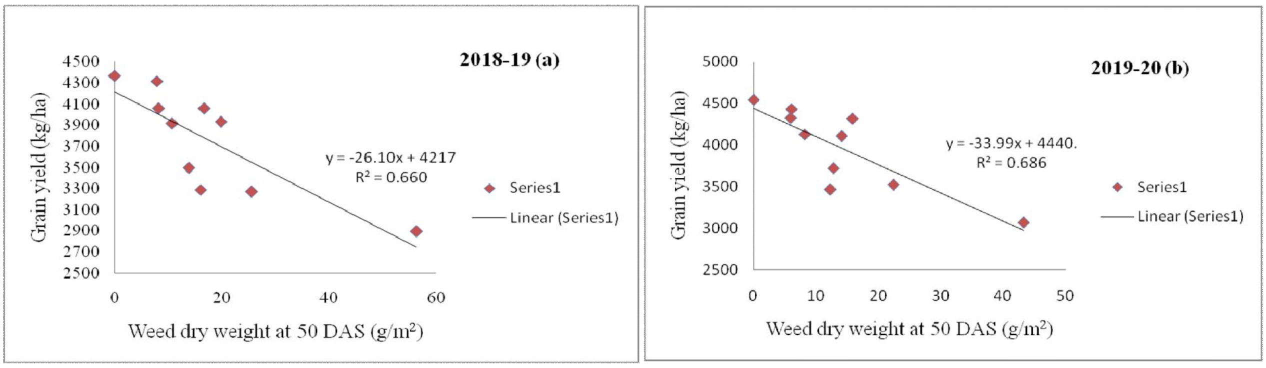

Figure 1. The linear regression between grain yield and weed biomass at 50 days after seeding during a: 2018-19 and b: 2019-2020

year while in second year, the highest net returns (₹ 79,777/ha) and B:C ratio (2.90) were recorded under application of 125% RDF (**Table 5**). The clodinafop-propargyl + metsulfuron-methyl 64 g/ha PoE recorded maximum net returns of ₹ 76,961/ha and it was at par with sulfosulfuron + metsulfuron-methyl (ready-mix) 32 g/ha PoE during first season. During second season of study, application of clodinafop-propargyl + metsulfuron-methyl (ready-mix) 64 g/ha PoE recorded maximum net returns of ₹ 84,359/ha and was at par with sulfosulfuron + metsulfuron-methyl (ready-mix) 32 g/ha PoE (₹ 81,508/ha) and metsulfuron-methyl 4 g/ha PoE (₹ 76,523/ha). Application of 100% RDF recorded B: C ratio of 2.67 and 2.78 in 2018-19 and 2019-20, respectively. The cost was reduced in herbicidal treatments due to lesser use of human labour.

The post-emergence application of clodinafop-propargyl 15% + metsulfuron-methyl 1% (ready-mix) 64 g/ha at 35 DAS along and 100% RDF could be used for effective management of weeds and higher productivity of wheat in arid climatic condition of Rajasthan.

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Indian Journal of Weed Science **53**(4): 374–380, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Influence of fertilizer application timing and reduced herbicide dosage on weed infestation and maize grain yield

Emmanuel Oyamedan Imoloame*, Elizabeth Alagbe and Oluwafemi Oluwatosin Lawal

Department of Crop Production, Kwara State University, Malete, Ilorin, Kwara State, Nigeria

**Email: oyaimoloame@yahoo.com*

Article information

DOI: 10.5958/0974-8164.2021.00069.1

Type of article: Research article

Received : 12 July 2021
Revised : 23 November 2021
Accepted : 25 November 2021

KEYWORDS

Atrazine, Herbicides, Hoeing, Maize, Metolachlor, Nigeria, Southern Guinea Savanna, Weed management

ABSTRACT

A field trial was conducted in the southern Guinea savanna of Nigeria during 2018 and 2019 to determine the better time of fertilizer application and identify effective weed management options to manage weed infestation and increase maize grain yield. The treatments consisted of two fertilizer application timings and six weed control treatments. The experiment was a 2 x 6 factorial in a randomized complete block design and replicated three times. The fertilizer application at 0 and 6 weeks after seeding (WAS) was found better than application at 2 and 6 WAS in minimising weeds, however both the application timings had no significant influence on maize grain yield. The formulated ready-mixtures (RM) of metolachlor (373 g) + atrazine (375 g) at 1.5 kg/ha followed by (*fb*) one hoeing at 6 WAS, metolachlor (375 g) + atrazine (373 g) at 1.5 kg/ha *fb* nicosulfuron 0.03 kg/ha at 6 WAS, metolachlor + atrazine (RM) 1.5 kg/ha *fb* paraquat 0.7 kg/ha at 6 WAS and metolachlor + atrazine (RM) at 1.5 kg/ha *fb* 2,4-D (900 g) at 1.5 kg/ha significantly (p=0.05) reduced weed infestation by 89.3, 63.8, 48.2 and 39.8%, respectively. The use of metolachlor + atrazine (RM) 1.5 kg/ha *fb* one hoeing at 6 WAS, metolachlor + atrazine (RM) 1.5 kg *fb* nicosulfuron 0.03 kg/ha increased maize grain yield by 82.5 and 69.7%, respectively. These treatment combinations integrated with fertilizer timing application at 0 and 6 WAS may be used for efficient, economical and more eco-friendly management of weeds for increasing maize grain yield.

INTRODUCTION

Nigeria is the 14th largest producer of maize in the world (Shahbandeh 2020) with an annual production in excess of 12 million tons (FAO 2020). Weeds have remained one of the major hindrances to Nigeria's quest for food self-sufficiency and environmental management (Tijani *et al.* 2015). Uncontrolled weed growth causes yield losses of 40 – 89% in maize in the tropics (Chikoye *et al.* 2004 and 2005, Imoloame and Omolaiye 2016). Therefore, weed control is crucial for economical production of maize. In Africa, farmers use hand hoeing to control weeds (Ekeleme *et al.* 2016). However, the use of this method has limitations as a result of high weed pressure in farmers' fields, inadequate and high cost of labour, and cumbersome nature of operation which requires great physical energy exertion. These factors have encouraged farmers in Nigeria to prefer the use of herbicides (Best-Ordinioha and Ataga 2017), due to ease of application and effectiveness for weed control. However, most of the herbicides are indiscriminately applied due to high illiteracy rates among the farmers in Nigeria which is adversely affecting the environment, crop yield and human health (Daniel *et al.* 2019). In order to minimize the effect of high input of herbicide into the environment, there is need to reduce the amount of herbicides that will give effective weed control and higher maize yield.

The time of fertilizer application is one of the factors affecting weed infestation and crop yield (Bin Lukangila 2016). It has been reported that optimum rate and time of application of nitrogen fertilizer can enhance maize yield while reducing environmental pollution (Fernandez *et al.* 2009, Nielsen 2013). The best time of fertilizer application for enhanced yield of maize was reported differently as: 10-15 days after planting (DAP) and 35-40 DAP (Abebe and Feyisa 2017), 2 and 6 WAP (Amali and Namo 2015) and at sowing and 6 WAP (Oyinbe *et al.* 1999). Hence, it is essential to find out the best application time and its interaction effect on weed management method. This study was conducted with an objective of identifying the optimal herbicides dosage integration with optimal time of fertilizer application and hoeing for effective weed control and higher yield of maize.

MATERIALS AND METHODS

A field trial was conducted during 2018 and 2019 at the Teaching and Research Farm of the College of Agriculture, Kwara State University, Malete (Latitude 08^o 71^{1}N and longitude 04^o 44^{1}E) in the southern Guinea savanna of Nigeria. The experiment was land out in 2 x 6 factorial in a randomized complete block design (RBCD) with three replicates. The fertilizer application timing was assigned to the main plot, while six weed control treatments were in the sub-plots. There were two fertilizer application timings as main plots: i. Fertilizer applications at seeding and 6 weeks after seeding (WAS) and ii. fertilizer application at 2 and 6 WAS. The weed control treatments tested, in the sub-plots, were: pre-emergence application (PE) (a day after seeding) of formulated ready mixture (RD) of metolachlor (373 g) + atrazine (373 g) 1.5 kg/ha followed by (*fb*) one hoeing at 6 WAS; metolachlor (373 g) + atrazine (373 g) 1.5 kg/ha PE *fb* post-emergence application (PoE) of 2, 4-D 1.5 kg/ha, metolachlor (373 g) + atrazine (373 g) (RM) 1.5 kg/ha PE *fb* nicosulfuron 0.03 kg/ha PoE, metolachlor (373 g) + atrazine (373 g) (RM) 1.5 kg/ha PE *fb* paraquat 0.7 kg/ha PoE; hoeing twice (HTW) at 3 and 6 WAS and a weedy check. Each of the sub plot in this experiment was of 3m x 3m.

Maize (*SUWAN 1-SR*) was seeded on the 11th and 26th of July, 2018 and 2019 respectively. Emerged seedlings were thinned to two plants per stand spaced at 60 × 60 cm at 3 WAS to maintain 55,555 plants/ha. NPK 15:15:15 and urea fertilizers were used for application to each plot for providing the required nutrients (120 kg N, 60 kg P, 60 kg K) to maize, which was applied in equal split doses. The first dose was applied at planting and at 2 WAS while the second dose was applied at 6 WAS. The pre-emergence application (PE) of formulated mixture of metolachlor + atrazine was applied a day after seeding, while all the post-emergence application (PoE) of nicosulfuron, paraquat and 2,4-D was done at 6 WAS. Harvesting of the mature maize was done on the 8th and 17th of November, 2018 and 2019, respectively. The parameters measured were weed density, weed dry matter (weed biomass), weed cover score, maize plant height, leaf area, 100 seed weight and grain yield.

The weed density (no./m^2**)** was measured at 6 and 12 WAS by counting the total number of weed species occurring within 1.0 m^2 quadrat placed randomly at three locations within each sub-plot. In order to measure weed dry weight (weed biomass) (g/m^2), weed species in a 1.0 m^2 quadrat placed randomly at three locations within each plot were uprooted at 6 and 12 WAS, gathered together and oven-dried at 80^{o}C for two days before weighing. Weed cover was visually assessed at 6 and 12 WAS, using a scale of 1 to 10, where 1 represents no weed cover and 10 complete weed cover.

The maize plant height (cm) was measured from five randomly selected maize plants in a plot and was measured from the soil level to the apex of the tassel at 9 and 12 WAS. The leaf area (cm^2) was obtained by measuring the length and width of leaves from five randomly selected plants from each plot and the average of these measurements was multiplied by a factor of 0.75 to give the leaf area per plant. The100 seed- weight (g) was determined by weighing 100 grains of maize (at 13% moisture content) taken from the maize grains harvested from each sub-plot. The maize grain yield (kg/ha) was weighed to obtain grain yield per net plot which were converted to grain yields per hectare.

Some of the information used for the economic assessment was obtained from the Kwara State Agricultural Development Programme, an agency responsible for agricultural extension Services in Nigeria, while the selling price of maize was obtained from the open market. These, information was used to calculate the production cost (PC), revenue (R) and gross margin (GM).

Production cost (PC) = the cost of inputs and farm operations used (Eni *et al.* 2013). These were cost of seeds, herbicides, insecticides, fertilizers, land preparation, labour for planting, herbicide and insecticide application, weeding, fertilizer application, harvest and processing operations.

$PC = PC_1 + PC_2 + PC_3 + \text{———} PCn$———— (1)

Gross revenue (GR) = Crop yield (Y) × Open market price (P)—(2)

Gross margin/Net revenue (NR) = Gross revenue (GR)- Production cost (PC)————(-3)

Benefit-cost ratio= GR/PC ——————(4)

All data were subjected to analysis of variance (ANOVA) using SAS statistical package. Significant differences among treatment means were determined using Tukey Honestly Significant Difference (HSD) test at 5% level of probability.

RESULTS AND DISCUSSION

The total rainfall was 1451.14 and 1432.73mm in 2018 and 2019, respectively. The two peaks of rainfall occurred in May and September during 2018 and in May and June during 2019 (**Figure 1**)

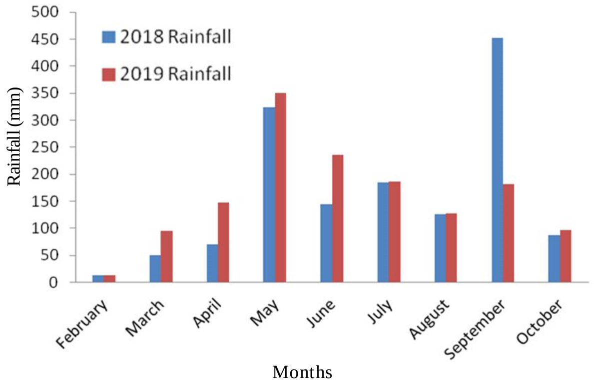

Figure 1. Amount of rainfall (mm) during 2018 and 2019 rainy seasons at the experimental site

Source: Hydrological Section of Lower Niger River Basin and Rural Development Authority, Ilorin, Kwara State, Nigeria

Effect on weeds

The time of fertilizer application had significant ($p \leq 0.05$) effect on weed biomass at 6 WAS in 2018, while having no significant effect on weed biomass in 2019 (**Table 1**). At 12 WAS, fertilizer treatments had significant ($p \leq 0.05$) effect in 2019. Weed dry matter production was significantly ($p \leq 0.05$) higher in the plots treated with fertilizer application at 2 and 6 WAS than those that received fertilizer application at 0 and 6 WAP in 2018 at 6 WAS and in 2019. All the weed control methods significantly ($p \leq 0.05$) reduced weed biomass at 6 WAS in 2018. At 12 WAS, treatment combinations of metachlor + atrazine + one SH, metolachlor + atrazine + nicosulfuron and HTW caused significantly ($p \leq 0.05$) greater reduction in weed biomass in both years of the experiment than metolachlor + atrazine + 2, 4-D and metolachlor + atrazine + paraquat in 2019 and weedy check in both years. Generally, weed biomass recorded in 2018 was significantly ($p \leq 0.05$) lower compared to that in 2019 (**Table 1**). The interaction between fertilizer timing and weed control methods on weed biomass was significant only at 6 WAS in 2018.

Weed density under the two fertilizer timing treatments did not differ significantly at 6 and 12 WAP in both the years. However, there was significant difference ($p \leq 0.05$) in weed density between weed control treatments. All the herbicide treatments, herbicide treatment and one SH and HTW at 3 and 6 WAS significantly ($p \leq 0.05$) brought down the weed population in both the years at 6 WAS (**Table 1**), however, at 12 WAS, metolachlor + atrazine + paraquat reduced weed density significantly which was comparable with the rest of the treatments in 2018, except metolachlor + atrazine + nicosulfuron and the weedy check which had higher weed density. All the weed control treatments were equally effective in significantly reducing weed density compared to the weedy in 2019 (**Table 1**).

Table 1. Effect of time of fertilizer application and weed control treatments on weed biomass, weed density and weed cover score

Treatment	Rates kg/ha	Weed biomass (g/m^2)				Weed density ($no./m^2$)				Weed cover score			
		6 WAS		12 WAS		6 WAS		12 WAS		6 WAS		12 WAS	
		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Time of fertilizer application (TA)													
0 and 6 WAS		283.3b[1]	1739.2a	992.9a	1173.3b	15.0a[1]	34.4a	19.1a	20.4a	5.9a	4.7a	4.7a	4.3a
2 and 6WAS	-	538.5a	1374.6a	856.4a	2020.8a	14.3a	31.4a	18.9a	28.4a	6.3a	4.7a	3.9a	4.7a
Weed control treatment (WC)													
Metolachlor (373 g) + atrazine (373 g) Ready-mix (RM) PE followed by (*fb*) one hoeing at 6WAS	1.5	226.3b	1100.0a	463.6b	133.4b	15.5b	33.0b	17.3bc	10.7b	5.3b	4.0b	2.0c	2.3b
Metolachlor + atrazine (RM)1.5 kg/ha *fb* 2, 4-D 1.5 kg/ha PoE	1.5+1.5	291.8b	1130.7a	902.9b	2458.9a	12.8b	26.5b	17.3bc	25.3b	6.1b	3.3b	4.2b	4.4b
Metolachlor + atrazine (RM)1.5 kg/ha PE *fb* nicosulfuron 0.03 kg/ha PoE	1.5+0.03	283.3b	1194.7a	1029.6b	992.2b	13.3b	34.0b	21.0b	16.8b	6.2b	4.0b	4.5b	3.6b
Metolachlor + atrazine (RM) 1.5 kg/ha PE *fb* paraquat 0.7 kg/ha PoE	1.5+0.7	246.2b	1899.8a	658.4b	2232.2a	12.3b	32.3b	11.5c	11.3b	5.4b	3.9b	3.4bc	3.5b
Hoeing twice at 3 and 6 WAS	-	223,1b	1198.1a	360.2b	314.5b	11.0b	16.2b	16.0bc	14.8b	4.2b	2.8b	1.8c	3.2b
Weedy check		1194.7a	2847.3a	2133.3a	3451.2a	23.0a	55.7a	30.8a	67.5a	9.8a	10.0a	10.0a	10.0a
Year		410.9b	1556.9a	924.7b	1597.6a	14.7b	32.92a	19.0a	24.4a	6.1a	4.7b	4.3a	4.5a
Interaction													
TA x WC		S	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
TA x year		-	-	-	-	-	-	-	-	-	-	-	-
WC x year		-	-	-	-	-	-	-	-	-	-	-	-
TA x WC x year		-	-	-	-	-	-	-	-	-	-	-	-

WAS=Weeks after seeding, 1=means followed by the same letters within a column are not significantly different at 5% level of probability using Tukey HSD test, NS=Not Significant, S=Significant ; PE =Pre-emergence application; PoE =Post-emergence application; WAS =Weeks after seeding

Fertilizer timing had no significant effect on weed cover, while, significant difference occurred in weed cover among different weed control methods (**Table 1**). Significant ($p \leq 0.05$) reduction of weed cover occurred in plots treated with metolachlor + atrazine *fb* one hoeing at 6 WAS, HTW and all the herbicide combinations compared to the weedy check at 6 WAP. At 12 WAS in 2018, HTW was more effective in lowering the weed cover compared to the other weed control treatments but was comparable to metolachlor + atrazine *fb* one hoeing and metolachlor + atrazine *fb* paraquat, but significantly lower than metolachlor + atrazine *fb* 2, 4-D and metolachlor +atrazine *fb* nicosulfuron, while in 2019, all the herbicide combinations and HWT resulted in significantly ($p \leq 0.05$) lower weed cover than the weedy check. The combinations of all the herbicides tested and herbicide *fb* one hoeing could therefore be applied in rotation to provide effective weed control on commercial farms as alternative to two hand weeding, which has been reported to be tedious, inefficient, time consuming and expensive (Adigun *et al.* 2017, Imoloame and Usman 2018). Furthermore, the use of integrated weed management and combinations of reduced herbicide rates are the two ways to reduce the harmful side effects of herbicides and minimize environmental pollution (Zhang *et al.* 2013). Incorporation of broadcast fertilizer into the soil at 2 WAS after pre-emergence herbicides application, opened up the soil to aeration and encouraged more weed growth in plots treated with fertilizer at 2 and 6 WAS compared to those where fertilizer was applied at 0 and 6 WAS. The significantly higher weed infestation in terms of weed density and biomass in the plots in 2019 compared to 2018, could be attributed to higher rainfall recorded before weed samples were taken in 2019 (1027 mm) compared to 2018 (912.62 mm) at 6 WAP and the superior ability of the crops to suppress weeds in 2018 than 2019 due to better growth and higher total amount of rainfall at later stage of crop growth. The interactive effect of the fertilizer application timing at 2 and 6 WAS and weed control treatments significantly increased the level of weed infestation in the weedy check at 6 WAP. The significantly higher growth of weeds in the weedy check could have caused intense weed competition leading to poor growth and performance of maize.

Maize growth and yield

The maize plant height in the plots treated with fertilizer at 2 and 6 WAS was significantly ($p \leq 0.05$) higher than those in plots where fertilizer was applied before sowing and 6 WAS in 2018, while no significant difference in plant height was observed between the two fertilizer treatments in 2019. The maize plant height at 12 WAS did not differ between the two fertilizer treatments (**Table 2**). But all the weed control treatments resulted in significantly ($p \leq 0.05$) taller plants than the weedy check, except metolachlor + atrazine *fb* nicosulfuron in 2018 and metolachlor + atrazine *fb* paraquat in 2019 in which plant height was similar to that in weedy check. Significantly taller maize plants were produced in 2018 than 2019 (**Table 2**). The interaction effect between fertilizer timing and weed control treatment on plant height was significant at 12 WAS in 2019 (**Table 2**). This interaction significantly ($p \leq 0.05$) reduced maize plant height in the weedy check compared to herbicide plus one hoeing, all the herbicide treatments and HTW at 3 and 6 WAS. Crops growing in plots treated with fertilizer at 2 and 6 WAS possessed significantly ($p \leq 0.05$) larger leaf area than those where application of fertilizer was done before planting in both years at 9 WAS (**Table 2**). All the herbicide treatments, herbicide treatment plus one hoing and HWT resulted in significantly ($p \leq 0.05$) larger leaf area of maize compared to the weedy check in 2019 at 9 WAS. Similar trend was recorded in 2019 at 12 WAS, where all the weed control treatments produced maize with significantly ($p \leq 0.05$) larger leaf area than the weedy check. Additionally, the interactive effect of fertilizer timing and weed control methods on leaf area was significant at 9 WAP in 2019. The leaf area of maize in 2018 was significantly larger than maize leaf area in 2019 (**Table 2**).

Promotion of crop growth in terms of greater plant height and leaf area was achieved with fertilizer application at 2 and 6 WAS compared to fertilizer application before planting and 6 WAS. Furthermore, application of fertilizer at 2 and 6 WAS resulted in significantly taller plants than those from plots treated with fertilizer application timing at 0 and 6 WAS in the two years of the experiment, especially at the early and middle stage of crop growth. This could be attributed to the development of maize root system at 2 WAS which enabled the uptake of higher amount of nutrients and water for better performance than the maize plants in the plots treated with fertilizer before planting, where most of the applied fertilizer must have been leached out by rainfall before the germination and root development of maize. This result corroborates the findings of Amali and Namo (2015) that application of fertilizer at 2 WAS significantly increased mean number of leaves per plant, leave area index and plant height. However, this advantage was short-lived at 12 WAS for plant height and leaf area, as both treatments produced crops that were growing at the same rate. All the weed control treatments resulted in better growth compared to the weedy check especially, metolachlor+ atrazine (RM) *fb* one hoeing, HTW, metolachlor +atrazine (RM) *fb* nicosulfuron, metolachlor + atrazine (RM) *fb* paraquat and metolachlor+ atrazine (RM) *fb* 2, 4-D, as they proved effective control of weeds. Similar result was reported by Khan *et al.* (2020) that utmost maize plant height from herbicide treatments were due to availability of nutrients to maize plants in the absence of weeds These combination of reduced herbicide rates could be added to the list of weed control options for better weed management in both small scale and commercial agriculture in Nigeria. The significant interaction effect between fertilizer timing and weedy check on plant height at 12 WAS and leaf area at 9 WAS could have resulted in significantly shorter and narrower-leaved plants in the weedy check. This could be due the encouragement of increased weed growth when broadcast fertilizer was incorporated in the soil at planting in the weedy check, leading to more intense weed competition and poor maize growth.

The time of fertilizer application had no significant effect on 100-seed weight, while in terms of weed control methods, metolachlor + atrazine (RM) *fb* one hoeing produced maize seeds that were comparable with other herbicide combinations but significantly ($p \leq 0.05$) heavier than the weedy check in both years. However, the other treatments except metolachlor + atrazine (RM) *fb* one hoeing resulted in seeds that were not statistically different from the weedy check (**Table 2**). Plots of HWT had yield significantly ($p \leq 0.05$) higher than the weedy check and was at par with the herbicide combinations in 2018, but in 2019, metolachlor + atrazine (RM) *fb* one hoeing resulted in the highest grain yield which was not statistically ($p \leq 0.05$) different from the other treatments except metolachlor + atrazine (RM) *fb* 2, 4-D, metolachlor + atrazine (RM) *fb* paraquat and the weedy check, which produced significantly ($p \leq 0.05$) lower grain yields (**Table 2**). Maize crop produced significantly heavier seeds and grain yields in 2018 compared to 2019 (**Table 2**) probably due to the early planting, lower weed infestation and higher total annual rainfall recorded in 2018. There was no interaction between time of fertilizer application and weed control treatments on seed weight and grain yields. All herbicide combinations especially, metolachlor + atrazine (RM) *fb* one hoeing at 6 WAS, metolachlor + atrazine (RM) *fb* nicosulfuron and HTW at 3 and 6 WAS, gave heavier seeds and grain yield of maize as a result of their ability to provide better selective and season long weed control which minimized weed competition, thus making more growth resources and assimilates available for maize plants for better growth. The low yield in the weedy check could be due to the intense weed competition with the maize plants as reported by Khan *et al.* (2016). Therefore, the afore mentioned weed

Table 2. Effect of time of fertilizer application and weed control method on growth and yield of maize

Treatment	Rates kg/ha	Leaf area (cm^2)				Plant height (cm)				Seed weight(g)		Grain yield (kg/ha)	
		9WAS		12WAS		9WAS		12WAS					
		2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Time of fertilizer application (TA)													
0 and 6 WAS													
2 and 6 WAS	-	302.6b	293.4b	323.0a	295.1a	74.4b[1]	71.6a	198.5a	150.9a	22.2a	18.5a	3010.5a	1449.6a
	-	389.7a	329.3a	326.2a	321.8a	94.4a	71.4a	205.6a	148.8a	22.1a	18.8a	3094.1a	1125.0a
Weed control method (WC)													
Metolachlor (373 g) + atrazine (373 g) PE *fb* hoeing at 6 WAS	1.5	350.3a	306.7a	317.5a	308.4a	84.3a	69.8a	199.8a	151.8a	22.4a	20.5a	3287.0ab	2036.8a
Metolachlor + atrazine (RM) PE *fb* 2, 4-D PoE													
Metolachlor + atrazine (RM) PE *fb*	1.5+1.5	372.5a	336.6a	361.6a	331.5a	93.3a	71.4a	204.1a	153.8a	22.3a	17.7ab	3148.1ab	878.0ab
nicosulfuron PoE				377.3a	344.3a	82.7ab	69.9a	199.4a	161.5a	23.6a	19.7ab	3105.6ab	1616.5ab
Metolachlor + atrazine (RM) PE fb Paraquat PoE	1.5+0.03	350.0a	313.6a	324.5a	310.9a	87.9a	72.3a	209.4a	149.6ab	22.0a	18.9ab	2963.0ab	1065.2abc
Hoeing twice at 3 and 6 WAS	1.5+0.7	338.9a	322.4a	352.1a	349.9a	89.7a	76.6a	203.5a	159.5a	22.3a	17.8ab	3379.6a	1640.1ab
Weedy Check	-	340.7a	350.8a	214.7b	205.8b	69.1b	69.9a	196.3a	123.1b	20.4b	17.3b	2430.6b	486.3c
Year	-	324.3a	238.0b	324.6a	308.5a	84.4a	71.5b	202.1a	149.87b	22.2a	18.7b	3090.3a	1287.3b
		346.1a	311.4b										
Interaction													
TA X WC		NS	S	NS	NS	NS	NS	NS	S	NS	NS	NS	NS
TA X Year		-	-	-	-	-	-	-	-	-	-	-	-
WC X Year		-	-	-	-	-	-	-	-	-	-	-	-
TA X WC X Year		-	-	-	-	-	-	-	-	-	-	-	-

1=means followed by the same letters within a column are not significantly different at 5% level of probability using Tukey HSD test. NS: Not Significant, S: Significant; WAS: Weeks after seeding, *fb*: Followed by; PE: Pre-emergence application; PoE: Post-emergence application management options, metolachlor + atrazine (RM) *fb* one hoeing at 6 WAS, metolachlor + atrazine (RM) *fb* nicosulfuron can serve as alternatives to HTW at 3 and 6 WAS for effective control of weeds on large scale commercial farms. Furthermore, the integration of metolachlor + atrazine (RM) and one hoeing at 6 WAS has reduced the quantity of herbicide used by 25-40% and the integration of metolachlor + atrazine (RM) *fb* nicosulfuron reduced the amount of herbicide used by 25-95% compared to the manufacturer's recommendations. These weed management options are also eco-friendly.

The economic assessment of a combination of fertilizer application timing and weed control treatments on profitability of maize revealed that the combination of fertilizer application timing at 0 and 6 WAS and metolachlor + atrazine (RM) *fb* one hoeing resulted in an average yield (2.79 t/ha) which was at par with the other treatment combinations but significantly ($P < 0.05$) higher than those from a combination of application timing at 0 and 6 WAS *fb* 2 4-D and 0 and 6 WAS *fb* paraquat (1.88 and 1.58 t/ha, respectively) and weed check (1.68 and 1.23 t/ha) (**Table 3**). The combinations of fertilizer timing application of 0 and 6 and 2 and 6 WAS and hoeing twice at 3 and 6 WAS incurred the highest cost of production (₦208,219.3 and ₦ 205,410.4), respectively compared to the other treatment combinations, while the integration of fertilizer timing at 0 and 6 and 2 and 6 WAS and weedy check had the least cost of production (₦ 166,765.6 and ₦ 163,529), respectively. HTW has been reported to be more expensive than chemical or integrated method of weed control in the production of maize (Imoloame 2020). Similarly, the treatment combination of fertilizer application timing at 0 and 6 WAS and metolachlor + atrazine (RM) *fb* one hoeing generated highest gross revenue (₦ 335,028.00) followed by treatment combinations of 0 and 6 WAS and HTW (₦ 326,904.00), 0 and 6 WAS and metolachlor + atrazine (RM) *fb* nicosulfuron (₦ 318,996.00) and 2 and 6 WAS and metolachlor + atrazine *fb* one hoeing (₦ 303,828.00), in the decreasing order of revenue generation. The highest gross margin emanated from treatment combinations of fertilizer timing at 0 and 6 WAS *fb* metolachlor + atrazine (RM) *fb* one hoeing (₦ 151,174.00) and 0 and 6 WAS and metolaclor + atrazine (RM) *fb* nicosulfuron (₦ 134,525.00), while the least gross margin resulted from treatment combination of 0 and 6 WAS and metolachlor + atrazine (RM) *fb* 2, 4-D and 2 and 6 WAS and weedy check (₦ 764.00 and ₦ -11,119.00). The benefit cost ratio was highest in the treatment combinations of 0 and 6 WAS and metolachlor + atrazine *fb* one hoeing (1.748) and 0 and 6 WAS *fb* metolachlor + atrazine (RM) *fb*

Table 3. Economic analysis of the effect of weed control treatments and fertilizer application timing on profitability in maize production

Production activity	0&6WAS* M+A (RB) *fb* 1 H**	2&6WAS M+A (RB) *fb* 1 H	0&6WAS M+A (RB) *fb* 2, 4-D	2&6WAS M+A (RB) *fb* 2, 4-D	0&6WAS M+A (RB) *fb* NS	2&6WAS M+A (RB) *fb* NS	0&6WAS M+A (RB) *fb PQ*	2&6WAS M+A (RB) *fb PQ*	0&6WAS HT 3 and 6 WAS	2& 6WAP HT 3 and 6WAS	0&6 WAS Weedy check	2&6 WAS Weedy check
Land preparation/ha	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
Seed/ha	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000	18,000
Planting/ha	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Fertilizer cost /ha	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000
Application of fert. (1st & 2nd doses)	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000
1st Hoeing at 3 WAS												
2nd hoeing at 6 WAS	-	-	-	-	-	-	-	-	17,000	17,000	-	-
Cost of herbicide/ ha	-	-	-	-	-	-	-	-	17,000	17,000	-	-
Cost of herb. Application/ha	9,000	9,000	9,000	9,000	9,000	9,000	9,000	9,000	-	-	-	-
Cost of pesticide/ha	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	-	-	-	-
Cost of pesticide application	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400	3,400
Labour for processing	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300
	20,000	18,138	19,042	16,415	11,325	15,482	13,489	15,367	19,519	16,440	12065	8,829
Total cost of prod.(₦)	191,700	189,838	190,743	188,115	183025	187182	185,183	187067	208,219	205140	166765	163529
Average yield (kg/ha)	2,792a	2,532a	2,658a	2,291a	1,581b	2,161a	1,883b	2,145a	2,725a	2,295a	1,684b	1,232c
Gross Revenue (₦).	335,028	303,828	318,996	274,980	189,708	259,344	225,960	257,412	326,904	275,400	202,116	147,900
Gross Margin(₦)	151,174	112,128	134,525	86,453	764	69,428	68,051	63,958	121,651	71,694	45,471	-11,119
Benefit/cost ratio	1.748	1.600	1.672	1.462	1.037	1.386	1.382	1.376	1.570	1.342	1.212	0.904

WAS: weed after seeding; *fb*: Followed by; PE: Pre-emergence application; PoE: Post-emergence application; N: Nigeria Naira; Selling price of maize in the open market= N 120 / kg; *Fertilizer application timings: 0&6WAS; 2&6WAS; N =Naira; **Treatments: M+A (RB) fb 1 H = Metolachlor (373g) + atrazine (373 g) Ready-mix (RM) PE followed by (*fb*) one hoeing at 6WAS; M+A (RB) *fb* 2, 4-D = Metolachlor + atrazine (RM)1.5 kg/ha *fb* 2, 4-D 1.5 kg/ha PoE; M+A (RB) *fb* NS = Metolachlor + atrazine (RM)1.5kg/ha PE *fb* nicosulfuron 0.03 kg/ha PoE; M+A (RB) *fb PQ* = Metalachlor + atrazine (RM)1.5 kg/ha PE *fb* paraquat 0.7 kg/ha PoE; HT 3 and 6 WAS = Hoeing twice at 3 and 6 WAS nicosulfuron (1.672). These treatment combinations did not only generate higher gross revenue compared to the other treatments, they resulted in higher gross margin and benefit - cost ratio and are therefore recommended for adoption in the southern Guinea savanna of Nigeria.

It was concluded that both the fertilizer application timings tested *i.e.* at 0 and 6 WAS can be recommended along with metolachlor+ atrazine at 1.5 kg/ha *fb* one hoeing at 6 WAS and metolachlor+ atrazine *fb* nicosulfuron at 0.03 kg/ha at 6 WAS as weed management options for effective weed control, better growth, higher yield and economic returns in maize production in the southern Guinea savanna of Nigeria.

ACKNOWLEDMENT

My appreciation goes to the technologists of Faculty of Agriculture Laboratory, Kwara State University, who assisted in the collection of field data and processing of samples.

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Indian Journal of Weed Science **53**(4): 381–386, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Non suitability of tembotrione and topramezone for weed management in sorghum [*Sorghum bicolor* (L.) Moench]

D. Krishnamurthy*, B. Gangaiah[1] and V.A. Tonapi[1]

All India Coordinated Research Project on Sorghum, Hagari-583 111, University of Agricultural Sciences, Raichur (Karnataka), India

[1]ICAR-Indian Institute of Millets Research, Hyderabad, Telangana, 500 030

Email: murthyagron@gmail.com

Article information

DOI: 10.5958/0974-8164.2021.00070.8

Type of article: Research article

Received : 22 May 2021
Revised : 30 November 2021
Accepted : 2 December 2021

KEYWORDS

Atrazine, Herbicides, Manual weeding, Phytotoxicity, Sorghum, Tembotrione, Topramezone, Weed management

ABSTRACT

A field experiment was conducted during rainy *(Kharif)* seasons of 2019 and 2020 at Hagari, Karnataka, India to assess the efficacy of post-emergence application (PoE) of two HPPD (p-hydroxy-phenyl-pyruvate dioxygenase) enzyme inhibitive herbicides, *viz.* tembotrione and topramezone in combination with pre-emergence application (PE) of atrazine. Among the 10 treatments tested, atrazine 1000 g/ha PE followed by (*fb*) atrazine 1000 g/ha PoE or 2,4-D Na salt 937.5 g/ha PoE or 2, 4-D Ethyl Ester 2368 g/ha PoE at 20 days after sowing (DAS) proved as effective as weed free treatment (hand weeding twice) in increasing the sorghum grain yield and net returns. The topramezone 37.5 and 56.3 g/ha PoE though provided effective weed control, caused phytotoxicity to sorghum resulting in 21 and 39% grain yield reduction and 32 and 74% net return reduction, respectively when compared to atrazine PE applied alone which recorded grain yield of 2.31 t/ha and net return of ₹ 45,007 but it was better than weedy check. The tembotrione 70.3 and 105.5 g/ha PoE also caused reduction of 2.1 and 3.3% in biological yield, 18.6 and 26.1 in grain yield and 19.2 and 63.9% in net returns, respectively and was significantly inferior to weedy check. The crop phytotoxicity of tembotrione resulted in negative herbicide efficiency index (-0.09 to -0.78) and high weed index values (37.32 to 51.7) indicating its non-suitability for use in sorghum. The uncontrolled weeds (weedy check) on an average have caused 32.1, 42.7 and 32.5% reduction in biological yield, grain yield and net returns, respectively when compared to weed free check.

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is the second most extensively grown millet crop of India after pearl millet under rainfed situations during both *Kharif* (rainy) and *Rabi* (winter) seasons. Of the estimated yield potential of 3.31 t/ha in *Kharif* season (Murty *et al.* 2007), farmers on an average (2013-14 to 2017-18) realized only 0.995 t/ha *i.e.* 30.1% of potential yields (Agricultural Statistics at a Glance, 2019). Karnataka, the second leading state of sorghum crop in terms of both area and production (1.09 Mha and 1.14 MT) after Maharashtra (Agricultural Statistics at a Glance 2019) too known for low productivity (1048 kg/ha during 2017-18). This low productivity realization of rain fed sorghum has been ascribed to various biotic and abiotic stresses and among the biotic stresses, weeds continue to be the most important one (Thompson *et al.* 2019, Mishra and Talwar 2020). This is more so during *Kharif* season owing to frequent rains that makes the crop prone to severe weed infestation and sometimes more than a flush of weeds are seen with untimely rains. Studies have indicated that uncontrolled weeds limit *Kharif* grain sorghum yield by 25.1% (Gharde *et al.* 2018) in India. This warrants for an effective weed management solution to achieve higher productivity and profitability. Traditional methods of weed management like animal drawn mechanical inter-row and manual hand weeding (Attalla 2002) though are quite effective, but are costly due to decline in draught animals and manpower availability leading to emergence of herbicides as effective weed management tool. Among herbicides, 2,4-D (Stahlman and Wicks 2000) and atrazine (Sharma *et al.* 2000) have become most commonly used herbicides for grain sorghum crop.

However, 2,4-D is selective to broad-leaved weeds and atrazine has low effectiveness against grasses and sedges (Dan *et al.* 2011) under moisture stress conditions. Further, repeated use of atrazine was found to bring in not only weed shift but also development of herbicide resistance in weeds (Heap 2020). Therefore, alternatives to atrazine are looked at for using in sorghum. The HPPD (p-hydroxy-phenyl-pyruvate dioxygenase) enzyme inhibitive post-emergent herbicides (topramezone and tembotrione) with broad-spectrum weed control, flexible application timing, tank-mix compatibilities, better crop safety (Singh *et al.* 2012) and ability to control triazine resistant weeds (Kohrt and Sprague 2017) have been made available to meet the above needs in maize. Thus, a study was undertaken at All India Coordinated Sorghum Improvement Project (AICSIP) to assess the suitability and efficacy of post-emergence application (PoE) of topramezone and tembotrione herbicides in sequence to the pre-emergence application (PE) of atrazine in grain sorghum grown in *Kharif* (rainy) season.

MATERIALS AND METHODS

A field experiment was conducted during two consecutive *Kharif* (rainy) seasons of 2019 and 2020 under All India Coordinated Sorghum Improvement Project at Agricultural Research Station Farm, Hagari, University of Agricultural Sciences, Raichur, Karnataka, India in grain sorghum. The experimental site was situated at 14° 70' N latitude, 76° 15' E longitude at an altitude of 458 m above mean sea level. The experimental non-saline (EC: 0.38 dS/m) alkaline (8.76 pH) clay soil was rated as medium for organic carbon (0.61%), available N and K (235.6 and 378.8 kg/ha) and high for available P (18.8 kg/ha). The experiment comprised of ten weed management treatments: atrazine 1000 g/ha PE followed by (*fb*) 2,4-D Na Salt 937.5 g/ha PoE at 20 days after seeding (DAS); atrazine 1000 g/ha PE *fb* 2,4-D ethyl ester 2368 g/ha PoE at 30 DAS; atrazine 1000 g/ha PE *fb* topramezone 37.5 g/ha PoE at 25 DAS; atrazine 1000 g/ha PE *fb* tembotrione 70.3 g/ha PoE at 25 DAS; atrazine 1000 g/ha PE *fb* topramezone 56.3 g/ha PoE at 25 DAS; atrazine 1000 g/ha PE *fb* tembotrione 105.5 g/ha PoE at 25 DAS; weed free (hand weeding twice at 15 and 35 DAS) and weedy check. Experiment was laid out in Randomized complete block design (RCBD) with three replications. Sorghum cv. *CSH-25* seed (7.5 kg/ha) was dibbled in rows at 45 cm apart with an inter-plant spacing of 15 cm on 5^{th} July, 2019 and 3^{rd} July, 2020, respectively. Recommended dose of fertilizers and manures (100:33.3:37 kg/ha N: P: K + FYM 5 t/ha) were used in the experiment. FYM was applied 15 days prior to sowing. Entire dose of P and K along with 50% nitrogen in the form of di-ammonium phosphate, muriate of potash and urea, respectively were broadcast applied at the time of sowing. Remaining nitrogen was placed near the hill at 4 weeks after sowing. Recommended package of practices was adopted for crop production and crop was harvested on 21^{st} November, 2019 and 12^{th} November 2020 at physiological maturity. Application of herbicides was done as per treatment using 500 litres of spray volume/ha. The pre-emergence application of atrazine was done immediately after sowing. A rainfall of 517.8 and 528.8 mm was received in 30 and 27 rainy days during 2019 and 2020 crop cycle, respectively.

The species wise weed density (no./m^2) was recorded at 20, 40, 60 DAS and at harvest by placing three quadrats of 0.5 x 0.5 m per plot. The collected weeds were categorized as grasses, sedge and broad-leaved weeds and likewise weed dry weight (biomass) was recorded. Weed control efficiency (WCE) and herbicide efficiency index (HEI) were worked out taking weed biomass and grain yield into consideration, respectively. Weed index was worked out as ratio of grain yield from weed free plot – grain yield from treated plot / yield from weed free plot. The observations on phytotoxicity on sorghum plants were recorded on the basis of phytotoxicity rating scale (PRS) for the applied herbicides at 3, 6, 9 and 12 DAT (days after treatment). The parameters on phytotoxicity were taken as leaf epinasty and hyponasty, necrosis (leaf tips and margins) and wilting. The observation on the level of phytotoxicity through visual assessment of crop response was rated in the scale of 0-10 (0 = no adverse effect of herbicide on sorghum and 10= 100 % adverse effect of herbicide). Data on sorghum growth and gain yield attributes were recorded from 5 randomly selected plants, while yield data on net plot basis at harvest. For economics, prevailing market price of inputs and support price of outputs was used. As similar trend was observed in the results of 2019 and 2020 for all the characters, a pooled analysis was done for all the results of all the parameters studied and were subjected for statistical analysis and interpretation as outlined by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Weed flora

The experiment field was infested by grassy and broad-leaved weeds during both the years. *Cynodon dactylon, Brachiaria reptans, Chloris inflata, Dactyloctenium aegeptium, Digitaria bicornis,* *Dinebra retroflexa* and *Cynotis culcullata* (grassy weeds); *Euphorbia geniculata, Corchorus aestuans, Abutilon hirtum, Amaranthus viridis, Aristolachia bractiata, Digeria muricata* (synonym: *D. aravensis*) and *Euphorbia humifusa* (broad-leaved weeds) and *Cyperus rotundus* (sedge) were predominant during both the years of study.

Effect on weed density, weed biomass and weed control efficiency

Weed density and biomass at 20 DAS showed the effectiveness of atrazine (PE) in the management of entire associated weed flora (grasses, sedges, broad-leaved weeds) as it recorded significantly lower weed density and biomass than weedy check but was markedly higher than weed free, where hand weeding was carried out just 5 days prior to the observation (15 DAS) (**Table 1** and **2**). The PoE herbicide application was observed to be essential to manage increased weed density and biomass of grass and broad-leaved weeds at 40 DAS when compared to those observed at 20 DAS. The repeated application of atrazine as PoE provided effective control of grasses. But it was less effective against broad-leaved weeds. The use of 2,4-D Na salt or 2,4-D ethyl ester as PoE after the pre-emergence application of atrazine provided effective control of broad-leaved weeds but was less effective against grasses when compared to atrazine PoE. Tembotrione at both doses and topramezone 56.3 g/ha as PoE showed greater effectiveness against grasses than atrazine, 2,4-D Na salt and 2,4-D Ethyl Ester (PoE). The efficacy of tembotrione and topramezone on broad-leaved weeds control was intermediate to the efficacy between 2,4-D Na salt & 2,4-D Ethyl Ester and atrazine (PoE). The total weed density at 40 DAS was markedly lower with tembotrione and topramezone PoE than all other PoE herbicides tested and least total weed density was recorded with tembotrione 105.5 g/ha.

Weed control efficiency (an estimate based on weed biomass) at 20 DAS indicated that atrazine (PE) attained WCE values of 80.5-83.8% as against 100% in hand weeding while at 40 DAS, repeat application of atrazine (PoE at 20 DAS) enhanced its weed management efficacy further with 13.5% higher WCE than that at 20 DAS (70.2%) achieved with atrazine (PE) (**Table 2**). Use of 2,4-D Na salt or 2,4-D Ethyl Ester (PoE) following atrazine (PE) further enhanced WCE over atrazine (PE + PoE). Tembotrione at both doses and topramezone 56.3 g/ha (PoE) brought marked improvements in WCE values over 2,4-D Na salt and 2,4-D Ethyl Ester (PoE) and topramezone (37.5 g/ha).

Table 1. Effect of pre- and post-emergence herbicides on weed density at 20 and 40 days after seeding of *Kharif* grain sorghum (pooled data of 2019 and 2020)

Treatment	Weed density (no./m^2)							
	Grasses		Sedges		Broad-leaved		Total	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
Atrazine 1000 g/ha PE	4.50 (2.18)	11.50 (3.43)	0.50 (0.86)	0.83 (1.04)	3.83 (2.02)	5.83 (2.47)	8.83 (3.01)	18.17 (4.29)
Atrazine 1000 g/ha PE *fb* atrazine PoE at 20 DAS	4.00 (2.06)	3.67 (1.97)	0.50 (0.86)	0.67 (0.96)	4.25 (2.12)	4.83 (2.25)	8.75 (3.00)	9.17 (3.07)
Atrazine 1000 g/ha PE *fb* 2,4-D Na salt 937.5 g/ha PoE at 20 DAS	4.17 (2.10)	6.67 (2.63)	0.67 (0.96)	0.83 (1.04)	4.17 (2.10)	1.83 (1.44)	9.00 (3.04)	9.33 (3.10)
Atrazine 1000 g/ha PE *fb* 2,4-D ethyl ester 2368 g/ha PoE at 30 DAS	3.67 (1.98)	6.17 (2.53)	0.67 (0.96)	0.83 (1.04)	4.83 (2.25)	1.83 (1.44)	9.17 (3.07)	8.83 (3.01)
Atrazine 1000 g/ha PE *fb* topramezone 37.5 g/ha PoE at 25 DAS	4.33 (2.14)	3.17 (1.85)	0.67 (0.96)	0.67 (0.96)	4.92 (2.27)	3.50 (1.94)	9.92 (3.19)	7.33 (2.75)
Atrazine 1000 g/ha PE *fb* tembotrione 70.3 g/ha PoE at 25 DAS	4.00 (2.06)	2.50 (1.66)	0.67 (0.96)	0.67 (0.96)	4.67 (2.22)	2.67 (1.71)	9.33 (3.10)	5.83 (2.47)
Atrazine 1000 g/ha PE *fb* topramezone 56.3 g/ha PoE at 25 DAS	4.00 (2.06)	2.33 (1.61)	0.50 (0.86)	0.67 (0.96)	4.58 (2.20)	2.75 (1.73)	9.08 (3.06)	5.75 (2.45)
Atrazine 1000 g/ha PE *fb* tembotrione 105.5 g/ha PoE at 25 DAS	4.00 (2.06)	2.00 (1.50)	0.83 (1.04)	0.67 (0.96)	4.17 (2.10)	2.50 (1.65)	9.00 (3.04)	5.17 (2.33)
Weed free hand weeding twice at 15 and 35 DAS	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)
Weedy check	23.33 (4.86)	31.50 (5.63)	3.22 (1.86)	3.67 (1.98)	16.33 (4.07)	24.00 (4.92)	42.89 (6.57)	59.17 (7.71)
LSD (p=0.05)	0.08	0.15	0.09	0.11	0.07	0.13	0.08	0.13

Note: Figures in the parentheses are transformed $\sqrt{x+0.25}$ values and ante parentheses are original values. Transformed values were statistically analysed; PE: Pre-emergence; PoE: Post-emergence; DAS: Days after seeding

Effect on sorghum growth and yield attributes

The higher sorghum plant height and yield attributes of sorghum was observed with all the weed management treatments when compared to weedy check, except topramezone 56.3 g/ha combination (**Table 3**). Topramezone 56.3 g/ha (PoE) had significantly lower plant height and yield attributes than weedy check due to its phytotoxicity as evidenced from negative HEI values (**Table 3**). Atrazine PE followed by atrazine or 2,4-D Na or 2,4-D Ethyl Ester PoE registered panicles/m^2 and test weight values at par to that of weed free treatment. However, weed free treatment recorded markedly taller plants and higher number of grains/panicle than all other treatments. Topramezone and tembotrione (PoE) were found to be phytotoxic to sorghum crop and the phytotoxicity increased with their higher doses. Tembotrione at both doses and topramezone at 56.3 g/ha significantly reduced the plant height, panicles/m^2 and grains/panicle and test weight when compared to atrazine PE. Tembotrione showed its negative impacts on test weight also when applied at 105.5 g/ha. Phytotoxicity scale indicated a dose dependence increase in both topramezone and tembotrione (2.00-3.83) and topramezone showed greater phytotoxicity ratings than tembotrione. The observed phytotoxicity in this study is in accordance with the findings of Dan *et al.* (2010).

Effect on sorghum grain yield and harvest index

The weed free treatment recorded the highest sorghum biological yield, grain yield and harvest index due to taller plants, higher yield attributes, while the lowest values were recorded in weedy check (**Table 4**). The uncontrolled weeds in sorghum caused 31.2 and 29.9% reduction in biological and grain yields as compared to weed free. Gharde *et al.* (2018) reported 25.1% sorghum grain yield loss due to uncontrolled weeds. Atrazine PE has bridged the grain yield gap by 51.4% and when atrazine PE was followed by PoE herbicide use (atrazine / 2,4-D Na Salt / 2,4-D Ethyl Ester), almost 94.8-97.7% yield gap was bridged resulting in grain yield that was at par with weedy free check. Atrazine PE *fb* tembotrione 70.3 g/ha PoE though proved as effective as above PE + PoE herbicide combinations

Table 2. Effect of pre- and post-emergence herbicides on weed biomass and weed control efficiency in grain sorghum (pooled data of 2019 and 2020)

Treatment	Weed biomass (g/m^2): Grasses 20 DAS	Grasses 40 DAS	Sedges 20 DAS	Sedges 40 DAS	Broad-leaved 20 DAS	Broad-leaved 40 DAS	Total 20 DAS	Total 40 DAS	Weed control efficiency (%) 20 DAS	Weed control efficiency (%) 40 DAS
Atrazine 1000 g/ha PE	1.41 (1.29)	8.18 (2.90)	0.11 (0.60)	0.46 (0.84)	1.37 (1.27)	4.85 (2.26)	2.88 (1.77)	13.48 (3.71)	80.53	70.23
Atrazine 1000 g/ha PE *fb* atrazine PoE at 20 DAS	1.08 (1.15)	2.94 (1.78)	0.11 (0.60)	0.34 (0.77)	1.25 (1.22)	4.07 (2.08)	2.45 (1.64)	7.35 (2.75)	83.61	83.78
Atrazine 1000 g/ha PE *fb* 2,4-D Na salt 937.5 g/ha PoE at 20 DAS	1.22 (1.21)	4.68 (2.22)	0.15 (0.63)	0.42 (0.81)	1.18 (1.19)	1.48 (1.32)	2.54 (1.67)	6.58 (2.61)	82.86	85.48
Atrazine 1000 g/ha PE *fb* 2,4-D ethyl ester 2368 g/ha PoE at 30 DAS	1.09 (1.16)	4.19 (2.11)	0.15 (0.63)	0.41 (0.81)	1.54 (1.34)	1.38 (1.27)	2.78 (1.74)	5.97 (2.49)	81.27	86.81
Atrazine 1000 g/ha PE *fb* topramezone 37.5 g/ha PoE at 25 DAS	1.27 (1.23)	2.11 (1.54)	0.16 (0.64)	0.33 (0.76)	1.40 (1.28)	2.46 (1.65)	2.83 (1.76)	4.90 (2.27)	80.90	89.19
Atrazine 1000 g/ha PE *fb* tembotrione 70.3 g/ha PoE at 25 DAS	0.98 (1.11)	1.57 (1.35)	0.14 (0.62)	0.32 (0.75)	1.28 (1.23)	1.92 (1.47)	2.40 (1.63)	3.81 (2.02)	83.82	91.58
Atrazine 1000 g/ha PE *fb* topramezone 56.3 g/ha PoE at 25 DAS	1.04 (1.13)	1.15 (1.18)	0.11 (0.60)	0.31 (0.75)	1.35 (1.26)	2.00 (1.50)	2.49 (1.65)	3.45 (1.92)	83.29	92.37
Atrazine 1000 g/ha PE *fb* tembotrione 105.5 g/ha PoE at 25 DAS	1.15 (1.18)	1.25 (1.22)	0.18 (0.65)	0.31 (0.75)	1.16 (1.18)	1.81 (1.43)	2.48 (1.65)	3.37 (1.90)	83.26	92.56
Weed free hand weeding twice at 15 and 35 DAS	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	0.00 (0.50)	100.00	100.00
Weedy check	7.28 (2.74)	24.47 (4.97)	0.78 (1.01)	1.95 (1.48)	6.81 (2.66)	18.88 (4.37)	14.87 (3.89)	45.30 (6.75)	0.00	0.00
LSD (p=0.05)	0.09	0.08	0.03	0.05	0.06	0.14	0.09	0.13	1.11	1.29

Note: Figures in the parentheses are transformed $\sqrt{x+0.25}$ values and ante parentheses are original values. Transformed values were statistically analysed; PE: Pre-emergence; PoE: Post-emergence; DAS: Days after seeding for grain yields, but was markedly inferior to weed free check. Better grain yield performance of these herbicide treatments could be ascribed to higher number of panicles/m^2, grains/panicle and test weight (**Table 3**) due to enhanced resource supplies (light, space, water, nutrients) to crop under effective management of complex weed flora. The atrazine (PE) + tembotrione 70.3 g/ha PoE has recorded sorghum grain yield markedly lower than that in sole application of atrazine PE. Topramezone PoE at both doses (37.5 and 56.3 g/ha) following atrazine (PE) proved counterproductive as evident from significantly reduced grain yields (21 and 39%) than PE atrazine (2.31 t/ha). There was a significant reduction in harvest index values with topramezone (56.3 g/ha) and tembotrione (105.5 g/ha) over their lower rates, all other herbicides and even in treatments without herbicides.

Herbicide efficiency index (HEI), weed index (WI) and phytotoxicity

Weed index data (**Table 3**) indicated that atrazine PE *fb* 2,4-D Na salt PoE / 2,4-D ethyl ester PoE being at par with atrazine PE *fb* atrazine (PoE) provided efficient weed control in grain sorghum. Topramezone 37.5 g/ha PoE proved ineffective as evident from its at par weed index values as weedy check (34.6) and less effective than weedy check when applied at higher dose (51.7 g/ha PoE). These low weed index values of topramezone are reflected in negative herbicide efficiency index values *i.e.* -0.09 and -0.78 with 37.5 and 56.3 g/ha rates of application, respectively. Significantly higher weed index values with tembotrione 105.5 g/ha PoE (24.3) over atrazine PE (15.9) reveals its ineffectiveness and its phytotoxicity when HEI of its lower and higher dose (2.41 and 1.92) are compared. Topramezone and tembotrione phytotoxicity (0-10 scale) increased from 2.83 to 3.83 and 2.00 to 2.83, respectively as dose increased from low to high level. Similar phytotoxicity effects of tembotrione (Dan *et al.* 2010) and topramezone (Grossmann and Ehrhardt 2007) have been already reported in sorghum, elsewhere. Tembotrione and topramezone phytotoxicity persisted for 20-25 days and later the sorghum crop gradually recovered at later stages as reported by Shidenura (2019) and Rajesh Patil (2020).

Economics

The weed free (hand weeding twice) treatment costed ₹ 8,955/ha and thus cost of production over weedy check (₹ 33,007/ha) was enhanced by 27.1% (**Table 4**). However, atrazine PE *fb* 2,4-D ethyl ester PoE, atrazine PE *fb* PoE and atrazine PE *fb* 2,4-D Na salt PoE incurred only 35.1, 37.2 and 40.5% of the cost of weed free treatment. The lower cost of weeding with PE *fb* PoE herbicides treatments coupled with statistically similar stover and grain yields has resulted in statistically at par net incomes as weed free treatment (₹ 51,834/ha). Atrazine PE *fb* 2,4-D Na salt PoE and atrazine PE *fb* PoE on account of lower cost of cultivation despite of slightly lower yields attained significantly higher B:C ratio (2.52 & 2.46) than weed free treatment (2.22). Similar economic superiority of PE *fb* PoE herbicides treatments over weed-free treatment was reported by Shidenura (2019) and Rajesh Patil (2020).

It was concluded that application of atrazine 1000 g/ha PE followed by 2, 4-D Na salt 937.5 g/ha PoE at 20 DAS could be the best herbicide weed-management option for grain sorghum grown in *Kharif* season, from productivity and profitability

Table 3. Effect of pre- and post-emergence herbicides on sorghum growth and yield attributes, weed index (WI), herbicide efficiency index (HEI) and phytotoxicity to sorghum (pooled data of 2019 and 2020)

Treatment	Sorghum plant height (cm) at harvest	Panicles no./m^2	Grains/ panicle (no.)	Test weight (g)	WI (%)	HEI	Phyto-toxicity (0-10 scale)
Atrazine 1000 g/ha PE	147.2	13.63	2475	29.2	15.93	0.94	0.00
Atrazine 1000 g/ha PE *fb* atrazine PoE at 20 DAS	148.6	14.25	2621	29.8	3.58	2.26	0.00
Atrazine 1000 g/ha PE *fb* 2,4-D Na salt 937.5 g/ha PoE at 20 DAS	149.6	14.22	2723	30.5	2.46	2.36	0.00
Atrazine 1000 g/ha PE *fb* 2,4-D ethyl ester 2368 g/ha PoE at 30 DAS	148.6	14.24	2575	29.8	6.17	2.14	0.00
Atrazine 1000 g/ha PE *fb* topramezone 37.5 g/ha PoE at 25 DAS	144.5	12.62	2260	28.7	37.32	-0.09	2.83
Atrazine 1000 g/ha PE *fb* tembotrione 70.3 g/ha PoE at 25 DAS	148.8	13.62	2583	29.5	9.66	2.41	2.00
Atrazine 1000 g/ha PE *fb* topramezone 56.3 g/ha PoE at 25 DAS	140.1	12.00	2106	28.2	51.70	-0.78	3.83
Atrazine 1000 g/ha PE *fb* tembotrione 105.5 g/ha PoE at 25 DAS	147.8	13.28	2337	29.2	24.33	1.92	2.83
Weed free hand weeding twice at 15 and 35 DAS	152.9	14.36	2955	30.5	0.00	-	0.00
Weedy check	144.9	12.99	2301	29.0	34.61	0.00	0.00
LSD (p=0.05)	2.19	0.72	213	0.70	13.44	-	0.14

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

Table 4. Economics of *Kharif* grain sorghum cultivation as influenced by pre- and post-emergence herbicides (pooled data of 2019 and 2020)

Treatment	Biological yield (t/ha)			Grain yield (t/ha)			Harvest Index	Cost of cultivation (₹/ha)	Net returns (₹/ha)	B:C
	2019	2020	Pooled	2019	2020	Pooled				
Atrazine 1000 g/ha PE	8.23	15.16	11.69	1.43	3.19	2.31	19.39	34730	45006	2.28
Atrazine 1000 g/ha PE *fb* atrazine PoE at 20 DAS	9.82	16.33	13.08	1.76	3.46	2.61	19.68	36340	53459	2.46
Atrazine 1000 g/ha PE *fb* 2,4-D Na salt 937.5 g/ha PoE at 20 DAS	9.92	17.20	13.56	1.77	3.51	2.64	19.24	36154	55404	2.52
Atrazine 1000 g/ha PE *fb* 2,4-D ethyl ester 2368 g/ha PoE at 30 DAS	9.34	16.42	12.88	1.65	3.48	2.56	19.56	36632	51618	2.40
Atrazine 1000 g/ha PE *fb* topramezone 37.5 g/ha PoE at 25 DAS	4.48	14.31	9.39	0.76	2.90	1.83	18.92	37271	26190	1.69
Atrazine 1000 g/ha PE *fb* tembotrione 70.3 g/ha PoE at 25 DAS	9.41	15.73	12.57	1.64	3.25	2.44	19.18	36794	48007	2.29
Atrazine 1000 g/ha PE *fb* topramezone 56.3 g/ha PoE at 25 DAS	4.02	11.59	7.81	0.62	2.18	1.40	17.37	38067	11697	1.30
Atrazine 1000 g/ha PE *fb* tembotrione 105.5 g/ha PoE at 25 DAS	7.81	15.06	11.43	1.16	3.09	2.12	17.99	36993	37699	2.01
Weed free hand weeding twice at 15 and 35 DAS	10.10	17.77	13.94	1.83	3.57	2.70	19.21	41962	51834	2.22
Weedy check	4.68	14.51	9.59	0.84	2.95	1.89	19.33	33007	32401	1.96
LSD (p=0.05)	1.46	0.77	1.06	0.26	0.34	0.17	0.87	-	5900	0.21

Note: Labour: ₹ 396.5, Bullock pair: ₹ 1250/day, Tractor hiring: ₹ 800/hour, FYM: ₹ 1250/t, Urea: ₹ 5.80/kg, DAP: ₹ 26.0/kg, MOP: ₹ 18.60/kg, Seeds: ₹ 115/kg, atrazine 50% WP ₹ 586/kg, 2,4-D Na Salt 80 WP/2,4-D Ethyl Ester 38EC: ₹ 360/l, Topramezone 33.6 SC: ₹ 3950 /75 ml, Tembotrione 34.4 SC: ₹ 1063/75 ml, Chloropyrifos: ₹ 600/l, Chlorantraniliprole 18.5% SC (Coragen) ₹ 15167/l, Sorghum grain (stover): 26.4 (2)/kg, Marketing charges 3% of the produce and Interest on outlay: 7% per annum.

point of view, in lieu of manual weeding (weed free with hand weeding twice) treatment. New herbicide, topramezone was found counter productive while tembotrione was also not an economically viable alternative.

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Indian Journal of Weed Science **53**(4): 387–391, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Weeds and phosphorus management effect on groundnut productivity, oil content and nutrient uptake

S.R. Harikesh*, M.K. Kaushik, J.L. Choudhary, P.B. Singh, J. Choudhary, R.H. Meena, R.S. Choudhary, S.C. Meena and G.L. Meena

Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan 313001, India

**Email: harikeshlittle@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00071.X

Type of article: Research article

Received : 16 March 2021
Revised : 9 October 2021
Accepted : 10 October 2021

KEYWORDS

Groundnut, Herbicides, Imazethapyr, Pendimethalin, Phosphorus, Weed management

ABSTRACT

The present study was conducted at MPUAT, Udaipur, India, during two consecutive *Kharif* (rainy season) of 2016 and 2017 to assess the effect of weed management treatments and phosphorus levels on weeds; groundnut growth, yield, quality and probability of groundnut cultivation. A split-plot design was used with six weed management treatments *i.e*., weedy check, weed free up to 60 days after seeding (DAS), pendimethalin 750 g/ha pre-emergence application (PE), oxyfluorfen 125 g/ha PE, imazethapyr 100 g/ha post-mergence application at 15 DAS (PoE) and quizalofop-ethyl 50 g/ha PoE at 15 DAS as main plots, and five phosphorus levels, *viz*. 0, 20, 40,60 and 80 kg P/ha as sub-plots with three replications. The lowest density of *Cyperus rotundus* and *Echinochloa colona* was recorded with imazethapyr and quizalofop-ethyl, respectively. The lowest density of other narrow-leaved weeds at 30, 60 DAS and harvest was registered with pendimethalin, quizalofop-ethyl and imazethapyr, respectively. Weed free up to 60 DAS was the most effective in managing weeds and increasing groundnut yield. Amongst herbicide treatments, imazethapyr 100 g/ha PoE recorded significantly minimum weed index, weed persistence index, crop resistance index, and the highest values of growth and yield parameters, and N, P and K uptake. Application of 60 kg P/ha has registered significantly the highest plant height, dry matter accumulation, 100 kernels weight and pod yield (1.76 t/ha), biological yield (4.86 t/ha) and also the harvest index (35.83%). Significantly higher protein and oil content were noticed when the crop was fertilized with 40 kg P/ha. The total N, P and K uptake by crop were significantly higher by 87.83, 92.10 and 60.97% over control, respectively with 80 kg P/ha.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is largely grown as a small holding crop in rainfed area under arid and semi-arid conditions in the world (Khan *et al.* 2018). In India, six states namely Gujarat, Rajasthan, Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu account for about 90% of the total groundnut area and production of the country. In India, groundnut is cultivated in on an area of 4.9 mha and production of 10.1 mt with productivity 2.06 t/ha (Government of India 2021). Rajasthan accounts nearly 15.08% of production on 10.48% cultivation area in 2016-17 (RAS 2018).

Among different constraints that limit the productivity of peanut in India, weed menace is a serious bottleneck as peanut is confronted with repeated flushes of diverse grassy, broad-leaved and sedge weeds cause substantial yield losses 24-70% (Jat *et al.* 2011). Thus, weed control is the foremost critical production practice in groundnut cultivation (Samant and Mishra 2014). Generally, weeds are controlled through hand weeding in groundnut, which is very expensive, laborious and sometimes damaging to the crop plants (Singh *et al.* 2014). Hence, there is a need to explore effective pre- and post-emergence herbicides for effective control of weeds in groundnut.

Phosphorus (P) is essential at all groundnut crop developmental stages till crop maturity. In addition, availability of P increases the N-fixing capacity and resistance to plant diseases (Malhotra *et al.* 2018 and Madhuri *et al.* 2019). P is most important for exploiting genetic potentials of the crop for its growth and development (Shen *et al.* 2011). Thus, the present study was carried out to identify suitable weed management treatments and optimum phosphorus dose for managing weeds and enhancing groundnut nutrient uptake, oil content and productivity.

MATERIALS AND METHODS

The present study was carried out during *Kharif* (rainy season) of 2016 and 2017 at Instructional Farm (24º35' N latitude and 73°44' E longitude at an altitude of 582.17 MAMSL), CTAE, MPUAT, Udaipur, Rajasthan, India. The experimental site is falls under agro-climatic zone IVa in South-Eastern region of Rajasthan, associated with typically semi-arid and sub-tropical climate. The analysis values of composite soil sample of experimental site have been furnished in (**Table 1**).

The experiment was laid out in a split-plot design comprised six weed management treatments as main plots, *viz*. weedy check, weed free up to 60 days after seeding (DAS), pendimethalin 750 g/ha pre-emergence application (PE), oxyfluorfen 125 g/ha PE, imazethapyr 100 g/ha post-emergence application (PoE) at 15 DAS and quizalofop-ethyl 50 g/ha as PoE at 15 DAS and five phosphorus levels as sub-plots *viz.* 0 (control), 20, 40, 60, and 80 kg P/ha as sub-plots. Three replications were maintained. Before sowing, till good tilth the field was thoroughly ploughed and leveled. Healthy treated groundnut (variety: *TG 37 A*) kernels were sown on 27.06.2016 and 06.07.2017 at spacing of 30 x 10 cm with a depth of nearly 4-5 cm by using seed rate of 100 kg/ha and harvested on 15.10.2016 and 25.10.2017, during 1st and 2nd trails, respectively. Pre- and post-emergence herbicides were applied at 2 and 15 DAS, respectively during rain free condition with a battery-operated knap-sack sprayer fitted with flat-fan nozzle. In weed free up to 60 DAS treatment, the weeds were removed manually to keep weed free up to 60 DAS while, weedy check plots were allowed to remain infested with weeds till crop harvest. The recommended dose of nitrogen 30 kg/ha and phosphorus (as per treatment) were applied as basal application using urea and DAP in the furrows below the kernel in all the plots. The rest of the packages of practices were adopted as per recommended in Rajasthan. Weed density was recorded from two randomly selected area of 0.25/m^2 using 0.5 x 0.5 m quadrat at 30, 45 DAS and harvest in each plot thereafter mean data were subjected to square root transformation $\sqrt{X + 0.05}$ to normalize their distribution (Gomez and Gomez 1984). Weed index, herbicidal efficiency index, weed persistence index and crop resistance index were calculated using formulae as given ISA (2009). The plant height, dry matter accumulation, crop or relative growth rate, yield attributing parameters like 100 kernels weight and yield such as pod, biological and harvest index as well as protein content of kernel was analysed by Lowry protein assay method (Lowry *et al*. 1951) and oil content was determined by Soxhlit's oil extraction method (Knowles and Watkins 1960). The percent of oil ingredient was calculated as follows:

Table 1. Physico-chemical characteristics of soil (0-15 cm depth) before start of the experiment

Soil physical properties						
Bulk density (Mg/m^3)	Particle density (Mg/m^3)	Porosity (%)	Particle size distribution (%)			Soil Texture
			Sand	Silt	Clay	
1.52	2.65	42.34	58.02	29.42	12.06	Sandy loam

Soil chemical properties					
Organic carbon (%)	Available soil nutrient (kg/ha)			Soil pH	EC (dS/m)
	N	P	K		
0.32	259.98	17.17	177.71	7.76	0.83

$$\text{Oil content (\%)} = \frac{\text{Weight of flask with extract - weight of empty flask}}{\text{Weight of sample taken}} \times 100$$

Further, total uptake of nutrients was worked out by using the following formula.

$$\text{Total nutrient uptake(kg/ha)} = \frac{\text{Nutrient concentration in pod/haulm (\%)} \times \text{Pod yield / haulm (kg/ha)}}{100}$$

Statistical analysis of the recorded data was carried out using analysis of variance technique for split plot design (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

There was a significant decrease in the density of weeds *i.e. Cyperus rotundus*, *Echinochloa colona* and other narrow-leaved weeds (other than *C. rotundus*, *E. colona* and *Cynodon dactylon)* due to tested weed management treatments as compared to weedy check (**Table 2**). The weed free recorded significantly lowest weed density and it was statistically superior to rest of the treatments. Among the herbicidal treatments, post-emergence application of quizalofop-ethyl was statistically superior than all other treatments in effectively reducing density of *E. colona* at 30, 45 DAS and harvest. Phosphorus application failed to significantly influence the weeds density.

Among the herbicide treatments, lowest weed index was registered with imazethapyr (2.86%) which was closely followed by pendimethalin (3.55%). Application of imazethapyr, pendimethalin, oxyfluorfen and quizalofop-ethyl recorded 1.09, 0.84, 0.65 and 0.48% herbicidal efficiency index, respectively. The minimum weed persistence index was recorded with imazethapyr (0.97), pendimethalin (0.99) followed by oxyfluorfen (0.99) and quizalofop-ethyl (1.02). The lower crop resistance index of total weeds was recorded under weed free (0.09) followed by imazethapyr (0.64), oxyfluorfen (0.78) and pendimethalin (0.80) than quizalofop-ethyl (0.99) (**Figure 1**). These results were in conformity with those of Adhikary *et al.* (2016).

The maximum plant height and dry matter accumulation were registered under weed free up to 60 DAS which was statistically at par with pendimethalin at 40 DAS and imazethapyr at harvest (**Table 3**). The crop fertilized with 60 kg P/ha increased the plant height by 36.33 and 29.78% and dry matter accumulation by 30.62 and 21.85% at 40 DAS and harvest, respectively when compared to control. Application of phosphorus up to 80 kg/ha registered significantly higher crop growth rate over control. The phosphorus beyond 20 kg/ha had no significant effect on CGR and phosphorus dosage rates effect on relative growth rate was non-significant. Weed free up to 60 DAS recorded maximum 100 kernels weight and was closely followed by imazethapyr and pendimethalin. The 100 kernels weight increased by 27.31, 4.97 and 2.53% with increased phosphorus levels from control-20, 20-40 and 40-60 kg P/ha, respectively (**Table 4**).

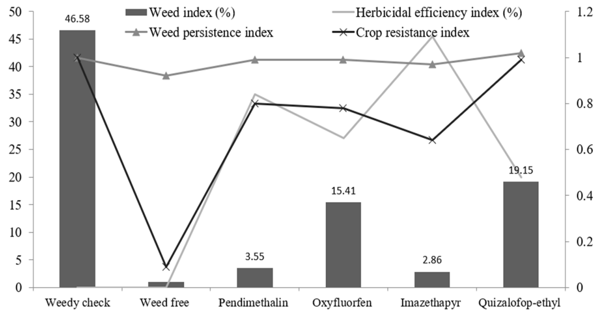

Figure 1. Effect of weed management practices on agronomic indices

The pod and biological yield increase over weedy check control was highest with weed free up to 60 DAS (87.16 and 51.91%) followed by imazethapyr (81.78 and 48.22%) and pendimethalin (80.54 and 47.34%) (**Table 4**). The enhanced yield attributing characters may be attributed to reduced

Table 2. Effect of weed management treatments and phosphorus levels on weeds density at different crop growth periods during *Kharif* season (pooled mean for two years)

Treatment	Weed density (no./m²)								
	Cyperus rotundus			*Echinochloa colona*			Other narrow weeds		
	30 DAS	45 DAS	Harvest	30 DAS	45 DAS	Harvest	30 DAS	45 DAS	Harvest
Weed management									
Pendimethalin 750 g/ha PE	2.56 (6.08)	3.16 (9.58)	3.72 (13.50)	2.53 (5.94)	3.81 (14.01)	4.74 (22.02)	1.64 (2.20)	3.47 (11.62)	2.97 (8.33)
Oxyfluorfen 125 g/ha PE	2.75 (7.08)	3.17 (9.55)	3.78 (13.85)	2.65 (6.58)	3.81 (14.04)	5.13 (25.79)	2.65 (6.56)	4.10 (16.33)	4.01 (15.58)
Imazethapyr 100 g/ha PoE	2.28 (4.72)	2.79 (7.29)	3.44 (11.44)	2.47 (5.64)	3.20 (9.75)	4.62 (20.84)	2.33 (4.94)	3.37 (10.84)	2.73 (6.99)
Quizalofop-ethyl 50 g/ha PoE	3.03 (8.71)	3.85 (14.35)	4.26 (17.63)	2.17 (4.24)	2.84 (7.55)	3.87 (14.54)	1.99 (3.45)	2.88 (7.80)	3.00 (8.52)
Weed free up to 60 DAS	0.71 (0.00)	0.71 (0.00)	1.20 (1.07)	0.71 (0.00)	0.71 (0.00)	1.63 (2.21)	0.71 (0.00)	0.71 (0.00)	1.94 (3.35)
Weedy check	3.42 (11.32)	4.22 (17.33)	4.76 (22.21)	4.93 (23.84)	6.17 (37.66)	6.95 (47.91)	3.36 (10.82)	4.99 (24.41)	4.98 (24.33)
LSD (p=0.05)	0.13	0.07	0.07	0.10	0.07	0.09	0.08	0.04	0.06
Phosphorus levels (P kg/ha)									
20	2.45 (6.29)	2.98 (9.65)	3.52 (13.25)	2.56 (7.65)	3.41 (13.74)	4.49 (22.23)	2.11 (4.63)	3.25 (11.80)	3.26 (11.12)
40	2.46 (6.32)	2.98 (9.67)	3.53 (13.35)	2.58 (7.71)	3.42 (13.86)	4.50 (22.27)	2.11 (4.65)	3.25 (11.82)	3.27 (11.16)
60	2.46 (6.35)	2.99 (9.72)	3.53 (13.32)	2.59 (7.76)	3.43 (13.91)	4.50 (22.29)	2.12 (4.69)	3.26 (11.87)	3.27 (11.20)
80	2.47 (6.38)	3.00 (9.75)	3.53 (13.22)	2.60 (7.80)	3.44 (13.99)	4.50 (22.19)	2.13 (4.71)	3.26 (11.90)	3.30 (11.34)
0 (Control)	2.45 (6.26)	2.97 (9.62)	3.52 (13.27)	2.55 (7.61)	3.41 (13.68)	4.47 (22.10)	2.11 (4.62)	3.24 (11.77)	3.26 (11.10)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

competitiveness of weed due to greater efficacy of weed control treatments as reported by Choudhary *et al.* (2017) and Singh *et al.* (2018). Application of 60 kg P/ha resulted in an increase of 70.91 and 59.88% pod and biological yield over control, respectively. The improvement in plant growth by phosphorus application leading to an increase in photosynthetic activity and translocation of photosynthates with adequate nutrients to sink and subsequently resulting in better development of yield attributes resulting in higher groundnut yield (Meena *et al.* 2014 and Sibhatu *et al.* 2016).

The protein content of kernel was highest with weed free up to 60 DAS. Among herbicides, imazethapyr recorded significantly highest protein content (23.05%) in kernel followed by pendimethalin (22.40%) over oxyfluorfen (21.52%), quizalofop-ethyl (21.89%) and weedy check (**Table 4**). This might be due to increase protein content in kernel (Adhikary *et al.* 2016). Oil content in groundnut kernel was not significantly affected by tested weed management treatments. An increasing trend of protein and oil content in kernel was observed with the increase in application rate of phusphorus. The application of 40-60 and 60-80 kg P/ha were equally efficient in terms of increasing the protein and oil content and were statistically at par with each other. Because nitrogen is a basic constituent of protein and with increase in the rate of phosphorus application, nitrogen availability increased which resulted in increased protein and oil content in kernel (Malhotra *et al.* 2018).

Table 3. Effect of weed management treatments and phosphorus levels on growth parameters of groundnut during *Kharif* season (pooled mean for two years)

Treatment	Plant height (cm)		Dry matter accumulation (g/m^2)		CGR (g/m^2/day)	RGR (mg/g/day)
	40 DAS	Harvest	40 DAS	Harvest	Between 60 DAS and harvest	
Weed management						
Pendimethalin 750 g/ha PE	16.74	28.96	181.46	447.72	2.60	7.31
Oxyfluorfen 125 g/ha PE	14.67	26.99	168.05	407.72	2.33	7.16
Imazethapyr 100 g/ha PoE	15.98	30.46	179.47	456.94	2.66	7.32
Quizalofop-ethyl 50 g/ha PoE	14.98	27.95	170.07	411.22	2.33	7.18
Weed free up to 60 DAS	16.99	30.59	183.73	461.14	2.70	7.33
Weedy check	12.51	24.92	155.76	295.47	1.02	3.90
LSD (p=0.05)	0.84	1.30	4.31	14.16	0.14	0.31
Phosphorus levels (P kg/ha)						
20	14.89	27.60	172.84	404.45	2.23	6.71
40	15.66	29.26	179.60	423.59	2.33	6.74
60	16.70	30.46	185.22	437.08	2.39	6.65
80	17.05	30.77	186.00	443.01	2.43	6.70
0 (Control)	12.25	23.47	141.80	358.70	1.98	6.72
LSD (p=0.05)	0.40	0.51	2.45	5.96	0.10	NS

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

Table 4. Effect of weed management treatments and phosphorus levels on yield attributes, yield and quality of groundnut during *Kharif* season (pooled mean for two years)

Treatment	100 kernels weight (g)	Pod yield (t/ha)			Biological yield (t/ha)			Harvest index (%)	Protein (%)	Oil (%)
		2016	2017	Pooled	2016	2017	Pooled			
Weed management										
Pendimethalin 750 g/ha PE	38.93	1.70	1.78	1.74	4.64	4.79	4.71	36.85	22.40	46.22
Oxyfluorfen 125 g/ha PE	36.20	1.50	1.56	1.53	4.29	4.44	4.36	34.94	21.52	45.12
Imazethapyr 100 g/ha PoE	39.12	1.72	1.79	1.76	4.67	4.81	4.74	36.88	23.05	46.12
Quizalofop-ethyl 50 g/ha PoE	36.58	1.43	1.49	1.46	4.23	4.40	4.32	33.75	21.89	45.09
Weed free up to 60 DAS	39.95	1.79	1.83	1.81	4.78	4.94	4.86	37.06	23.67	46.63
Weedy check	30.40	0.94	0.99	0.97	3.16	3.24	3.20	30.24	21.42	44.29
LSD (p=0.05)	1.00	0.13	0.07	0.07	0.25	0.15	0.12	1.22	0.49	NS
Phosphorus levels (P kg/ha)										
20	36.83	1.45	1.48	1.47	4.25	4.36	4.31	33.74	21.87	45.20
40	38.66	1.66	1.73	1.70	4.65	4.80	4.73	35.26	22.41	45.88
60	39.64	1.72	1.79	1.76	4.77	4.95	4.86	35.83	22.53	46.09
80	39.87	1.73	1.81	1.77	4.80	4.98	4.89	35.90	22.74	46.27
0 (control)	28.93	1.02	1.04	1.03	3.00	3.08	3.04	33.34	21.25	44.45
LSD (p=0.05)	0.24	0.05	0.05	0.03	0.08	0.10	0.03	0.56	0.23	0.56

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

Table 5. Effect of weed management treatments and phosphorus levels on total nutrient uptake by groundnut during *Kharif* season (pooled mean for two years)

Treatment	Nutrient uptake(kg/ha)		
	Nitrogen	Phosphorus	Potassium
Weed management			
Pendimethalin 750 g/ha PE	116.75	28.78	50.00
Oxyfluorfen 125 g/ha PE	105.28	26.07	46.40
Imazethapyr 100 g/ha PoE	117.18	29.19	50.25
Quizalofop-ethyl 50 g/ha PoE	103.78	25.39	46.27
Weed free up to 60 DAS	121.60	30.08	51.83
Weedy check	72.03	17.21	34.48
LSD (p=0.05)	3.56	0.81	1.54
Phosphorus levels (P kg/ha)			
20	102.31	24.72	45.99
40	117.19	28.49	50.20
60	121.50	30.41	51.84
80	123.67	30.89	52.22
0 (control)	65.84	16.08	32.44
LSD (p=0.05)	1.31	0.31	0.50

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

The N, P and K uptake by the crop was significantly highest with weed free up to 60 DAS followed by imazethapyr and pendimethalin whereas, pendimethalin and imazethapyr were found non-significant to each other in this regard but significantly superior over oxyfluorfen, quizalofop-ethyl and weedy check (**Table 5**). The higher nutrient uptake by crop might be due to decreased crop weed competition concurrently increased nutrient availability, better crop growth and higher crop biomass production coupled with more nutrient content (Samant and Mishra 2014, Singh *et al.* 2017).

Based on the results of this study, it is concluded that the post-emergence application of imazethapyr at 100 g/ha at 15 DAS and soil application of 60 kg P/ha results in adequate management of weeds and optimum groundnut pod yield.

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Indian Journal of Weed Science **53**(4): 392–397, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Herbicides' efficacy on Egyptian broomrape *(Orobanche aegyptiaca Pers.)* in tomato and brinjal in South-West Haryana, India

S.S. Punia*, Paras Kamboj, Dharam Bir Yadav, Vinay Sindhu and Sushil Kumar

Department of Agronomy, CCS Haryana Agricultural University, Hisar, Haryana 125004, India

**Email: puniasatbir@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00072.1

Type of article: Research article

Received : 10 May 2019
Revised : 10 August 2021
Accepted : 12 August 2021

KEYWORDS

Brinjal, Egyptian broomrape, Ethoxysulfuron, Metalyxyl, *Orobanche aegyptiaca*, Pendimethalin, Sulfosulfuron, Tomato

ABSTRACT

Egyptian broomrape (*Orobanche aegyptiaca* Pers.) is the most troublesome root holoparasitic weed which causes severe damage to tomato and brinjal crops grown in Mewat and Bhiwani areas of Haryana. A study was conducted to test the efficacy and selectivity of two sulfonylurea herbicides, *viz.* sulfosulfuron and ethoxysulfuron, and neem cake; pendimethalin in combination with metalaxyl along with sulfonylurea herbicides for managing *O. aegyptiaca* in tomato and brinjal in field conditions. The post-emergence application (PoE) of sulfosulfuron and ethoxysulfuron at 50 g/ha 30, 60, 90 DAP (days after planting) were more selective to tomato and to control the parasite, *O. aegyptiaca*, more effectively with average yield increase of 51.7% over untreated check. Neem cake or metalaxyl were not effective to inhibit the growth of *O. aegyptiaca* in brinjal. It is inferred from this study that ethoxysulfuron at 25 g/ha PoE at 30 DAP and at 50 g/ha or sulfosulfuron at 50 g/ha PoE at 30 and 60 DAP, provided 85-90% control of *O. aegyptiaca* in tomato. Both the herbicides caused phytotoxicity to brinjal. The results of eight adaptive on-farm trials conducted in tomato during 2016-17 also revealed 92.3% control of *O. aegyptiaca* with a yield increase of 30.8% over untreated control.

INTRODUCTION

Egyptian broomrape (*Orobanche aegyptiaca* Pers.) locally known as margoja/rukhri/khumbhi/gulli is an achlorophyllous, phanerogamic troublesome root parasite which depends completely on host to complete its life cycle. This parasitic plant causes economic damage in field crops and vegetable production worldwide (Parker and Riches 1993, Eizenberg *et al.* 2004). Tomato (*Lycopersicon esculentum* Mill.) is highly vulnerable to three broomrape species, *viz. O. aegyptiaca, O. ramosa* L. and *O. cernua* Loefl. that are known to cause damage and reduce tomato yields (Joel *et al.* 2007). *Orobanche aegyptiaca* is the major limiting factor in tomato production in Israel, Egypt, Sudan, Syria, Tunisia, Turkey and Lebanon.

Survey of weed flora in tomato and brinjal (*Solanum melongena* L.) fields in Haryana during 2013-2014 revealed that both tomato and brinjal were found badly infested with *Orobanche aegyptiaca* threatening their cultivation in Nuh, Ferozepur Jhirka, Nagina, Taoru areas of Mewat, Charkhi Dadri and Loharu areas of Bhiwani of Haryana state in India. Farmers reported 40-75% yield loss due to its infestation in tomato depending on the intensity of infestation (Punia *et al.* 2016). A continuous increase in *O. aegyptiaca* infestation in these areas has forced farmers to abandon tomato and brinjal cultivation and switch over to other less-profitable alternative crops.

Orobanche aegyptiaca exerts the greatest damage prior to emergence of flowering shoot. Therefore, most of the field losses would occur before diagnosis of infection. In such situations, chemical control measures and host resistance appear to be the most appropriate measures whenever available and affordable. Potential herbicides must be selective for the host plant but phytotoxic to the parasite. Most promising soil fumigant methyl-bromide is phased out. The conventional methods of weed control are time consuming, expensive and laborious, more over ineffective due to continuous germination of *O. aegyptiaca* throughout the crop growth period.

The herbicides to be used must be selective for the host plant but phytotoxic to the parasite. The effectiveness and selectivity of sulfosulfuron and other ALS inhibiting herbicides to control *O. aegyptiaca* in tomato *(Solanum lycopersicum)* was demonstrated earlier in Israel (Hershenhorn *et al.* 2009) and India (Punia *et al.* 2016). Hence, herbicides use can be an effective measure for *O. aegyptiaca* management. The herbicide should persist up to certain period so that it may provide adequate weed control for a certain period and later it should degrade.

The studies conducted between 2012-2016 by Punia *et al.* (2016) demonstrated efficacy of ethoxysulfuron and sulfosulfuron in tomato but the results, over the years, were inconsistent with respect to time of application and dose of herbicides. Optimal crop stage for herbicide application is critical for the herbicide to cause mortality of preconditioned seeds or young attachments of *O. aegyptiaca.* Hence, to validate results of the previous studies under field conditions and assess their efficacy under Indian context, the present study was undertaken to quantify the efficacy of sulfonylurea herbicides on *O. aegyptiaca* in tomato and brinjal under Indian conditions with the objectives: 1. To assess the efficacy of sulfonyl urea herbicides against *O. aegyptiaca* and their effect on growth and yield of brinjal and tomato; 2. To study efficacy of neem cake and metalyxyl in combination with pendimethalin in managing *O. aegyptiaca* in brinjal; and 3. To quantify the phytotoxic effects of tested herbicides on tomato and brinjal.

MATERIALS AND METHODS

Tomato hybrid '*2853*' was planted for two consecutive years on November 18, 2016 and November, 11, 2017 at the farm of Abaas of village Rehna (Nuh) Mewat and November 19, 2016 at the farm of Arsad of village Bivan, Tehsil Nuh of Mewat district (Haryana). The experimental plot size was 25 x 6 m^2. A randomized block design was used with three replications. Tomato was grown as per the recommended package of practices of CCS Haryana Agricultural University (CCSHAU), except for the tested weed management treatments *i.e* ethoxysulfuron 25 g/ha pre-emergence application (PE); oxyfluorfen 120 g/ha PE; ethoxysulfuron 50 g/ha post-emergence application (PoE) at 60 and 90 days after transplanting (DAP); sulfosulfuron PoE 25 g/ha at 60 DAP followed by (*fb*) 50 g/ha 90 DAP, sulfosulfuron 50 g/ha PoE at 60 and 90 DAP and farmers practice of hand pulling. In the first year of the study, all the pre-emergence application of herbicides was done by using a knap sack sprayer fitted with flat fan nozzle using 750 litres of water/ha. The ethoxysulfuron PE and oxyfluorfen PE have caused toxicity to crop during 2016 and hence these treatments were deleted during experimentation of 2017. The post-emergence application of herbicides was done using 375 litres/ha of water. The observations on number of *O. aegyptiaca* spikes/m^2 and *O. aegyptiaca* visual control (0-100 scale) as affected by different treatments was recorded at 60, 90, 120 days after planting (DAP) and at harvest. Data on tomato plant height and number of fruits/plant was recorded at 120 DAP. The number of tomato fruits/plant was recorded from five tagged plants at 120 DAT and the values were averaged to compute the number of tomato fruits/plant. The tomato fruits were picked in four flushes, weighed and tomato total yield/plot was computed. Crop phyto-toxicity due to different treatments was assessed at 120 DAP and harvest on a scale of 0-100, where 0 means no injury and 100 = complete mortality of tomato plant. Foliar necrosis, yellowing, stunting, necrosis and wilting were the main symptoms considered while making visual estimate of visual injury on tomato plants. Keeping in view the excellent efficacy of sulfonylurea herbicides even in 2015, eight field trials at farmers' fields were conducted in tomato during 2016-17.

The experiment on brinjal was conducted using the brinjal hybrid '*707*' at farmers' field in V. Bivan tehsil Nuh, Distt. Mewat (Haryana) during (rainy season) *Kharif* 2017 in randomized block design with 4 replications Each plot size was 15x 10 m2. The brinjal crop was grown as per CCSHAU recommended package of practices, except the herbicide treatment, *viz.* neem cake 200 kg/ha at sowing *fb* pendimethalin 1.0 kg/ha at 3 DAP *fb* soil drenching of metalaxyl MZ 0.2 % at 20 DAP, ethoxysulfuron 20 g/ha PE *fb* PoE at 45 DAP, ethoxysulfuron 20 g/ha PE *fb* PoE at 45 DAP, sulfosulfuron 25 g/ha PoE at 25 and 45 DAP and sulfosulfuron 25 g/ha PE at sowing *fb* PoE 45 DAP. The post-emergence herbicides were applied using 375 litres/ha of water. The observations on number of *O. aegyptiaca* spikes/m^2 as affected by different treatments were recorded on 60, 90, 120 DAP and at harvest. The *O. aegyptiaca* control was assessed visually using 0-100 scale and was recorded at 120 DAP and harvest. The data on plant height, length of *O. aegyptiaca* spike were recorded at 120 DAP. The number of brinjal fruits/plant was recorded from five tagged plants and were averaged to compute number of brinjal fruits/plant. The crop phyto-toxicity due to different treatments was assessed at 30, 60 and 120 DAP on a scale of 0-100, where 0 means no injury and 100 = complete mortality of brinjal plant

The recorded observations were subjected to ANOVA and means were compared with appropriate Fisher's protected LSD test at 5% level of probability. The crop injury data were arc sin transformed prior to ANOVA but data was also presented in their original form for clarity.

Phytotoxicity/injury data in both commodities were arcsin transformed prior to ANOVA. All other data were also subjected to ANOVA and means were compared with appropriate Fisher's protected LSD test at 5% level of probability.

RESULTS AND DISCUSSION

Evaluation of herbicides efficacy on *Orobanche aegyptiaca* in tomato

The *Orobanche aegyptiaca* panicles didn't appear in any of the treatment up to 60 DAP during 2017-18 at field of Arsad but during 2016-17 at the field of Abaas of Nuh, some panicles appeared even at 60 DAP. During 2016-17, although, the pre-emergence application of ethoxysulfuron at 25 g/ha and oxyfluorfen at 120 g/ha proved very effective against *O. aegyptiaca* but they caused toxicity to tomato plants. The percentage toxicity was more due to oxyfluorfen as compared to ethoxysulfuron. At 30 days after planting (DAP), 100% mortality of tomato plants was recorded. Plants which survived after treatment of ethoxysulfuron (PRE) were also very weak and wrinkled with stunted growth. Excellent control of *O. aegyptiaca* was achieved with post-emergence spray of sulfosulfuron and ethoxysulfuron compared to untreated control. During 2016-17, at the field of Arsad, ethoxysulfuron and sulfosulfuron treated plots showed infestation of 2.0-7.7 *O. aegyptiaca* spikes/m^2 at 120 DAP with no injury to tomato crop but at the field of Abaas, number of *O. aegyptiaca* panicles in the plots treated with sulfosulfuron and ethoxysulfuron (PoE) were 0.7-2.7/m^2 and 1.3-1.7/m^2 during 2016-17 and 2017-18, respectively as against 14.7-40.0 panicle/m^2 in untreated check (**Table 1**). During 2017-18, plots treated with ethoxysulfuron remained free from *O. aegyptiaca* even up to 120 DAP and exhibited 85 to 100% control of *O. aegyptiaca* up to harvest without any crop suppression. The *O. aegyptiaca* spikes which emerged 120 DAP or at harvest in ethoxysulfuron and sulfosulfuron treatments were very weak and small sized. Sulfosulfuron is registered for *O. aegyptiaca* control in Israel in tomato, so obviously it was well expected no any damage in tomato. These results corroborate the earlier findings of Eizenberg *et al*. (2004) and Punia *et al*. (2016) who reported effective control of *O. aegyptiaca* in tomato with post emergence use of sulfosulfuron at 25, 50 and 75.0 g/ha. Ethoxysulfuron 25 g/ha (PRE)

Table 1. Effect of different weed control treatments on *Orobanche aegyptiaca* population, visually assessed control and spike length of broom rape, tomato plant height, crop toxicity and tomato fruit yield and B:C (2016-17) (farmer Arsad field)

Treatment	No. of broom rape spikes/m^2			Broom rape control (%)			Broom rape spike length (cms)	Tomato plant height (cms)	Tomato crop phytotoxicity (%) 30 DAT	No. of tomato fruits/ plant	Tomato fruit yield (t/ha)	B:C
	90 DAP	120 DAP	Harvest	90 DAP	120 DAP	Harvest						
Ethoxysulfuron 25 g/ha PE	1.24 (0.7)	1.33 (1.0)	2.35 (5.0)	79.5 (95.0)	71.9 (90.0)	69.3 (90.0)	1.2	14.3	70.0 (88.3)	3.3	0.2	0.06
Oxyfluorfen 120 g/ha PE	1 (0)	1.24 (0.7)	1.24 (0.7)	77 (95.0)	66.8 (85.0)	71.5 (90.0)	0.9	16.0	79.5 (95)	2.7	0	0
Ethoxysulfuron 50 g/ha PoE at 60 and 90 DAP	1.58 (1.6)	1.79 (2.3)	3.15 (9.0)	71.6 (92.0)	63.5 (65.0)	60.1 (76.0)	16.9	44.9	0 (0)	26.7	18.3	5.78
Sulfosulfuron PoE 25 g/ha at 60 DAP *fb* 50 g/ha 90 DAP	1 (0)	2.89 (7.7)	2.06 (3.3)	71.9 (90.0)	65 (80.0)	56.9 (70.0)	15.7	44.0	0 (0)	24	17.9	5.27
Sulfosulfuron 50 g/ha PoE at 60 and 90 DAP	1 (0)	1.67 (2.0)	2.81 (7.0)	90 (100.0)	79 (95.0)	67.2 (82.0)	18.5	45.0	0 (0)	29	20.5	5.88
Farmers practice of hand pulling	1 (0)	2.21 (4.0)	3.45 (11.0)	50.8 (60.0)	45 (45.0)	36.2 (35.0)	12.6	45.0	0 (0)	20	14.6	3.22
Weedy check	3.49 (11.3)	6.40 (40.0)	6.03 (35.6)	0 (0)	0 (0)	0 (0)	19.3	39.7	0 (0)	14	10.5	3.44
LSD (p=0.05)	0.6	0.96	0.99	8.8	9.4	5.8	0.45	2.4	6.92	1.58	0.75	-

*Original figures in parentheses related to *broom rape* density were subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis. Values on broom rape control were subjected to arc sin^{-1} transformation before statistical analysis. Broom rape did not emerge above ground up to 60 DAP so no data is generated. PE: Pre-emergence application; PoE: Post-emergence application; DAP: Days after planting was more phytotoxic than its PoE application and tomato exhibited severe growth reduction. At the field of Abaas, during 2016-17 and 2017-18, minor developmental delay in tomato was observed with ethoxysulfuron applied PE or 30 DAP at 25 g/ha with 10% phytotoxicity recorded at 10 DAT which further reduced to only 3.3% at harvest. No damage was observed to tomato plants with the use of post-emergence application of either sulfosulfuron or ethoxysulfuron during 2016-17 at the field of Arsad and Abaas during 2016-17 and 2017-18 as well (**Table 2**). During 2016-17, maximum fruit yield (20.5 and 26.9 t/ha) was recorded in the plots treated with sulfosulfuron 50 g/ha at 60 and 90 DAP at both the locations but during 2017-18 (Abaas's farm), sulfosulfuron 25 g/ha at 60 DAP and 50 g/ha at 90 DAP resulted the maximum fruit yield (35.7 t/ha) which was 42.8% higher than untreated check, and it was at par with ethoxysulfuron 50 g/ha at 60 and 90 DAP, and sulfosulfuron 50 g/ha at 60 and 90 DAP (**Table 3**). During 2016-17, maximum B:C (5.88 and 8.0) was obtained with post-emergence use of sulfosulfuron 50 g/ha at 60 and 90 DAP but during 2017-18, the maximum B:C of 5.0 was obtained with use of sulfosulfuron at 25 g/ha at 60 DAP and 50 g/ha at 90 DAP. These findings were in accordance with those of Dinesha *et al*. (2012) and Hershenhorn *et al.* 2009 who reported excellent efficacy of sulfosulfuron 75 g/ha at 30 DAP in preventing the development of *O. aegyptiaca* and reducing the seed inoculums potential in the soil by registering significantly lowest *O. aegyptiaca* number, spike

Table 2. Effect of different weed control treatments on *Orobanche aegyptiaca* population, visually assessed control, plant height, crop toxicity and fruit yield of tomato (farmer Abaas field) 2016-17

Treatment	No. of broom rape spikes/m²				Broom rape control (%)			Visual phytotoxicity (%) on crop			Plant height (cms) 120 DAP	No. of fruits/ plant	Fruit yield (t/ha)	B:C
	60 DAP	90 DAP	120 DAP	Harvest	90 DAP	120 DAP	Harvest	10 DAP	30 DAP	120 DAP				
Ethoxysulfuron 25 g/ha PE)	1.0 (0)	1.0 (0)	1.24 (0.7)	1.49 (1.3)	90 (100.0)	90 (100.0)	72.3 (86.7)	58. (73.3)	55.8 (68.3)	49.9 (58.3)	17.0	3.7	0.27	0.1
Oxyfluorfen 120 g/ha (PE)	1.0 (0)	1.0 (0)	1 (0)	1 (0)	90 (100.0)	90 (100.0)	90 (100)	60. (75.0)	90 (100)	90 (100)	0.0	0.0	0.00	0.0
Ethoxysulfuron 50 g/ha at 60 and 90 DAP	1.4 (1)	1.75 (2.33)	1.91 (2.7)	1.85 (3.0)	79.5 (95.0)	67.8 (80.0)	62.5 (78.3)	18 (10.0)	19.3 (11.7)	8.6 (3.3)	47.0	32.0	23.50	7.6
Sulfosulfuron 25 g/ha at 60 DAT *fb* 50 g/ha 90 DAP	1.4 (1)	1.47 (1.33)	1.58 (1.7)	1.66 (2.0)	78.1 (93.3)	72.8 (86.7)	73.5 (88.3)	1 (0)	1 (0)	1 (0)	47.0	35.0	25.30	7.7
Sulfosulfuron 50 g/ha at 60 and 90 DAP	1.0 (0)	1.24 (0.67)	1.24 (0.7)	1.48 (1.7)	90 (100.0)	82.4 (95.0)	82.4 (95.0)	8.6 (3.3)	4.3 (1.7)	1 (0)	47.0	37.0	26.90	8.0
Hand pulling (FP)	1.7 (2)	2.57 (5.67)	2.95 (8.0)	3.08 (8.7)	62.3 (78.3)	33.2 (31.7)	27.1 (21.7)	1 (0)	1 (0)	1 (0)	44.7	28.3	16.57	3.7
Weedy check	1.7 (2)	3.31 (10.0)	3.65 (12.3)	4.07 (15.7)	72.4 (86.7)	1 (0)	1 (0)	1 (0)	1 (0)	1 (0)	43.7	26.7	14.37	4.9
LSD (p=0.05)	0.3	0.66	0.72	1.13	13.9	19.8	18.9	6.7	68.3	6.4	3.2	4.6	1.13	

*Original figures in parentheses related to broom rape density were subjected to square root transformation ($\sqrt{x+1}$) and visual toxicity to arc/sin transformation before statistical analysis

Table 3. Effect of different weed control treatments on *Orobanche aegyptiaca* population, visually assessed control, plant height, crop toxicity and fruit yield of tomato (2017-18) (farmer Abaas field)

Treatment	No. of *O. aegyptiaca* spikes/m²				Visual phytotoxicity (%) on crop	Visual broom rape control (%)		Plant height (cms) 120 DAP	No. of fruits/ plant	Fruit yield (t/ha)	B:C
	60 DAP	90 DAP	120 DAP	Harvest	10 DAT	120 DAP	Harvest				
Ethoxysulfuron 50 g/ha PoE at 60 and 90 DAP	0	1.14 (0.40)	1.49 (1.33)	1.99 (3.00)	14.0 (6)	73.5 (88)	62.9 (79)	52.0	35.0	25.4	4.9
Sulfosulfuron 25 g/ha PoE at 60 DAT *fb* 50 g/ha 90 DAP	0	1.24 (0.60)	1.58 (1.67)	1.73 (2.33)	0 (0)	71.1 (85)	72.4 (87)	51.7	35.7	24.9	5.0
Sulfosulfuron 50 g/ha PoE at 60 and 90 DAP	0	1(0)	1.63 (1.67)	1.72 (2.00)	15.2 (7)	90 (100)	67.4 (85)	51.7	34.3	24.4	4.6
Farmers practice - hand pulling	0	2.76 (6.20)	2.70 (6.33)	2.52 (5.67)	0 (0)	37.2 (37)	33.1 (30)	46.3	27.3	16.7	2.7
Weedy check	0	3.21 (9.40)	3.93 (14.67)	4.50 (19.33)	0 (0)	0.0 (0)	0.0 (0)	43.3	25.0	13.0	3.0
LSD(P=0.05)		0.52	0.74	1.05	2.59	20.0	14.9	5.6	2.6	1.4	-

*Original figures in parentheses related to broom rape density were subjected to square root transformation ($\sqrt{x+1}$) and visual toxicity to arc/sin transformation before statistical analysis; PoE= post-emergence application; DAP= days after planting height, spike dry weight with higher *O. aegyptiaca* control efficiency, which also accounted for higher tomato plant height, number of branches, leaf area/ plant at harvest, higher fruit weight/ plant and fruit yield of tomato in Karnataka state of India.

Adaptive on-farm trials on the use of herbicides to manage *Orobanche aegyptiaca* in tomato

To demonstrate the efficacy of sulfosulfuron and ethoxysulfuron against parasitic weed *O. aegyptiaca*, adaptive on-farm trials were conducted at 8 locations in the village Rehna of Nuh tehsil of Mewat district. The application of ethoxysulfuron provided 85-90% control of *O. aegyptiaca with* 3.5-3.7 panicle of *O. aegyptiaca* at harvest and tomato yield of 27.0-27.6 t/ha as against 16.8-19.5 t/ha in untreated check (**Table 4**). Per cent control with the use of sulfosulfuron was higher as compared to ethoxysulfuron which ranged from 90-100% yielding 23.8-26.5 t/ha. On an average, the use of herbicides provided 92.4% control of *O. aegyptiaca* resulting 43% increase in tomato yield,

Evaluation of herbicides against *Orobanche aegyptiaca* in brinjal

The *O. aegyptiaca* panicles didn't appear in any of the treatment up to 60 DAP. Application of neem cake at sowing in combination with pendimethalin followed by soil drenching of metalaxyl (MZ 0.2%) at 20 DAP didn't cause any inhibition in *O. aegyptiaca* emergence as evident from its density at 120 DAP (**Tables 5 and 6**). Although an excellent control of *O. aegyptiaca* was obtained with PoE or PE plus PoE treatments of sulfosulfuron and ethoxysulfuron when compared with untreated controls but these herbicides proved phytotoxic to brinjal crop. *O. aegyptiaca* stalks to the tune of 1.7-3.0 panicles/m^2 appeared in various herbicide treatments which was

Table 4. Efficacy of demonstrated herbicides at the on-farm multi-locational demonstrations conducted on *Orobanche aegyptiaca* control in tomato during 2016-17

Name & address of farmer	Hybrid	Herbicide used	*O. aegyptiaca* panicles/m^2 Treated		Untreated	*O. aegyptiaca* control (%)	Tomato yield (t/ha)	
			120 DAP	Harvest			Treated	Untreated
Arsad, V.Bivan (Nuh)	2853	Sulfosulfuron 25 g/ha PoE at 60 DAT *fb* 50 g/ha 90 DAP	0.2	1.5	16	90	23.8	18.5
Abaas, V. Rehna (Mewat)	Namdhari	Sulfosulfuron 25 g/ha PoE at 60 DAT *fb* 50 g/ha 90 DAP	0	0.4	58	95	24.7	14.0
Abaas, v. Rehna (Mewat)	2853	Ethoxysulfuron 50 g/ha PoE at 60 and 90 DAP	0.3	3.5	48	90	27.0	16.8
Jaid V. Rehna (Nuh)	Himsikhar	Sulfosulfuron 25 g/ha PoE at 60 DAT *fb* 50 g/ha 90 DAP	0	2.4	24	95	24.1	18.9
Jaid, V. Rehna (Nuh)	2853	Sulfosulfuron 25 g/ha PoE at 60 DAT *fb* 50 g/ha 90 DAP	0	1.5	14	94	22.0	17.2
Vaseem,V. Rehna (Nuh)	2853	Sulfosulfuron 25 g/ha PoE at 60 DAT *fb* 50 g/ha 90 DAP	0	4	78	100	24.3	17.0
Lykat,V.Rehna (Nuh)	Satyam	Sulfosulfuron 25 g/ha PoE at 60 DAT *fb* 50 g/ha 90 DAP	0.2	2.4	56	90	26.5	18.0
Lykat,V.Rehna (Nuh)	2853	Ethoxysulfuron 50 g/ha PoE at 60 and 90 DAP	0.4	3.7	50	85	27.6	19.5
Mean	-	-*	0.13	2.42	43	92.37	25.0	17.5

PE: Pre-emergence application; PoE: Post-emergence application; DAP: Days after planting

Table 5. Effect of different weed control treatments on *Orobanche aegyptiaca* population visually assessed control, crop toxicity and fruit yield of brinjal during 2016-2017

Treatment	Number of *O. aegyptiaca* spikes/m^2 (120 DAP)	Visual control (%) (120 DAP)	Visual phytotoxicity (%) on crop 120 DAP	Fruit yield (t/ha)
Neem cake 200 kg/ha at sowing *fb* pendimethalin 1.0 kg/ha at 3 DAP *fb* soil drenching of metalaxyl MZ 0.2% at 20 DAP	5.22(26.2)	0(0)	0(0)	22.5
Ethoxysulfuron 20 g/ha PE *fb* PoE at 45 DAP	1.0(0)	59.3(74)	56.7(70)	11.2
Sulfosulfuron 25 g/ha PoE at 25 and 45 DAP	1.95(3)	63.5(80)	29.9(25)	22.7
Sulfosulfuron 25 g/ha PE at sowing *fb* PoE 45 DAP	1.64(1.7)	64.9(82)	42.1(45)	14.8
Weedy check	4.93(23.5)	0(0)	0(0)	23.4
LSD (p=0.05)	0.50	3.01	2.18	2.4

*Original figures in parenthesis related to *broom rape* density were subjected to square root transformation ($\sqrt{x+1}$) and t on *broom rape* control were subjected to arc sin^{-1} transformation before statistical analysis; PE= pre-emergence application; PoE= post-emergence application; DAT = days after transplanting

Table 6. Effect of different weed control measures on *Orobanche aegyptiaca* population visual control, crop toxicity and fruit yield of brinjal during 2017- 2018

Treatment	Number of *O. aegyptiaca* spikes/m^2 (120 DAS)	Visual control (%) (120 DAS)	Visual phytotoxicity (%) on brinjal crop 120 DAP	Brinjal fruit yield (t/ha)
Neem cake 200 kg/ha at sowing *fb* pendimethalin 1.0 kg/ha at 3 DAP *fb* soil drenching of metalaxyl MZ 0.2 % at 20 DAT	5.13(25.4)	0(0)	0(0)	21.2
Ethoxysulfuron 20 g/ha (PRE) and at 45 DAT	1.41(1.0)	63.5(80)	56.7(70)	12.4
Sulfosulfuron 25 g/ha at 25 and 45 DAT	2.0(3)	56.7(70)	33.1(30.0)	20.8
Sulfosulfuron 25 g/ha at sowing and 45 DAT	1.41(1.0)	73.5(88.3)	36.5(35.0)	15.6
Weedy check	5.29(27.0)	0(0)	0(0)	21.8
LSD (p=0.05)	0.46	3.01	2.18	2.6

*Original figures in parentheses related to broom rape density were subjected to square root transformation ($\sqrt{x+1}$) and t on broom rape control were subjected to arc/sin transformation before statistical analysis

significantly less than untreated control. The *O. aegyptiaca* spikes which emerged in ethoxysulfuron and sulfosulfuron treatments were very weak and small sized. Ethoxysulfuron 20 g/ha was more phytotoxic than sulfosulfuron as 70% brinjal growth reduction occurred with this treatment. Only 25 - 30% suppression on brinjal plant was recorded with sulfosulfuron at 25 g/ha PoE at 25 and 45 DAP (**Tables 5** and **6**) resulting in 80 and 88% control of *O. aegyptiaca* during 2017 and 2018, respectively. The crop suppression with the use of sulfosulfuron 25 g/ha had also an adverse effect on plant height, number of fruits/plant and total fruit yield of brinjal. The herbicide treatment in brinjal resulted into malformed and splitted brinjal fruits along with yield penalty was earlier reported by Anonymous (2018 and 2019) in sandy loam soils of Haryana. Malformation and splitting of brinjal fruits were also reported with use of rimsulfuron (Vouzounis and Americanos 1998).

Maximum fruit yield of 23.4 and 21.8 t/ha was recorded from untreated check during 2016-17 and 2017-18, respectively which was at par with sulfosulfuron 25 g/ha at 25 and 45 DAP (22.7 and 20.8 t/ha) and also neem cake *fb* pendimethalin and metalyxyl, but significantly higher than ethoxysulfuron and sulfosulfuron PE (**Table 5**). Sulfosulfuron at 20 g/ha at 45 and 90 DAP in brinjal provided effective control of *O. aegyptiaca* but with 5-10% crop suppression (Singh *et.al.* 2017).

Conclusions

Based on the present investigation, it was concluded that post-emergence application of (30, 60/ 90 DAP) ethoxysulfuron/sulfosulfuron 25 g/ha at 30 DAP followed by its use at 50 g/ha or sulfosulfuron at 50 g/ha at 30 and 60 DAP could effectively manage *O. aegyptiaca* in the tomato. The neem cake and metalaxyl could not inhibit the growth of *O. aegyptiaca* in brinjal and also none of tested herbicide was selective to the brinjal crop.

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Indian Journal of Weed Science **53**(4): 398–404, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Efficacy of sequential application of herbicides on weed management, rice nutrient uptake and soil nutrient status in dry direct-seeded rice-greengram sequence

B. Jyothi Basu*, P.V.N. Prasad, V.R.K. Murthy, Y. Ashoka Rani and P.R.K. Prasad

Department of Agronomy, Agricultural College, Acharya N.G. Ranga Agricultural University, Bapatla, Andhra Pradesh 522101, India

**Email: jyoba226@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00073.3

Type of article: Research article

Received : 9 May 2021
Revised : 29 November 2021
Accepted : 1 December 2021

KEYWORDS

Chlorimuron-ethyl, Dry direct-seeded rice, Greengram, Metsulfuron-methyl, Nutrient uptake, Soil nutrient status

ABSTRACT

A field experiment was conducted on sandy loam soils of Agricultural College Farm, Bapatla, Andhra Pradesh, India, during 2015-16 and 2016-17 in direct-seeded rice (DSR) to test the efficacy of sequential application of herbicides on weed management, rice nutrient uptake and productivity and to assess herbicides residual effect on succeeding greengram. The maximum total nitrogen, phosphorus and potassium uptake at maturity of rice was recorded with pre-emergence application (PE) of bensulfuron-methyl + pretilachlor with safener (ready-mix) at 500 g/ha *fb* post-emergence application (PoE) of azimsulfuron 20 g/ha at 25 days after seeding (DAS) *fb* metsulfuron-methyl and chlorimuron-ethyl (ready-mix) 4 g/ha PoE 45 DAS. The soil available nutrient status and the uptake of nitrogen, phosphorus and potassium by succeeding greengram was not influenced by different weed management treatments applied in DSR.

INTRODUCTION

Rice is the staple food crop of the tropics, in general and India in particular. "Rice is Life" aptly describes the importance of rice in food and nutritional security for the Asian countries. India is the second largest producer of rice in the world grown in an area of 43.8 million hectares with a production of 118.4 million tonnes and productivity of 2.7 t/ha (GOI 2021). In Andhra Pradesh, it is grown in an area of 2.21 million hectares with a production of 8.23 million tons and productivity of 3.73 t/ha (Reserve Bank of India 2020). Weed infestation is the major biotic constraint for higher productivity especially in dry direct-seeded rice (DSR) (Rao *et al.* 2007, 2017). The degree of competition and extent of yield losses vary greatly with method of rice cultivation. Weeds compete with crop plants for moisture, nutrients, light, space and other growth factors and in the absence of effective control measures, deplete considerable amount of applied nutrients resulting in a significant yield loss (Rao *et al.* 2007). Thus, the present study was carried out with an objective to assess the efficacy of sequential application of herbicides on weed management, rice productivity, nutrient uptake and soil nutrient status in direct-seeded rice-greengram sequence.

MATERIALS AND METHODS

A field study was carried out during rainy season of *(Kharif)* 2015 and 2016 at the Agricultural College Farm, Bapatla, Guntur, Andhra Pradesh under irrigated conditions. The soil of the experimental field was sandy loam in texture, having pH 8.0 and 7.5 during 2015 and 2016, respectively, low in organic carbon (0.45 and 0.48%), low in available nitrogen (212 and 230 kg/ha) and available phosphorus (17 and 18 kg/ha) and medium range in available potassium (261 and 285 kg/ha).

The field was dry ploughed with tractor drawn cultivar and harrowed with rotavator. The area was divided into required number of plots as per layout plan. Irrigation channels were formed so as to give sufficient water to each plot. A seed rate of 50 kg/ha was adopted and the cultivar was '*Samba mahsuri (BPT-5204)*'. Seeds were weighed separately for each plot and sown in solid rows in the furrows opened by line markers at 25 cm interval. The field was irrigated immediately after sowing the dry seeds to get good germination. Application of fertilizers was done as per the recommendation *i.e.* 120 kg N, 60 kg P and 60 kg K/ha in the form of urea, single superphosphate and muriate of potash, respectively. Nitrogen was applied in 3 equal splits at sowing, active tillering and panicle initiation stage. Entire quantity of phosphorus was applied as basal. Potassium was applied in 2 splits 2/3 as basal and 1/3 at panicle initiation stage along with urea. Weed flora from the experimental field were collected randomly selected quadrats each of 0.25/m^2 area (0.5 x 0.5 m) in the sampling rows of each plot at 30, 60 days after seeding (DAS) and at maturity. Weeds in each quadrat were grouped into grasses, sedges and broad-leaved weeds and these groups were added to obtain total weed density (no./m^2). The weed samples were initially shade dried followed by oven dried at 60^{o}C till to a constant weight to measure total dry weight of weeds (biomass) in g/m^2.

There were fourteen treatments:- pyrazosulfuron-ethyl 25 g/ha pre-emergence (PE) followed by (*fb*) azimsulfuron 20 g/ha post-emergence (PoE); pyrazosulfuron-ethyl 25 g/ha *fb* bispyribac-sodium 25 g/ha PoE; bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE; bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE; oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE; oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE; pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE; pyrazosulfuron ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE; bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE; bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE, oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE; oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE; weed free and weedy check.

Herbicides were sprayed using a knapsack sprayer fitted with a flat-fan nozzle with a recommended spray volume of 500 l/ha. Pre-emergence herbicides (pyrazosulfuron-ethyl and oxadiargyl) were applied uniformly at 3 DAS by using knapsack sprayer. Bensulfuron methyl + pretilachlor with safener applied uniformly at 3 days after sowing (DAS) by mixing the herbicide with dry sand at 50 kg/ha and broadcasted uniformly under thin film of water. The post-emergence herbicides *i.e.* azimsulfuron, bispyribac-sodium were applied at 25 DAS, and metsulfuron-methyl + chlorimuron-ethyl was applied at 45 DAS by using knapsack sprayer. After harvest and threshing of crop, grain yield was recorded in net plot wise and converted to grain yield per hectare. Plant samples collected to estimate the uptake of nitrogen, phosphorus and potassium at harvest of the direct-seeded rice and greengram. The oven dried pant samples were chopped and ground into fine powder. The analysis of N, P and K was made by following methodology of Bremner, (1965), Koeing and Johnson, (1942) and Jackson, 1973, respectively. Immediately after harvest of direct-seeded rice and greengram during both the annual cropping cycles, soil samples were drawn from individual plots of the replications and analyzed for post-harvest fertility status of N, P and K by respective standard procedures. N uptake was calculated using the formula:

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient concentration (\%)x weight of dry matter (kg/ha)}}{100}$$

Statistical analysis was done by analysis of variance for randomized complete block design as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect on total weed density in dry direct-seeded rice

All the weed management practices significantly reduced the total weed density in rice during both the years of study at all the stages of crop growth compared to weedy check. At 30 and 60 DAS, among the herbicide combinations, significantly the lowest total weed density was recorded with bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE and it was at par with bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE. A similar trend in treatments response was observed at harvest as well. None of the herbicide treatments were as effective as weed free, which was significantly lowest weed density than rest of the treatments at all stages of observation during both the years of study (**Table 1**). The present findings are inconformity with Hossain and Mondal (2014), Rammu Lodhi (2016) and Ajay Singh *et al.* (2017).

Effect on total weed biomass in dry direct-seeded rice

Significantly higher weed biomass was observed in weedy check. The lowest weed biomass was with bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/

ha PoE and it was at par with bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE in herbicide combinations during both the years of study at 30 and 60 DAS and harvest (**Table 2**). The results of this study are in agreement with Madhukumar *et al.* (2013), Rammu Lodhi (2016) and Vijay Singh *et al.* (2016).

Effect on grain yield of dry direct-seeded rice

The maximum grain yield (5.11 and 5.31 t/ha, respectively) was obtained with bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE and it was at par with bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE; pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE; oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE and pyrazosulfuron ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE (**Table 3**). Among all the weed management treatments, the highest grain yield (5450 and 5455 kg/ha during 2015-16 and 2016-17, respectively) was recorded in weed free treatment, which was significantly superior to rest of the treatments except bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE,, which was however, comparable to the treatments bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE; pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE; oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE and pyrazosulfuron ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE. The lowest grain yield (2.16 and 2.53 t/ha during 2015 and 2016,

Table 1. Total weeds density at different growth stages of dry direct-seeded rice as influenced by weed management treatments during *Kharif* season 2015-16 and 2016-17

Treatment	Total weeds density (no./m^2)					
	30 DAS		60 DAS		At harvest	
	2015	2016	2015	2016	2015	2016
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE	6.3 (39.7)	6.0 (36.0)	10.2 (103.3)	10.2 (104.7)	8.1 (65.3)	8.5 (72.0)
Pyrazosulfuron-ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	6.4 (40.7)	6.4 (40.3)	10.2 (103.3)	9.9 (97.7)	8.4 (70.3)	8.4 (70.3)
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE	4.8 (22.3)	5.0 (24.3)	8.8 (76.3)	8.9 (79.3)	6.5 (42.3)	6.9 (46.7)
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	4.8 (22.3)	5.1 (25.7)	8.7 (75.7)	9.0 (80.0)	7.0 (48.0)	6.7 (44.0)
Oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE	6.2 (38.7)	6.2 (38.0)	10.5 (109.3)	10.3 (106.0)	8.6 (74.0)	8.7 (76.0)
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	6.5 (42.0)	6.2 (37.7)	10.9 (117.7)	10.8 (116.3)	9.0 (81.3)	9.1 (81.7)
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	5.9 (34.7)	6.2 (38.3)	7.3 (52.7)	7.6 (57.7)	6.1 (37.3)	6.0 (35.0)
Pyrazosulfuron ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	6.1 (37.3)	6.3 (39.7)	7.5 (55.7)	7.7 (58.3)	6.4 (40.0)	6.3 (38.7)
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	4.4 (19.0)	4.8 (23.7)	5.8 (33.0)	6.6 (43.3)	4.7 (21.3)	4.4 (19.0)
bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	5.1 (26.3)	5.5 (29.3)	6.4 (40.7)	6.8 (45.7)	5.4 (28.3)	5.5 (29.3)
oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	6.2 (37.7)	6.1 (37.3)	7.6 (57.3)	7.5 (56.3)	6.1 (36.7)	6.6 (43.3)
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	6.5 (42.3)	6.6 (42.7)	7.8 (60.3)	7.7 (59.0)	6.4 (40.3)	6.4 (41.0)
Weed free	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)
Weedy check	10.8 (117.3)	11.2 (124.3)	13.5 (182.0)	13.2 (173.0)	10.7 (114.3)	11.3 (127.7)
LSD (p = 0.05)	0.8	0.8	0.9	0.7	0.5	0.6

DAS: Days after seeding; PE : Pre-emergence PoE: Post-emergence; *fb*: Followed by; Data in parentheses are original values respectively) was in untreated weedy check plot, which was significantly lower than any of the herbicide treatment. These results were in agreement with the findings of Naseeruddin and Subramanyam (2013), Hossain and Mondal (2014), Rammu Lodhi, (2016), and Ajay Singh *et al.* (2017)

Residual effect of on seed yield of succeeding greengram

The seed yield of succeeding greengram crop after rice were statistically at par during both the years of study. This indicates lack of any adverse impact of herbicides applied to rice on succeeding greengram due to their degradation in the soil resulting in no residual effect left to affect the seed yields of greengram as reported by Kumaran *et al.* (2015).

Effect on rice nutrient uptake

The highest uptake of nitrogen, phosphorous and potassium at maturity of dry direct-seeded rice was recorded with weed free treatment which was significantly superior to rest of the treatments. However, weed free did not differ statistically with bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE; bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE ; pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE and oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE in nitrogen, phosphorous and potassium uptake (**Table 4, 5** and **6**). All the weed management practices treatments distinctly increased the nitrogen, phosphorous and potassium uptake over weedy check. Increased rice productivity under various weed management practices was obviously due to effective weed control right from the initial stages up to maturity that resulted in higher nutrient uptake. The present findings are in agreement with those of Mandhata Singh *et al* (2010).

Nitrogen, phosphorous and potassium uptake estimated at harvest of greengram was not influenced by herbicidal treatments taken up in preceding rice crop during both the years.

Table 2. Total weeds biomass at different growth stages of direct seeded rice as influenced by weed management treatments during *Kharif* 2015-16 and 2016-17

Treatment	Total weeds biomass (g/m^2)					
	30 DAS		60 DAS		At harvest	
	2015	2016	2015	2016	2015	2016
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE	5.4 (29.2)	5.2 (26.1)	10.2 (104.4)	9.1 (82.1)	7.8 (59.9)	10.2 (103.5)
Pyrazosulfuron-ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	6.0 (35.1)	6.0 (35.4)	9.5 (89.2)	8.7 (74.9)	10.2 (105.2)	9.5 (90.4)
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE	3.4 (11.1)	3.5 (11.6)	6.4 (40.5)	6.8 (45.4)	5.6 (31.3)	6.0 (35.5)
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	3.6 (12.6)	3.7 (13.5)	6.8 (45.2)	6.9 (46.7)	6.5 (42.4)	6.4 (40.5)
Oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE	5.5 (29.5)	5.5 (29.4)	10.3 (104.8)	10.0 (99.3)	10.1 (102.7)	9.4 (87.8)
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	5.7 (32.2)	5.3 (28.0)	10.2 (103.9)	10.5 (110.4)	10.1 (103.6)	10.5 (110.8)
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	5.1 (25.5)	5.2 (26.5)	6.3 (40.2)	6.8 (46.0)	6.4 (40.9)	6.6 (44.0)
Pyrazosulfuron ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	5.4 (28.8)	5.8 (32.7)	6.4 (40.6)	6.5 (42.8)	7.3 (53.0)	5.8 (34.2)
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	3.2 (9.5)	3.4 (11.9)	4.1 (16.1)	4.7 (21.9)	3.6 (12.7)	3.6 (12.4)
bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	3.9 (14.7)	4.0 (15.3)	4.7 (22.1)	4.9 (24.2)	4.2 (17.5)	4.5 (19.7)
oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	5.6 (30.9)	5.3 (27.6)	6.7 (44.7)	6.8 (46.1)	6.1 (36.3)	7.1 (49.5)
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	5.8 (33.8)	5.7 (31.9)	7.6 (58.0)	7.2 (52.5)	6.8 (47.1)	7.0 (48.6)
Weed free	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)	0.7 (0.0)
Weedy check	10.9 (117.8)	10.6 (112.8)	15.8 (249.6)	14.0 (196.8)	16.7 (282.1)	18.6 (347.8)
LSD (p = 0.05)	0.7	0.8	1.0	0.9	1.5	1.2

DAS: Days after seeding; PE: Pre-emergence PoE: Post-emergence; *fb*: Followed by; Data in parentheses are original values

Table 3. The grain yield of rice-greengram sequence as influenced by weed management treatments during *Kharif* season 2015-16 and 2016-17

Treatment	Grain yield kg/ha				Return per rupee investment of rice-greengram system	
	Rice		Greengram			
	2015	2016	2015	2016	2015	2016
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE	3844	3619	548	632	1.42	1.58
Pyrazosulfuron-ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	3604	3521	532	624	1.23	1.49
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE	4118	4203	556	652	1.47	1.81
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	3674	3923	548	548	1.21	1.38
Oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE	3593	3423	537	625	1.26	1.47
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	3302	3261	529	617	1.07	1.34
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	4714	4687	559	652	1.63	1.93
Pyrazosulfuron ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	4599	4661	537	655	1.48	1.90
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	5107	5313	571	662	1.72	2.11
bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	4828	5014	565	656	1.56	1.94
oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	4666	4601	530	649	1.52	1.87
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	4371	4437	534	642	1.37	1.75
Weed free	5450	5455	585	662	1.41	1.70
Weedy check	2159	2529	523	594	0.63	1.05
LSD (p=0.05)	678	865	NS	NS	-	-

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

Table 4. Nutrient uptake of direct-seeded rice at harvest as influenced by weed management treatments during *kharif* 2015-16 and 2016-17

Treatment	Nutrient uptake (kg/ha)					
	N		P		K	
	2015	2016	2015	2016	2015	2016
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE	87.2	89.0	22.1	24.5	98.6	100.1
Pyrazosulfuron-ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	82.2	86.0	19.7	23.0	95.6	103.0
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE	97.8	107.6	24.5	28.8	107.8	120.9
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	88.8	99.8	20.9	27.8	99.0	125.6
Oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE	80.1	83.1	19.4	22.0	95.3	101.4
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	73.8	76.6	17.6	20.2	87.3	96.6
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	115.2	124.0	28.7	36.3	123.1	137.6
Pyrazosulfuron ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	109.8	120.6	25.8	34.1	119.7	139.4
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	125.5	139.1	33.7	41.1	132.8	151.3
bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	118.3	129.5	30.3	37.8	128.1	145.9
oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	111.4	117.6	28.0	33.2	123.0	128.6
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	104.9	110.8	24.5	31.5	116.1	132.9
Weed free	132.6	144.0	36.3	43.5	137.9	155.0
Weedy check	53.1	61.9	11.3	15.7	66.0	79.1
LSD (p=0.05)	16.6	27.1	5.4	8.1	15.5	24.7

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

Table 5. The influence of weed management treatments on the soil fertility status (kg/ha) after the harvest of direct-seeded rice as during *Kharif* 2015-16 and 2016-17

Treatment	Soil fertility status (kg/ha)					
	2015-16			2016-17		
	Available N	Available P	Available K	Available N	Available P	Available K
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE	190.2	12.6	147.1	183.5	14.7	137.4
Pyrazosulfuron-ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	194.2	13.2	148.4	186.3	14.4	141.6
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE	190.2	12.1	144.5	176.7	13.5	134.1
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	192.3	12.2	146.1	179.0	13.9	138.4
Oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE	196.7	14.3	150.0	187.3	14.5	138.4
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	198.9	14.5	151.8	189.3	14.8	142.9
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	181.4	12.6	142.9	177.8	13.8	139.3
Pyrazosulfuron ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	184.1	12.4	144.2	175.2	14.2	138.1
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	179.1	11.6	141.4	174.0	13.2	133.4
bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	180.7	12.7	143.3	178.2	13.6	137.4
oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	186.6	12.5	145.5	177.1	14.1	140.7
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	191.5	12.9	146.7	183.2	14.4	143.5
Weed free	182.8	14.5	153.5	188.2	16.3	147.9
Weedy check	180.0	11.5	144.4	176.8	12.8	135.2
LSD (p=0.05)	NS	NS	NS	NS	NS	NS

Table 6. The influence of weed management treatments on the nutrient uptake of greengram as in rice-greengram sequence during *Rabi* season 2015-16 and 2016-17

Treatment	Nutrient uptake (kg/ha)					
	N		P		K	
	2015	2016	2015	2016	2015	2016
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE	26.9	32.3	4.3	5.4	24.1	28.4
Pyrazosulfuron-ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	26.6	31.4	4.0	5.2	21.9	27.8
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE	28.0	32.3	4.6	5.8	24.7	29.1
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	27.0	28.8	4.1	4.7	23.3	26.1
Oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE	25.3	33.1	3.9	5.5	21.9	30.7
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	26.8	31.2	4.1	5.1	23.1	27.3
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	27.9	31.4	4.2	5.1	24.3	27.0
Pyrazosulfuron ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	26.5	32.7	3.9	5.6	23.0	29.0
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	27.8	33.4	4.3	5.6	24.4	28.5
bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	27.6	32.9	4.5	5.6	23.8	28.7
oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	26.6	32.1	4.1	5.4	22.1	28.2
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	26.3	32.2	4.0	5.6	22.0	28.0
Weed free	28.1	33.4	4.6	5.8	24.5	29.4
Weedy check	25.6	30.9	4.0	5.3	22.3	27.9
LSD (p=0.05)	NS	NS	NS	NS	NS	NS

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

Table 7. The influence of weed management treatments on the soil fertility status as recorded after greengram harvest in rice-greengram sequence during 2015-16 and 2016-17 *Rabi* (winter) season

Treatment	Soil fertility status (kg/ha)					
	2015-16			2016-17		
	Available N	Available P	Available K	Available N	Available P	Available K
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE	208	10	131	204	11	119
Pyrazosulfuron-ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	213	11	132	207	12	125
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE	207	10	129	197	10	117
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	208	10	129	202	10	120
Oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE	214	12	133	210	11	123
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE	214	13	134	211	12	125
Pyrazosulfuron-ethyl 25 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	200	10	125	198	11	121
Pyrazosulfuron ethyl 25 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	202	10	130	196	11	120
Bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	195	9	125	193	9	117
bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	199	10	127	197	10	119
oxadiargyl 75 g/ha PE *fb* azimsulfuron 20 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	207	11	130	204	11	123
Oxadiargyl 75 g/ha PE *fb* bispyribac-sodium 25 g/ha PoE *fb* metsulfuron-methyl + chlorimuron-ethyl 4 g/ha PoE	210	12	131	206	12	125
Weed free	212	11	133	209	13	128
Weedy check	201	10	128	195	10	118
LSD (p = 0.05)	NS	NS	NS	NS	NS	NS

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

Soil available nutrients

Soil available nutrients (nitrogen, phosphorous and potassium) after rice-greengram sequence was not influenced by the different weed management practices during both the years of study (**Table 7**).

The pre-emergence application of bensulfuron-methyl + pretilachlor with safener 60 + 500 g/ha PE *fb* post-emergence application of azimsulfuron 20 g/ha at 25 DAS *fb* post-emergence application of metsulfuron-methyl and chlorimuron-ethyl 4 g/ha applied at 45 DAS may be used for attaining effective weed management, maximum rice grain yield and nutrients uptake with no residual effect on succeeding greengram.

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Indian Journal of Weed Science **53**(4): 405–410, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Weed management with pre- and post-emergence herbicides in maize under maize-greengram cropping system

B. Sandhya Rani*, V. Chandrika, G. Prabhakara Reddy, P. Sudhakar and G. Karuna Sagar

Department of Agronomy, S.V. Agricultural College, Tirupati, Andhra Pradesh 517502, India

**Email: sandhya.reddy010@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00074.5

Type of article: Research article

Received : 30 June 2021
Revised : 12 October 2021
Accepted : 15 October 2021

KEYWORDS

Cropping system, Greengram, Halosulfuron-methyl, Herbicides, Maize, Tembotrione, Topramezone, Weed management

ABSTRACT

An experiment was conducted during the two consecutive years of winter, 2017-18, 2018-19 and summer, 2018 and 2019 at wetland farm of S.V. Agricultural College, Tirupati, Andhra Pradesh, in a randomized block design with ten weed management treatments and three replications. The lowest weed density and biomass, highest weed control efficiency and maize growth parameters, yield attributes, kernel and straw yields were recorded with hand weeding (HW) twice at 15 and 30 days after seeding (DAS), which was statistically at par with atrazine 1.0 kg/ha as pre-emergence application (PE) followed by (*fb)* topramezone 30 g/ha or tembotrione 120 g/ha as post-emergence application (PoE) or one HW at 30 DAS. Higher greengram seed yield, haulm yield, and lower total weed density and biomass in succeeding greengram were noticed with HW twice at 15 and 30 DAS, which was comparable with atrazine 1.0 kg/ha as PE *fb* one HW at 30 DAS or topramezone 30 g/ha or tembotrione 120 g/ha or halosulfuron methyl 67.5 g/ha as PoE applied in maize. Based on this study it was concluded that atrazine 1.0 kg/ha as PE *fb* topramezone 30 g/ha or tembotrione 120 g/ha as PoE can be used for the most effective weed management to increase the productivity in winter maize followed by summer greengram cropping system.

INTRODUCTION

Maize (*Zea mays* L.) is the third most economically important cereal crop after rice and wheat in India and is being used as food, feed and in the preparation of vast industrial products like starch, oil, protein, alcoholic beverages, food sweeteners, pharmaceutical, cosmetic, textiles, package and paper industries. Weed infestation is the major biotic stress responsible for the lower yield of maize in India (Rao *et al.* 2014, Rao and Chauhan 2015). Grain losses in maize varied between 28-100%, if weeds were not controlled during the critical stages of crop weed competition (Kumar *et al.* 2017) by competing for water, light, nutrients, space and other resources. Weeds also interfere with the harvesting process and ultimately increase the production cost. The critical period for weed control starts from four to six- leaf stage and may continue until ten leaf stage or flowering of maize (Gantoli *et al.* 2013). Hand weeding is most popular among the farmers for weed control but it is expensive, laborious and time-consuming. In India an acute shortage of labour occurs where the peak labour requirement is often for hand weeding. The application of herbicides for weed control is an important alternative to manual weeding because they are cheaper, faster and give better weed control. Usage of pre-emergence herbicides assumes greater importance in view of their effectiveness during initial stages. As the weeds interfere during aftercare operation and the harvesting of the crop, post-emergence or sequential use of herbicides may help in avoiding the problem of weeds at later stages. Some herbicides with residual effects may restrict the emergence and growth of succeeding crops in rotation. Hence, the present investigation was carried out to study the effect of sequential application of pre- and post-emergence herbicides on weeds and maize growth and yield and their residual effect in succeeding greengram.

MATERIALS AND METHODS

An experiment was conducted during two consecutive years of winter, 2017-18 and 2018-19 and summer, 2018 and 2019 at wetland farm of S.V. Agricultural College, Tirupati, which is geographically situated at 13.6°N latitude and 79.3°E longitude, at an altitude of 182.9 m above the mean sea level in the Southern Agro-Climatic Zone of Andhra Pradesh, India. The soil of the experimental site was sandy clay loam in texture, neutral in soil reaction, low in organic carbon (0.25%) and available nitrogen (174 kg/ha), medium in available phosphorus (20.5 kg/ha) and potassium (186 kg/ha). The experiment was conducted using a Randomized Block Design with ten treatments and was replicated thrice. Treatments include: atrazine 1.0 kg/ha pre-emergence application (PE) followed by (*fb)* one hand weeding (HW) at 30 days after seeding (DAS), atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha post-emergence application (PoE), atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha PoE, atrazine 1.0 kg/ha PE *fb* 2,4-D amine salt 580 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tank mix of tembotrione 60 g + 2,4-D amine salt 290 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tank mix of topramezone 15 g + 2,4-D amine salt 290 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tank mix of halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha PoE, hand weeding twice at 15 and 30 DAS and weedy check.

Maize hybrid '*DHM–117'* was sown at a spacing of 60 x 20 cm, on 19th November 2017 and 11th November 2018. After maize harvest, greengram variety '*IPM-02-14'* was sown in undisturbed layout of maize experimental plots as a succeeding crop after ploughing the maize field, at a spacing of 30 x 10 cm to study the residual effect of pre and post-emergence herbicides applied to maize on the weeds and greengram. Gross plot size of the experimental unit was 5.4 x 4. 6 m. Recommended doses of 240 kg N, 80 kg P and 80 kg K/ha for maize and 20 kg N and 50 kg of P/ ha for greengram was applied using urea, single super phosphate and muriate of potash to all the plots uniformly. The pre-emergence application of herbicide was done within 24 hours after sowing and post-emergence application of herbicide was done at 21 DAS of maize. Weeding was not done in greengram plots since the crop was raised to study the residual effect of herbicides applied to maize.

The weed population was counted with the help of 0.5 m^2 quadrat thrown randomly at two places in each plot and expressed as weed density (no./m^2). While recording weed density, weeds were harvested from each of the quadrat for estimating the weed biomass. Different weed species collected for assessing the density of weeds were dried separately in a hot air oven at 65ºC till constant dry weight was reached and expressed as weed biomass (g/m^2). Five randomly selected plants were tagged in each treatment, from each replication in the net plot area and used for making observations on yield attributes of maize and greengram. Due to large variation in values of weed density and biomass, the corresponding data was subjected to square root transformation ($\sqrt{x+0.5}$) and the corresponding transformed values were used for statistical analysis as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect on weeds

The predominant weed species in the experimental site were: *Brachiaria ramose* L., *Cynodon dactylon*, *Dactyloctenium aegyptium* (L.) Beauv, *Digitaria sanguinalis* (L.) Scop, amongst grasses, *Cyperus rotundus* L, a sedge and *Boerhavia erecta* L, *Borreria hispida* (L.) K. Schum, *Celosia argentea* L., *Cleome viscosa* L., *Clitoria ternatea* L., *Commelina benghalensis* L., *Corchorus aestuans* L., *Digera arvensis, Euphorbia hirta* L., *Phyllanthus niruri* L., *Trichodesma indicum* L. and *Tridax procumbens* L. amongst the broad-leaved weeds.

The HW twice at 15 and 30 DAS recorded significantly lower grass weed density and biomass which was closely followed by atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS, without any significant difference among themselves. Sequential application of herbicides might have resulted in effective control of grass weed density and biomass and was equally effective to that of twice HW as also reported earlier by Puscal *et al.* (2018).

Sedge's density and biomass at 80 DAS of maize was significantly lower with atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha PoE which might be due to greater efficacy of halosulfuron-methyl in reducing the sedges than other PE or PoE herbicides. HW twice at 15 and 30 DAS, atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha PoE, atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS were the next best treatments in reducing the sedges density and biomass without any significant difference among themselves.

Hand weeding twice at 15 and 30 DAS and atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS were equally effective in significantly lowering broad-leaved weed density and biomass. Broad-leaved weeds were not observed in the rest of the weed management treatments during the study due to greater efficacy of PE application of atrazine 1.0 kg/ ha in controlling the broad-leaved weeds in the initial stages of maize growth whereas and their management later stages of crop growth was done by

PoE herbicides or HW done at 30 DAS of resulting in absence of broad-leaved weeds in these treatments even at 80 DAS of maize.

The total weed density and biomass at 80 DAS was lower with HW twice at 15 and 30 DAS, which was at par with atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS. Lower total weed density and biomass might be attributed to effective control of weeds with two HW or due to initial flush of weeds management by PE application of atrazine whereas and prevention of the emergence and establishment of weeds at later stages of crop growth due to the PoE herbicides as reported by Dharam *et al.* (2018) and Sandeep *et al.* (2018).

At 80 DAS, **(Table 1)** higher weed control efficiency (WCE) was recorded with HW twice at 15 and 30 DAS, which was followed by atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS. Reduced weed density and biomass from the initial stages of crop growth with these treatments might have resulted in higher WCE as observed earlier by Mukherjee and Rai (2015).

Maize growth parameters, yield attributes and yield

The hand weeding twice at 15 and 30 DAS has resulted in taller maize plants with higher leaf area index, dry matter production, yield attributes, kernel and stover yield (**Table 2**). 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, atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS, were equally effective in attaining higher growth, yield attributed and yield of maize without any statistically significant difference between these treatments. This could be mainly due to the reduced weed density and growth thus providing weed free environment during initial and later stages of crop growth, due to which all the growth resources were optimally utilized by the crop plants for better vegetative growth and reproductive potential that reflected as noticed with increased growth parameters, yield attributes and yield as reported by Mitra *et al.* (2018).

Table 1. The influence of different weed management treatments on weed density and biomass of three categories of weeds in maize at 80 days after seeding (DAS)

Treatment	Weed density (no./m^2)								Weed biomass (g/m^2)								WCE (%)	
	Grasses		Sedges		BLW		Total		Grasses		Sedges		BLW		Total			
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS	3.0 (8.3)	2.4 (4.67)	3.5 (11.6)	3.4 (10.7)	1.6 (1.7)	1.6 (2.3)	4.8 (21.7)	4.3 (17.7)	4.6 (20.4)	4.6 (20.6)	3.8 (13.4)	3.7 (12.6)	1.6 (1.7)	1.7 (1.8)	6.0 (35.5)	6.0 (35.1)	82.7	79.2
Atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha as PoE	2.9 (7.7)	2.3 (4.3)	3.5 (11.3)	3.4 (10.3)	1.0 (0.0)	1.0 (0.0)	4.5 (19.0)	3.9 (14.7)	4.6 (19.8)	4.5 (19.9)	3.8 (13.3)	3.67 (12.5)	1.0 (0.0)	1.0 (0.0)	5.8 (33.2)	5.7 (32.4)	83.8	80.6
Atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha as PoE	2.6 (6.0)	2.2 (4.0)	3.4 (11.0)	3.3 (9.7)	1.0 (0.0)	1.0 (0.0)	4.2 (17.0)	3.8 (13.7)	4.5 (19.5)	4.4 (18.3)	3.7 (13.2)	3.6 (12.3)	1.0 (0.0)	1.0 (0.0)	5.8 (32.7)	5.6 (30.6)	84.0	81.8
Atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha as PoE	8.5 (72.0)	8.7 (75.7)	1.9 (3.0)	2.1 (3.3)	1.0 (0.0)	1.0 (0.0)	8.7 (75.0)	8.9 (79.0)	10.5 (108)	8.7 (74.4)	2.0 (3.3)	2.3 (4.3)	1.0 (0.0)	1.0 (0.0)	10.6 (112)	8.9 (78.7)	45.5	53.3
Atrazine 1.0 kg/ha PE *fb* 2,4-D amine salt 580 g/ha as PoE	7.6 (57.6)	7.7 (59.0)	7.0 (48.6)	7.7 (59.0)	1.0 (0.0)	1.0 (0.0)	10.3 (106)	10.9 (118)	9.2 (84.5)	7.7 (58.5)	5.7 (31.8)	5.8 (32.3)	1.0 (0.0)	1.0 (0.0)	10.8 (116)	9.6 (90.7)	43.3	45.8
Atrazine 1.0 kg/ha as PE *fb* tembotrione 60 g + 2,4-D amine salt 290 g/ha as PoE	4.9 (23.6)	5.3 (26.7)	6.2 (37.3)	6.14 (36.7)	1.0 (0.0)	1.0 (0.0)	7.9 (61.0)	8.0 (63.3)	7.5 (54.9)	6.3 (38.5)	4.9 (23.2)	4.62 (20.3)	1.0 (0.0)	1.0 (0.0)	8.9 (78.2)	7.7 (58.8)	61.7	65.1
Atrazine 1.0 kg/ha PE *fb* topramezone 15 g + 2,4-D amine salt 290 g/ha as PoE	4.9 (23.3)	5.1 (25.3)	6.1 (36.0)	6.1 (36.0)	1.0 (0.0)	1.0 (0.0)	7.8 (59.3)	7.9 (61.3)	7.3 (52.5)	6.2 (37.4)	4.6 (20.4)	4.4 (18.5)	1.0 (0.0)	1.0 (0.0)	8.6 (72.9)	7.5 (55.9)	64.0	66.6
Atrazine 1.0 kg/ha PE *fb* halosulfuron- methyl 34 g + 2,4-D amine salt 290 g/ha as PoE	7.8 (60.6)	8.1 (65.3)	3.4 (10.3)	3.2 (09.3)	1.0 (0.0)	1.0 (0.0)	8.5 (71.0)	8.7 (74. 7)	9.6 (92.2)	7.9 (61.5)	3.2 (9.1)	3.1 (8.6)	1.0 (0.0)	1.0 (0.0)	10.1 (101)	8.4 (70.1)	50.5	58.2
Hand weeding twice at 15 and 30 DAS	2.5 (5.3)	2.1 (3.7)	3.2 (9.3)	2.4 (07.6)	1.5 (1.3)	1.5 (2.0)	4.1 (16.0)	3.7 (13.3)	4.5 (19.4)	4.4 (18.2)	3.2 (9.07)	3.1 (8.5)	1.5 (1.3)	1.6 (1.7)	5.5 (29.8)	5.4 (28.3)	85.4	83.2
Weedy check	9.6 (93.0)	9.5 (89.3)	8.18 (64.3)	8.8 (76.3)	4.6 (20.3)	4.68 (20.3)	13.4 (177)	13.7 (186)	12.3 (149)	10.6 (111)	6.7 (43.9)	6.4 (40.0)	3.5 (11.4)	4.3 (17.5)	14.3 (205)	13.0 (169)	0.0	0.0
LSD (p= 0.05)	0.67	0.62	0.48	0.48	0.43	0.43	0.68	0.56	0.58	0.68	0.45	0.48	0.23	0.20	0.52	0.64	-	

Data in parentheses are original values, which were transformed to $\sqrt{x + 0.5}$ and analysed statistically; PE= Pre-emergence application; PoE: Post-emergence application; *fb*: followed by; HW: Hand weeding

Table 2. The effect of different weed management treatments on growth, yield attributes and yield of maize

Treatment	Plant height (cm)		Leaf area index		Dry matter production (t/ha)		Cob length (cm)		Cob girth (cm)		No. of kernels/cob		Kernel yield (t/ha)		Stover yield (t/ha)	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS	203	203	1.90	1.85	15.13	13.40	20.37	20.21	17.64	17.03	461	462	8.16	7.40	10.62	9.99
Atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha as PoE	205	206	1.91	1.87	15.20	13.40	20.73	20.24	17.80	17.40	469	469	8.25	7.42	10.72	10.01
Atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha as PoE	206	207	1.93	1.89	15.38	13.57	21.07	20.85	17.97	17.53	478	470	8.39	7.52	10.74	10.15
Atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha as PoE	164	154	1.47	1.53	11.63	10.06	16.11	16.35	13.86	12.20	377	386	5.12	4.57	7.61	6.90
Atrazine 1.0 kg/ha PE *fb* 2,4-D amine salt 580 g/ha as PoE	163	151	1.46	1.48	11.05	9.89	16.07	16.27	13.43	12.03	375	383	4.84	4.48	7.57	6.88
Atrazine 1.0 kg/ha PE *fb* tembotrione 60 g + 2,4-D amine salt 290 g/ha as PoE	180	177	1.68	1.68	13.63	11.35	18.15	18.27	15.63	14.30	411	415	6.73	5.79	9.01	8.25
Atrazine 1.0 kg/ha as PE *fb* topramezone 15 g + 2,4-D amine salt 290 g/ha as PoE	184	179	1.70	1.69	13.91	11.54	18.43	18.29	15.80	14.47	412	422	6.94	5.92	9.10	8.15
Atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha as PoE	143	132	1.25	1.32	9.25	8.17	14.10	14.26	11.32	10.27	331	347	3.62	3.12	5.39	5.46
Hand weeding twice at 15 and 30 DAS	209	210	1.96	1.92	15702	13.82	21.30	20.96	18.30	17.60	489	471	8.52	7.65	10.86	10.30
Weedy check	123	114	0.96	0.88	8043	6.85	12.07	11.30	9.48	8.70	281	286	2.28	2.02	3.94	3.93
LSD (p=0.05)	5	14	0.06	0.13	927	1.19	1.25	1.89	1.61	1.47	29	27	0.57	0.54	1.11	1.02

*PE= Pre-emergence application; PoE: Post-emergence application; *fb*= followed by; HW= Hand weeding

Phytotoxicity on succeeding greengram

Phytotoxicity was not observed on succeeding greengram crop at 10th and 15th day after sowing due to various pre and post emergence herbicides applied in maize. Similar results of post emergence application of tembotrione in maize with no residual phytotoxicity on succeeding wheat and mustard crop was reported by Dharam *et al.* (2018).

Weed density and biomass in succeeding greengram

At 20 DAS of greengram lower grasses weed density and biomass **(Table 3)** was recorded with HW twice at 15 and 30 DAS, which was at par with atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS, atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE and atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE. The density and biomass of sedges were lower with atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha PoE, which was at par with atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha PoE, which indicated that recommended dose or half of the recommended dose of halosulfuron-methyl is effective in controlling the sedges in maize-greengram cropping system, whereas the broad-leaved weed density and biomass were lower with atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, which was comparable with atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE, HW twice at 15 and 30 DAS and atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS. Weedy check recorded significantly highest density and biomass of grasses, sedges and broad-leaved weeds in the succeeding greengram.

The total weed density and biomass in greengram at 20 DAS **(Table 3)** due to the residual effect of weed management practices imposed in preceding maize, was lower with atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE , which was in parity with hand weeding twice at 15 and 30 DAS, atrazine 1.0 kg/ha as PE *fb* one HW at 30 DAS and atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE, without significant differences amongst them due to better control of weeds under these treatments in maize that might have resulted in the lower weed seedbank in the soil, which in turn reduced the density and dry weight of weeds in succeeding greengram as also reported by Verma *et al.* (2009).

Greengram growth parameters, yield attributes and yield

The growth parameters, yield attributes and yield of succeeding greengram differed significantly due to different weed management practices

Table 3. The weed density and biomass at 20 days after seeding (DAS) of greengram as influenced by weed management treatments applied in preceding maize

Treatment	Weed density (no./m^2)								Weed biomass (g/m^2)							
	Grasses		Sedges		BLW		Total		Grasses		Sedges		BLW		Total	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Atrazine 1.0 kg/ha as PE *fb* one HW at 30 DAS	7.7 (57.7)	5.8 (33.0)	6.6 (43.3)	5.5 (29.0)	2.1 (3.3)	2.1 (3.3)	10.3 (104)	8.1 (65.3)	4.2 (16.5)	3.9 (14.1)	4.5 (18.9)	4.4 (18.2)	1.8 (2.4)	1.8 (2.4)	6.0 (35.1)	6.2 (37.9)
Atrazine 1.0 kg/ha as PE *fb* tembotrione 120 g/ha as PoE	8.2 (66.0)	6.0 (34.7)	6.5 (42.0)	5.2 (26.3)	1.7 (2.0)	1.8 (2.3)	10.5 (110)	8.0 (63.3)	4.5 (19.2)	4.2 (16.3)	4.3 (17.8)	4.2 (17.1)	1.7 (2.0)	1.72 (2.0)	6.0 (35.4)	6.3 (39.0)
Atrazine 1.0 kg/ha as PE *fb* topramezone 30 g/ha as PoE	8.1 (65.0)	5.9 (33. 7)	6.2 (38.0)	5.1 (25.3)	1.6 (1.7)	1.7 (2.0)	10.3 (104)	7.9 (61.0)	4.4 (18.7)	4.1 (16.2)	4.1 (16.1)	4.1 (16.1)	1.5 (1.4)	1.5 (1.4)	5.9 (33.6)	6.1 (36.2)
Atrazine 1.0 kg/ha as PE *fb* halosulfuron-methyl 67.5 g/ha as PoE	9.9 (98.0)	9.4 (87.0)	2.9 (7.7)	3.4 (10.7)	3.1 (8.3)	3.2 (9.3)	10.7 (114)	10.4 (107)	5.8 (32.8)	5.5 (28.9)	2.5 (5.3)	2.5 (5.3)	3.1 (8.6)	3.1 (8.6)	6.6 (42.9)	6.9 (46.7)
Atrazine 1.0 kg/ha as PE *fb* 2,4-D amine salt 580 g/ha as PoE	9.9 (97.3)	9.3 (85.0)	7.6 (57.3)	6.6 (42.3)	3.1 (8.7)	3.3 (9.7)	12.8 (163)	11.7 (137)	5.8 (33.1)	5.5 (30.1)	5.3 (26.8)	5.4 (28.6)	3.2 (9.2)	3.1 (8.9)	8.3 (67.7)	8.3 (68.7)
Atrazine 1.0 kg/ha as PE *fb* tembotrione 60 g + 2,4-D amine salt 290 g/ha as PoE	9.9 (96.7)	9.2 (83.7)	7.6 (57.0)	6.4 (40.0)	2.9 (7.3)	3.1 (8.7)	12.7 (161)	11.5 (132)	5.8 (32.2)	5.4 (27.9)	5.2 (26.3)	5.3 (26.9)	3.1 (8.6)	3.1 (8.6)	8.0 (63.5)	8.2 (67.1)
Atrazine 1.0 kg/ha as PE *fb* topramezone 15 g + 2,4-D amine salt 290 g/ha as PoE	9.6 (91.3)	9.2 (83.3)	7.6 (56.3)	6.3 (38.3)	2.8 (7.0)	3.0 (8.0)	12.5 (154)	11.4 (129)	5.6 (30.4)	5.2 (26.4)	5.1 (25.2)	5.2 (26.5)	2.9 (7.3)	2.9 (7.3)	7.8 (60.2)	7.9 (62.9)
Atrazine 1.0 kg/ha as PE *fb* halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha as PoE	10.1 (102)	9.4 (87.3)	3.0 (08.3)	3.7 (13.0)	3.1 (9.0)	3.3 (10.0)	10.9 (119)	10.5 (110)	6.1 (35.9)	5.61 (30.5)	2.8 (6.7)	2.8 (6.7)	3.1 (8.9)	3.2 (9.1)	6.9 (46.2)	7.3 (52.1)
Hand weeding twice at 15 and 30 DAS	7.4 (54.7)	5.7 (31.3)	6.6 (42.7)	5.4 (28.3)	1.9 (3.0)	1.9 (3.0)	10.0 (100)	7.9 (62.7)	3.9 (14.7)	3.8 (13.4)	4.4 (18.6)	4.3 (17.3)	1.8 (2.4)	1.8 (2.3)	5.8 (33.2)	6.0 (35.7)
Weedy check	12.1 (147)	10.6 (112)	10.3 (104)	9.5 (90.0)	5.0 (24.3)	5.2 (25.7)	16.6 (276)	15.1 (228)	6.9 (47.3)	6.3 (39.3)	6.5 (41.8)	6.5 (41.8)	4.1 (15.9)	4.1 (15.9)	9.9 (97.1)	10.3 (105)
LSD (p= 0.05)	1.27	0.82	0.50	0.63	0.48	0.47	1.07	0.77	0.58	0.48	0.49	0.52	0.37	0.33	0.54	0.49

Data in parentheses are original values, which were transformed to $\sqrt{x + 0.5}$ and analysed statistically; PE: Pre-emergence application; PoE: Post-emergence application; *fb*: followed by; HW: Hand weeding

Table 4. Influence of different weed management treatments applied in maize on yield attributes and yield of succeeding greengram

Treatment	Germination (%)		Plant height (cm)		Dry matter production (kg/ha)		No. of pods/ plant		No. of seeds/ pod		Seed index (g)		Seed yield (kg/ha)		Haulm yield (kg/ha)	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS	89.0	90.3	50.0	50.3	2135	2082	12.93	12.30	9.87	9.26	43.3	42.6	663	637	1026	1020
Atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE	89.6	91.7	48.6	47.3	2123	2077	12.57	12.23	9.70	9.22	41.9	41.8	637	623	1010	1014
Atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE	91.1	90.7	49.0	49.0	2130	2079	12.63	12.27	9.80	9.23	42.6	42.2	641	628	1023	1017
Atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha PoE	92.6	89.4	47.4	46.9	2120	2032	12.53	12.16	9.53	9.20	41.5	41.5	633	621	1007	1013
Atrazine 1.0 kg/ha PE *fb* 2,4-D amine salt 580 g/ha PoE	89.9	90.1	40.7	38.6	1908	1868	10.83	9.80	8.27	7.93	38.1	37.5	534	531	875	847
Atrazine 1.0 kg/ha PE *fb* tembotrione 60 g + 2,4-D amine salt 290 g/ha PoE	89.8	91.6	40.9	39.1	1910	1871	10.87	10.13	8.30	8.04	38.5	37.8	546	536	890	880
Atrazine 1.0 kg/ha PE *fb* topramezone 15 g + 2,4-D amine salt 290 g/ha PoE	89.9	90.4	41.4	40.2	1912	1872	10.93	10.17	8.37	8.05	39.1	38.4	551	541	814	863
Atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 34 g + 2,4-D amine salt 290 g/ha PoE	88.0	89.5	39.4	37.0	1901	1860	10.73	9.53	8.20	7.91	37.5	36.9	518	525	872	832
Hand weeding twice at 15 and 30 DAS	89.6	89.8	51.1	51.1	2177	2089	12.97	12.47	9.97	9.30	43.8	43.2	679	660	1033	1032
Weedy check	90.8	90.2	32.6	31.9	1654	1655	8.83	8.23	6.80	6.88	33.3	33.6	391	446	761	726
LSD (p=0.05)	NS	NS	1.32	4.9	71.8	153	0.357	1.12	0.33	0.90	1.23	2.81	18.7	56	85	24.3

*PE= Pre-emergence application; PoE: Post-emergence application; *fb*=followed by; HW: Hand weeding implemented in maize **(Table 4)**. The higher growth parameters, yield attributes, seed and haulm yield of greengram was recorded with hand weeding twice at 15 and 30 DAS, which was closely followed by application of atrazine 1.0 kg/ha PE *fb* one HW at 30 DAS, atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha PoE, atrazine 1.0 kg/ha PE *fb* tembotrione 120 g/ha PoE and atrazine 1.0 kg/ha PE *fb* halosulfuron-methyl 67.5 g/ha PoE, in the order of descent, without significant disparity among them **(Table 4)**. This might be due to higher WCE in the respective treatments in both maize and greengram, which might have lead to lower weed density and biomass in the succeeding greengram that in turn favored greengram to accumulate higher dry matter, enhanced synthesis and translocation of assimilates to developing pods and seeds that may lead to higher yields of succeeding greengram.

The present study has revealed that atrazine 1.0 kg/ha PE *fb* topramezone 30 g/ha or tembotrione 120 g/ha PoE were the most effective weed management treatments that effectively managed weeds and increased the productivity of winter maize and succeeding summer greengram. These treatments may be used for effective management of weeds in maize at times of labor shortage, and without any residual effect on succeeding greengram

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Indian Journal of Weed Science **53**(4): 411–416, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Multiple herbicide resistance in *Phalaris minor* Retz. in Haryana, India

Paras Kamboj*, Satbir Singh Punia and Dharam Bir Yadav

CCS Haryana Agricultural Univeristy, Hisar, Haryana 125004, India

**Email: paras.thind@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00075.7

Type of article: Research article

Received : 7 August 2021
Revised : 24 October 2021
Accepted : 26 October 2021

KEYWORDS

Clodinafop, Herbicide resistance, Mesosulfuron + iodosulfuron, Multiple resistance, *Phalaris minor,* Pinoxaden, Sulfosulfuron, Wheat

ABSTRACT

A screen house study was conducted at CCS Haryana Agricultural University, Hisar during (winter) *Rabi* 2018-19 and 2019-20 to evaluate the resistance in various populations of *Phalaris minor* Retz. in Haryana against clodinafop and also to evaluate the efficacy of alternate herbicides against the herbicide resistant weed populations. The alternate herbicides were sulfosulfuron, pinoxaden and mesosulfuron + iodosulfuron (ready-mix). The seeds of *P. minor* were sown in pots and 20 plants per pot were maintained. All the herbicides were applied at 2-3 leaf stage of *P. minor i.e.* about 25-27 days after sowing. Herbicides were applied with graded doses *viz.* 1/2X, X (recommended dose), 2X and 4X dose. The variation in the percentage decrease in the biomass was observed amongst *P. minor* populations with the application of different herbicides under their doses. Clodinafop (60 g/ha) and mesosulfuron + iodosulfuron (14.4 g/ha) provides <30% decrease in the biomass of Sitamai, Karnal population at the recommended dose. The poor efficacy of clodinafop at recommended dose was observed in most of the *P. minor* populations expect those populations of Hindwan, Hisar (susceptible population) and Laloda, Fatehabad. An increase in the reduction of biomass was observed with an increase in the dose to 2X and 4X but at 2X dose of clodinafop, Kalwan, Jind population showed minimum decrease in the biomass during both years of the study. There was decrease in the efficacy of sulfosulfuron during 2nd year of study particularly in Rasidan, Jind population. The reduced efficacy (<70%) against clodinafop, sulfosulfuron, mesosulfuron + iodosulfuron and pinoxaden was observed in Sitamai, Kalwan, Ramba and Ramba populations of *P. minor*, respectively.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the second most important crop in India, grown in 29.57 million ha (Anonymous 2019). In wheat, weeds are the major concern which can cause up to 40% reduction in the yield (Das 2008). Among the weeds in wheat, *Phalaris minor* Retz. is major weed (Singh *et al.* 1992). Wheat yield can be reduced from 30% by 150 plants/m^2 (Balyan and Malik 1989) to complete crop loss by a density of 2000-3000 plants/m^2 of *Phalaris minor* (Das *et al.* 2014).

Manual weeding is labor intensive, expensive, tedious and ineffective method, as *P. minor* can escape during manual weeding due to its phenotypic mimicry with wheat, even though experts can easily differentiate it because of pink coloration stem near the base at early stages. Hence, farmers prefer to rely on the herbicides, which is comparatively a cheaper method to control weeds. Isoproturon had been recommended for the effective control of *P. minor* in wheat since 1977 (Gill *et al.* 1978). But the continuous reliance on the same herbicide isoproturon to control the weeds in wheat, has led to the development of resistance in *P. minor*, which is a major issue since it was reported in early 1990's. It was observed that *Phalaris minor* has developed resistance against isoproturon due to enhanced degradation via N-dealkylation and ring alkyl oxidation by reduced nicotinamide adenine dinucleotide phosphate (NADPH)-cytochrome P-450 monooxygenase (Singh *et al.* 1998). A similar P-450 monooxygenase system operates in wheat, degrading isoproturon. This type of resistance can lead to the evolution of cross-resistance or multiple resistance against herbicides of different modes of action (Singh 2007, Chhokar and Sharma 2008). The alternate herbicides, *viz.* clodinafop-propargyl, fenoxaprop-p-ethyl, sulfosulfuron and tralkoxydim were recommended in 1997-98 to control the resistant populations of *P. minor* (Das 2008). Later on, resistance in *Phalaris minor* against alternate herbicides was also reported, with fenoxaprop-p-ethyl being the first herbicide (Abbas *et al.* 2016). Other herbicides have also shown poor efficacy and instances of multiple herbicide resistance in *P. minor* have been noticed.

The herbicide resistant *Phalaris minor* populations have spread in all rice-wheat growing areas of Haryana (Punia *et al.* 2020), which is a serious concern for the sustainability of rice-wheat cropping system. Herbicides applied in the mixtures can provide acceptable control of *P. minor*, wild oat and some broad-leaved weeds also. Tank mixture of clodinafop + sulfosulfuron (3: 1) at 60 g/ha and fenoxaprop + sulfosulfuron (4: 1 and 5: 1) at 120 g/ha provided 85–90% control of *Avena ludoviciana* and *Phalaris minor* and 60% control of broad-leaved weeds like *Chenopodium album*, *Melilotus indica* and *Rumex retroflexus* (Punia *et al.* 2005). Selection pressure can be reduced by use of alternate herbicides, use of herbicide mixtures, herbicide rotation and other practices. However, the continuous monitoring of extent of herbicide resistance amongst *P. minor* populations is essential for effectively managing them. Hence, a study was conducted to assess the efficacy of different herbicides in managing *P. minor* populations vis-a-vis herbicide resistance.

MATERIALS AND METHODS

The experiment was conducted during (winter) *rabi* 2018-19 and *rabi* 2019-20 in the screen houses of Department of Agronomy, CCS Haryana Agricultural University, Hisar. The seeds of 15 *P. minor* populations (14 populations with poor control history and one susceptible population for comparison) were collected during April 2018 and April 2019 from wheat fields of farmers on the basis of problem reported by the farmers. All the populations were taken from rice-wheat cropping system except susceptible population (Hindwan, Hisar) which was taken from cotton-wheat cropping system. Of these 15 populations; four were from Karnal (Kachwa, Ramba, Sitamai, Uchana), four from Jind (Rasidan, Kalwan, Danoda, Ujahana), two from Kaithal (Kheri raiwali and Teek), two from Hisar (Hindwan and CCSHAU Farm), one each from Yamuna Nagar, Fatehabad and Kurukshetra districts of Haryana **(Table 1)**. The population collected from Hindwan, Hisar was taken as susceptible population to clodinafop.

The soil for the pot experiment was taken from CCSHAU farm where there was no herbicide application during last two years, in order to attain the proper effect of the tested herbicides. Soil was sieved before filling the pots. Soil: Vermicompost – 4:1 mixture was used to fill 1020 pots of 8 inch diameter in which *P. minor* seeds were surface seeded with seeds just covered with soil, followed by watering the pots to facilitate germination. After germination, the *P. minor* populations were thinned out to 20 plants per pot. Pots were watered regularly as per the requirement.

Table 1. *Phalaris minor* populations collected for study from various districts of Haryana

District	Village	Population code	Latitude and Longitude
Karnal	Kachwa	1	29.7274° N, 76.8872° E
	Ramba	5	29.7935° N, 76.9837° E
	Sitamai	11	29.7837° N, 76.7629° E
	Uchana	13	29.7403° N, 76.9704° E
Jind	Rasidan	7	29.7256° N, 76.0319° E
	Kalwan	10	29.7063° N, 75.9709° E
	Danoda	12	29.5218° N, 76.0508° E
	Ujhana	14	29.7153° N, 76.1349° E
Kaithal	Kheri raiwali	4	29.8643° N, 76.5546° E
	Teek	8	30.0379º N, 76.7853° E
Hisar	Hindwan	2	29.1191° N, 75.6121° E
	CCSHAU Farm	6	29.1504° N, 75.7057° E
Yamuna Nagar	Khijrabad Raiyawala	3	30.2919° N, 77.4974° E
Fatehabad	Laloda	9	29.6407° N, 75.8752° E
Kurukshetra	Chanarathal	15	30.0701° N, 76.8671° E

All the herbicides were applied at 25-27 DAS as post-emergence application at 2-3 leaf stage of *P. minor*. Clodinafop was applied at 30 g/ha (1/2X), 60 g/ha (X: recommended rate), 120 g/ha (2X), 240 g/ha (4X); sulfosulfuron at 12.5 g/ha (1/2X), 25 g/ha (X), 50 g/ha (2X), 100 g/ha (4X); mesosulfuron + iodosulfuron at 7.2 g/ha (1/2X), 14.4 g/ha (X), 28.8 g/ha (2X), 57.6 g/ha (4X); pinoxaden at 25 g/ha (1/2X), 50 g/ha (X), 100 g/ha (2X), 200 g/ha (4X). The pots were arranged in completely randomized design in the screen house. A control without herbicide application was maintained for all the *P. minor* populations for comparison. Total number of pots used were 1020 for the 15 populations with 4 replications. The pots were arranged outside the screen house for herbicide application. These pots were arranged in marked area and the required quantities of herbicides, corresponding to a dose, were applied with 300 L/ha of water (calibrated earlier) with a manually operated knapsack sprayer. Flat-fan nozzle was used for the application. After 30 days of the application, mean dry weight of per plant was recorded and compared with the control pots (where there was no application of herbicide). Percent decrease in the dry weight with respect to increase in the dose of different herbicides was calculated using by using the following formula. Data was statistically analyzed by using OP Stat online statistical tool (Sheoran *et al.* 1998).

Decrease in dry weight (%) = $\frac{DMC - DMT}{DMC} \times 100$

DMC= Dry matter of weeds in control (untreated) pots

DMT= Dry matter of weeds in treated pots

RESULTS AND DISCUSSION

P. minor populations showed variable response to the recommended dose of tested post-emergence herbicides, *viz.* clodinafop-propargyl 60 g/ha, sulfosulfuron 25 g/ha, mesosulfuron + iodosulfuron (RM) 14.4 g/ha and pinoxaden 50 g/ha. Among the tested populations; Ramba, Karnal showed very poor control with clodinafop 60 g/ha (**Figure 1**). Laloda, Fatehabad and Hindwan, Hisar showed maximum decrease in the dry matter with the application of recommended dose of clodinafop (**Figure 1**). The Sitamai, Karnal population's percentage decrease in dry weight was less with the application of clodinafop, sulfosulfuron and mesosulfuron + iodosulfuron (RM) (**Figure 1, 2** and **3**). Most of the farmers relied on the single herbicide for more than four years for the control of *P. minor* in the problematic areas. During second year of the study, higher dry weight of some populations was observed as compared to the previous year, which indicated a decrease in the herbicide efficacy with the repeated use of single herbicide in long run. Decrease in efficacy of mesosulfuron + iodosulfuron (RM) was recorded in Kheri Raiwali, Kaithal population during second year of study and in Sitamai, Karnal population during both the years. A decrease in efficacy of mesosulfuron + iodosulfuron (RM) against *P. minor* populations was also observed in this study which might be due to continuous reliance on sulfonylureas (sulfosulfuron and mesosulfuron + iodosulfuron) (**Figure 2** and **3**). Abundant evidence is available on loss of sensitivity in majority of the *P. minor* populations against clodinafop with its long-term use (Chhokar and Sharma 2008, Dhawan *et al.* 2009, Smit and Cairns 2000, Gherekhloo *et al.* 2011, Das *et al.* 2014). The repeated use of herbicides with similar modes of action for weed control in wheat leads to evolution of multiple herbicide resistance in *P. minor* (Bhullar *et al.* 2017).

In 2018-19, populations from Kalwan, Jind followed by Ramba, Karnal showed minimum decrease in the dry matter with the 2X dose (double of the recommended dose) application of clodinafop. The Sitamai, Karnal followed by Kheri Raiwali,

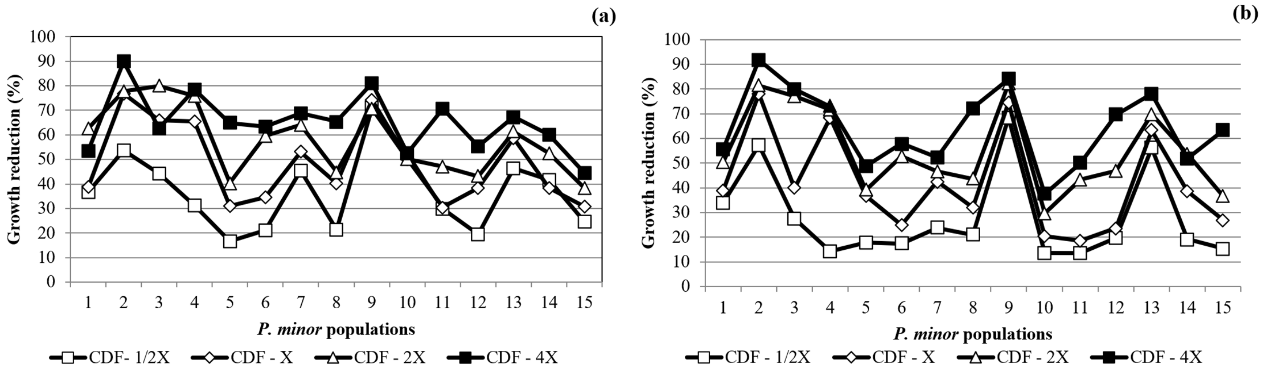

Figure 1. Growth reduction (%) of *P. minor* population with graded dose of clodinafop during 2018-19 (a) and 2019-20 (b); 1/2X – 30 g/ha, X – 60 g/ha, 2X – 120 g/ha, 4X- 240 g/ha

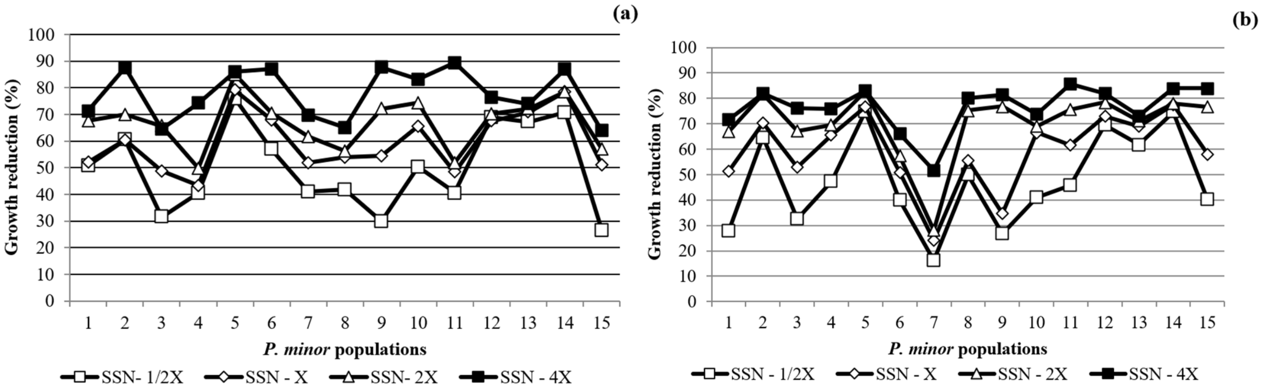

Figure 2. Growth reduction (%) of *P. minor* populations with graded doses of sulfosulfuron during 2018-19 (a) and 2019-20 (b); 1/2X – 12.5 g/ha, X –25 g/ha, 2X – 50 g/ha, 4X- 100 g/ha

Kaithal and Rasidan, Jind populations showed minimum decrease in the dry matter with the application of sulfosulfuron (**Figure 2**). Sitamai, Karnal population showed lowest decrease in the dry matter among the tested populations with the 2X dose of mesosulfuron + iodosulfuron (ready-mix) (**Figure 3**). A decrease in efficacy of this ready-mix herbicide on the *P. minor* population was observed.

In 2019-20, Kalwan, Jind followed by Ramba, Karnal population showed minimum decrease in the dry matter with the application of clodinafop at 2X dose; whereas Laloda, Fatehabad and Hindwan, Hisar (susceptible population) showed the maximum reduction in the dry matter with the application of clodinafop at similar dose (**Figure 1**). Rasidan, Jind showed minimum reduction in the dry matter with the application of sulfosulfuron at 2X dose (**Figure 2**). Among the tested populations, Sitamai, Karnal followed by Kheri Raiwali, Kaithal population showed lower efficacy of mesosulfuron + iodosulfuron (RM) even at 2X dose (**Figure 3**). But when compared with the first year of study, there was decline in the efficacy of herbicides with less dry matter reduction observed during the second year (**Table 2**). The need for 10-fold increase in dose for fenoxaprop and sulfosulfuron and 2-3-fold dose increase of clodinafop for 50% growth reduction was observed earlier also (Dhawan *et al.* 2005). Punia *et al.* (2012) reported decrease in the efficacy of ready-mix formulation of sulfonylurea herbicides viz. mesosulfuron + iodosulfuron.

Pinoxaden application at the rate of 2X of the recommended dose resulted in more than 80% decrease in the dry matter over the control in most of the populations except Kalwan, Jind and Kachwa, Karnal populations indicating higher efficacy of pinoxaden as compared to the other herbicides tested (**Figure 4**). This indicated suitability of this herbicide in tackling the problem of resistance in *P. minor* in wheat.

To check the level of resistance among the tested populations, herbicides were applied even up to 4X dose. During 2018-19, clodinafop 4X application resulted in minimum decrease in the *P. minor* populations' dry matter followed by sulfosulfuron at 4X (**Figure 1** and **2**). Resistance in *P. minor* to clodinafop and sulfosulfuron was also reported by Bhullar *et al.* (2014). Less decrease in the dry matter with the application of 4X of mesosulfuron + iodosulfuron (ready-mix) was recorded in Sitamai, Karnal populations followed by Rasidan, Jind. Rasidan, Jind recorded minimum decrease in the dry matter with pinoxaden 4X (**Figure 3**). During 2019-20, Kalwan, Jind showed lowest decrease in the dry matter (37%) followed by Ramba, Karnal (<50%) with 4X dose of clodinafop (**Figure 1**). Amongst the tested *P. minor* populations, Rasidan, Jind population showed less decrease in the dry matter with the 4X dose of the sulfosulfuron (**Figure 2**). Sitamai, Karnal populations showed lowest decrease in the dry matter production (50%) among all the tested populations. Khijrabad Raiyawala, Yamuna Nagar populations showed reduction in the efficacy of mesosulfuron + iodosulfuron (ready-mix) with minimum decrease in the dry matter with its application (**Figure 3**). A decrease in the efficacy of mesosulfuron + iodosulfuron (ready-mix) was observed in this study (**Table 2**). Only Kalwan and Jind populations showed less than 80% decrease in the dry matter with the application of 4X dose of pinxoaden, while rest of the populations showed more than 84% decrease in the dry matter (**Figure 4**). *P. minor* has developed multiple resistance across three modes of action: photosynthesis at the PS- II site, acetyl CoA caboxylase (ACCase) and acetolactate synthase

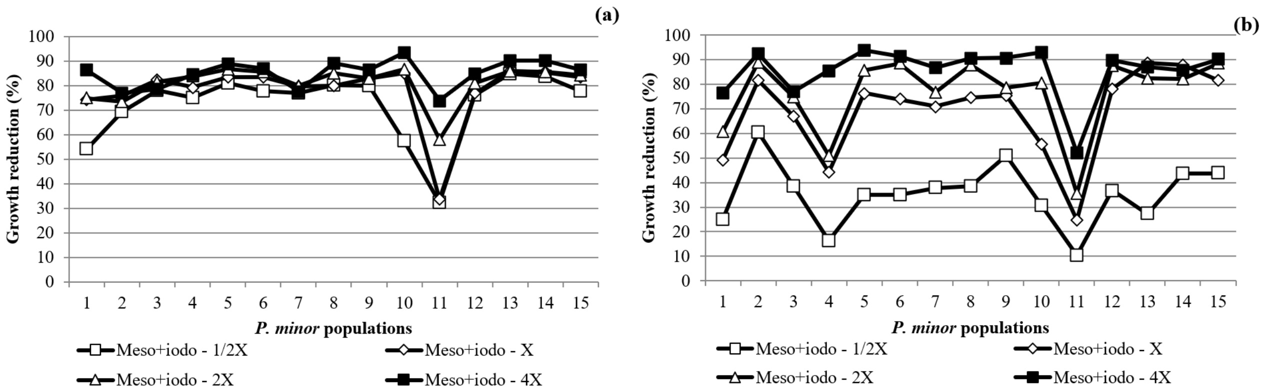

Figure 3. Growth reduction (%) of *P. minor* populations with graded doses of mesosulfuron+ iodosulfuron (ready-mix) during 2018-19 (a) and 2019-20 (b); 1/2X – 7.2 g/ha, X –14.4 g/ha, 2X – 28.8 g/ha, 4X- 57.6 g/ha

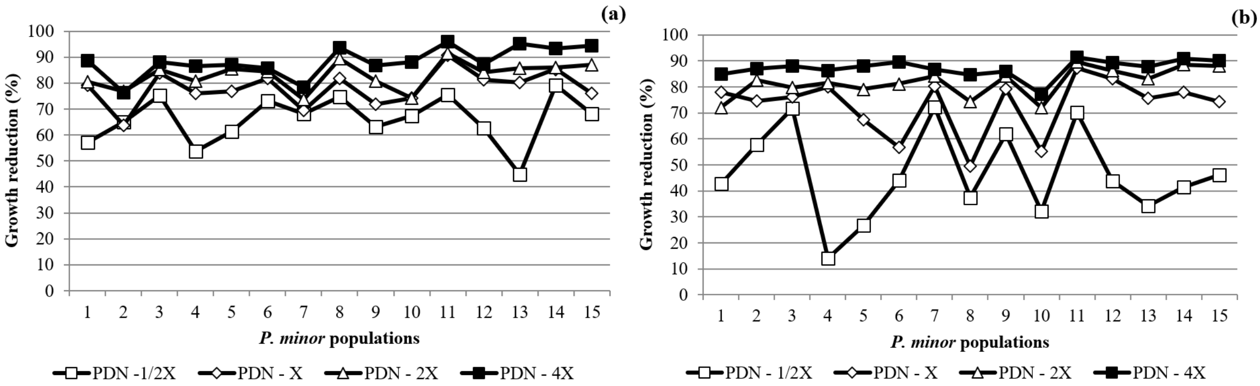

Figure 4. Growth reduction (%) of *P. minor* populations with graded doses of pinoxaden during 2018-19 (a) and 2019-20 (b); 1/2X – 25 g/ha, X –50 g/ha, 2X – 100 g/ha, 4X- 200 g/ha

Table 2. Mean percent decrease in the dry weight of *P. minor* populations against graded doses (1/2X to 4X) of herbicides

Populations	Clodinafop		Sulfosulfuron		Mesosulfuron + iodosulfuron (ready-mix)		Pinoxaden	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Kachwa	47.87	44.73	60.53	54.43	72.44	52.82	76.33	69.40
Hindwan	74.55	77.16	69.59	74.67	73.83	80.83	70.46	75.44
Khijrabad Raiyawala	63.18	56.09	52.66	57.20	80.11	64.29	83.15	78.86
Kheri Raiwali	62.79	56.86	51.97	64.53	80.64	49.24	74.29	65.50
Ramba	38.22	35.66	81.51	79.22	84.98	72.65	77.70	65.29
HAU Farm	44.64	38.30	70.62	53.63	83.42	72.12	81.32	67.84
Rasidan	57.85	41.35	56.07	29.97	78.51	68.02	72.43	80.84
Teek	42.98	42.28	54.26	65.17	83.58	72.86	84.95	61.46
Laloda	74.20	77.27	61.03	54.89	83.05	73.89	75.72	77.85
Kalwan	51.34	25.34	68.41	62.59	80.63	64.96	75.96	59.10
Sitamai	44.56	31.44	57.56	67.16	49.48	30.72	88.54	84.59
Danoda	39.04	40.05	70.76	75.74	79.70	73.02	78.87	75.60
Uchana	58.41	66.82	71.04	68.74	86.69	71.29	76.51	70.19
Ujhana	48.19	40.89	78.75	78.52	86.21	74.81	85.99	74.70
Chanarathal	34.59	35.61	49.68	64.74	82.94	75.97	81.39	74.59
LSD (p=0.05)	13.53	8.25	11.40	6.83	8.08	6.01	9.73	5.21

(ALS) inhibitors (Heap 2021). The multiple herbicide-resistant populations showed a low level of sulfosulfuron resistance, moderate level of resistance to pinoxaden and a high level of resistance to clodinafop and fenoxaprop (Chhokar and Sharma 2008).

Based on the current study, it may be concluded that efficacy of all the tested herbicides against *P. minor* in Haryana has reduced to a significant extent. The clodinafop has the least efficacy against *P. minor* populations, which might be due to continuous reliance on a single herbicide. The efficacy of the sulfonylureas (sulfosulfuron and mesosulfuron + iodosulfuron) has been also reduced due to use of different herbicides but with same mode of action. The better control of most of *P. minor* populations by pinoxaden indicated towards its cautious use in management of resistant *P. minor* populations. To control the resistant weeds, integrated weed management approach with use of herbicides with different modes of action may be the most sustainable approach.

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Indian Journal of Weed Science **53**(4): 417–420, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Interception of non-indigenous weed seeds in lentil and lentil husk shipments imported from Australia, Canada, U.S.A., and Sri Lanka to India

D.K. Nagaraju*, D. Iyyanar, Maharaj Singh, B. Esakkirani, Venkatareddy, G.M. Keshavamurthy, K.S. Kapoor, Om Prakash Verma, Ravi Prakash and M.C. Singh[1]

Directorate of Plant Protection, Quarantine and Storage, NH-IV, Faridabad 121001, India

[1]ICAR-National Bureau of Plant Genetic Resources, New Delhi, Delhi 110012, India

**Email: dkn.raju@gov.in*

Article information

DOI: 10.5958/0974-8164.2021.00076.9

Type of article: Research article

Received : 23 July 2021
Revised : 3 November 2021
Accepted : 4 November 2021

KEYWORDS

Biosecurity, Exotic weed species, Invasive weeds, Plant quarantine, Weed seed

ABSTRACT

Four weed species, non-indigenous to India, were intercepted from lentil and lentil husk import shipments. *Raphanus raphanistrum* L. in lentil shipment from Australia, *Polygonum lapathifolium* L. and *Thlaspi arvense* L. in lentils from Canada and U.S.A., and *Echinochloa crus-pavonis* (Kunth) Schult. in lentil husk imported from Sri Lanka were intercepted. The extent of contamination by the non-indigenous species was 0.1 to 0.2% by number. The infested shipments were salvaged. The non-compliances were notified to the trading partners on each interception as per the International Plant Protection Convention (IPPC) guidelines. Molecular characterization of intercepted weed seeds is envisaged.

INTRODUCTION

India is the world's largest producer, consumer, and importer of pulses. Nine types of pulses are being imported from 14 different countries to meet the domestic requirement. Total import was 25.23 lakh tons during 2018-19, of which lentils constituted 9.84 lakh tons (DA and FW 2021). Lentils are being imported as bulk shipments either in shipping containers or as shiploads. The imported lentils are processed in daal (pulse) mills, the lentil is distributed either for public distribution system or sold in the open market. The bulk shipments of cereals and pulses known to contain weed seeds of indigenous and non-indigenous and other extraneous materials as contaminants (DPPQS 2021). In India, the earliest documented interception of exotic weed seeds in imported shipments was during 1997-1998 (Singh 2001). Seven noxious weeds and 12 exotic weed species were intercepted from the bulk wheat grain shipments imported from USA. The contaminated 33 shiploads of 2.5 million tons of wheat were diverted to non-wheat growing areas to mitigate the risk associated with shipments (Muthaiyan *et al.* 1984, Moolchand *et al.* 1999).

This paper reports the observations of a study aimed at inspecting and quantifying weed seed contaminants in lentil and lentil husk import shipments from Australia, Canada, U.S.A., and Sri Lanka to India.

MATERIAL AND METHODS

The Plant Quarantine (Regulation of Import into India) Order 2003 issued under Destructive Insects & Pests Act, 1914 (Act 2 of 1914), Government of India (DA&FW 2003) regulates the import of all agricultural commodities into India. Imported lentil shipments were inspected as per provisions of Plant Quarantine Order. The representative samples were drawn and sieved on to a white sheet spread uniformly on the floor. Sieves of different mesh sizes were used to get all possible sizes of seeds and plant materials contaminating the commodity. Seeds and plant material thus collected both on the white sheet and retained in the sieve were examined. Parameters like size, shape, colour, texture, presence of any attachment, *etc.* were used to separate foreign material from the main commodity. Extremely small seeds and plant material were examined under a stereo binocular microscope for weed detection (DPPQS 2015). Detected weed seeds were identified to species level by studying the basic characteristics and comparing with reference collection maintained in the weed science laboratories of Plant Quarantine Station, Tuticorin and Regional Plant Quarantine Station, Chennai. Species requiring further confirmation were sent to ICAR-National Bureau of Plant Genetic Resources, New Delhi. Intercepted non-indigenous weed seeds were photographed using a Leica M205C microscope. Multiple images taken at different depths were combined using Combine ZM software.

RESULTS AND DISCUSSION

The observations incorporated in this paper were made on a total of 709 lentils and one lentil husk shipments weighing 109,598 and 26 tons imported to India through Tuticorin port, Tamil Nadu State during the period of 2018-2020. Canada was the major exporter of lentils (74,948 MT) followed by USA (29,975 MT) and Australia (4,675 MT). Sri Lanka exported one shipment of lentil husk (26 MT) as animal feed. Weed seeds of 50 plant species representing 13 families were observed contaminating imported shipments. Of these, four weed species *i.e.*, *Raphanus raphanistrum*, *Thlaspi arvense* (both Brassicaceae), *Polygonum lapathifolium* (Polygonaceae) and *Echinochloa crus-pavonis* (Poaceae) are exotic to India. Lentils from both Canada and USA were contaminated with *T. arvense* and *P. lapathifolium*, whereas lentils from Australia were contaminated with *R. raphanistrum*. *Echinochloa crus-pavonis* was intercepted in a lentil husk shipment imported from Sri Lanka (**Table 1** and **Figure 1**).

Shipments intercepted with non-indigenous weed seeds were 05 out of 535 from Australia, 50 out of 493 from Canada and 18 out of 178 from U.S.A., which accounted for 13% of imported shipments from Australia and 10% each from Canada and USA. One shipment imported from Sri Lanka was intercepted with non-indigenous weed seed (**Table 2**).

Indigenous weeds of 46 species representing 13 plant families were intercepted. Shipments from Canada contaminated with maximum number of indigenous species (30 species) followed by USA (23 species), Australia and Sri Lanka (7 species each) (**Figure 2**).

Figure 1. Non-indigenous weed species seeds intercepted, A) *E. crus-pavonis*, B) *P. lapathifolium*, C) *T. arvense*, D) *R. raphanistrum*.

Indigenous species intercepted were *Amaranthus* sp., *Atriplex patula* L., *Ranunculus parviflorus* L. (Amaranthaceae), *Coriandrum sativum* L. (Apiaceae), *Cirsium arvense* L., *Helianthus annuus* L., *Sonchus arvensis* L., *S. oleraceus* L., *Xanthium* sp. (Asteraceae), *Lappula echinata* Gilib. (Boraginaceae), *Brassica campestris* L., *Brassica kaber* (DC.) L.C.Wheeler, *Brassica napus* L., *Brassica nigra* L., *Brassica tournefortii* (Gouan)., *Brassica* sp., *Sinapis alba* L., *Sisymbrium officinale* (L.) Scop. (Brassicaceae), *Convolvulus arvensis* L. (Convolvulaceae), *Medicago denticulata* L., *Medicago sativa* L., *Medicago scutellata* (L.) Mill., *Pisum sativum* L., *Vigna unguiculata* (L.) Walp., *Vicia* sp. (Fabaceae), *Linum usitatissimum* L., (Linaceae), *Malva parviflora* L., (Malvaceae), *Aegilops cylindrical*, *Avena fatua* L., *A. sterilis* L., *A.*

Table 1. Country, commodity, and non-indigenous weed species seeds intercepted in India

Country	Commodity	Weed species seeds intercepted in India
Australia	Lentils	Wild radish, *Raphanus raphanistrum* L. (Brassicaceae)
Canada and USA	Lentils	Pale persicaria, *Polygonum lapathifolium* (L.) Delarbre (Polygonaceae)
Canada and USA	Lentils	Field Pennycress, *Thlaspi arvense* L. (Brassicaceae)
Sri Lanka	Lentil husk	Gulf cockspur grass, *Echinochloa crus-pavonis* (Kunth) Schult. (Poaceae)

Table 2. Details of shipments imported and intercepted with non-indigenous weed species seed

Country	Import		Interception	
	Quantity (MT)	Shipments (no.)	Quantity (MT)	Shipments (no.)
Australia	4,675	38	535	05
Canada	74,948	493	7,925	50
Sri Lanka	26	01	26	01
USA	29,975	178	5,305	18
Total	109,624	710	13,791	74

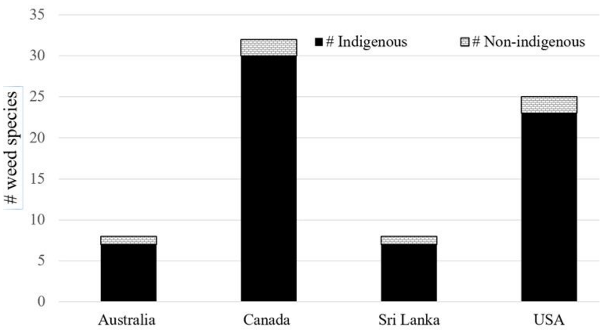

Figure2. Number of indigenous and non-indigenous weed species seed intercepted

sativa L., *Bromus* sp., *Hordeum vulgare* L., *Lolium rigidum* Gaud., *L. perenne* L., *Lolium* sp. *Panicum capillare* L., *P. miliaceum* L., *Phalaris paradoxa* L., *Sorghum halepense* (L.) Pers., *Triticum* sp., *Zea mays* (Poaceae), *Emex* sp., *Polygonum convolvulus* (L.) Á. Löve (Polygonaceae), *Delphinium virescens* (Ranunculaceae), *Galium tricornutum* Dandy (Rubiaceae). One third of intercepted weed species were of the plant family Poaceae (33%) followed by Brassicaceae (17%), Fabaceae (13%), Asteraceae (11%), Polygonaceae (4%), Amaranthaceae (7%). Apiaceae, Boraginaceae, Convolvulaceae, Linaceae, Malvaceae, Ranunculaceae and Rubiaceae represented 2% each.

The Plant Quarantine (Regulation of Import into India) Order, 2003 under Schedule VIII has notified 57 species as quarantine weeds to India. Of which, four species were intercepted in imported lentils and lentil husk shipments during 2018-2020 by the Plant Quarantine Station at Tuticorin.

Intercepted weeds have wide distribution and report to cause serious direct and indirect economic damage in their native range. *R. raphanistrum* is a pest of 45 crops in 65 countries, serious weed in nine countries and a principal weed in fourteen countries. It is also an alternate host of many pests and pathogens. It is widespread in Australia, present in Canada and USA, the three major lentil exporting countries. Whereas *T. arvense* a temperate species is widespread in Canada and USA, present in Australia is a serious weed of cereals, rapeseed, vegetables, sugar beets, etc. *T. arvense* is a prolific seed producer (20,000 seeds/plant). *Polygonum lapathifolium* is cosmopolitan in temperate region, widespread in Canada and Australia and present in USA. *Echinochloa crus-pavonis*is a clump forming grass native to the central and south America. Found in Canada, USA, Australia, Africa, Asia, Oceania, and Europe. It is found in China and Nepal too, countries sharing land borders and having trade with India. It is considered invasive in Cuba, Paraguay, Cameroon, the Ivory Coast, Nigeria, Italy and California, USA. The species occurs in wetlands, along wet road sides, in drainages, ditches, muddy stream verges in marshes and by spring (Holm *et al.* 1997; Kaufman 2020).

All the four species intercepted are known to occur in Australia, Canada, and USA at different degree of distribution. Whereas *E. crus-pavonis* intercepted in lentil husk imported shipments is not found in Sri Lanka. The present observation establishes that all the four intercepted species are probably infesting lentil fields in all the three major lentil exporting countries. Therefore, there is a possibility of intercepting all of them in a lentil shipment from all the three countries exporting to India and in Sri Lankan shipments, if re-exported. Lentils are not grown in Sri Lanka and country's requirement is met only through the imports. The intercepted weed might have contaminated lentils imported to Sri Lanka from any of the exporting countries. The imported lentils are processed in daal (pulse) mills and husk is a by-product of processing industries and is often exported to India. The pulse processing industry is known to be relatively small and located in rural areas in Sri Lanka (Jayaweera *et al.* 2021). Interception of *E. crus-pavonis* in lentil husk shipment from Sri Lanka establishes the ability of a weed species to escape through multiple quarantine inspections at least at three levels such as country of export, country of import and re-export. It is further interesting to note that, the whole system of processing could not eliminate the weed seed infestation, which is undesirable. New interceptions on any shipment lead to review the existing Pest Risk Analysis (PRA) and new set of guidelines to be implemented for import intercepted consignments. The plant quarantine inspectors must be cautious till new guidelines are introduced while inspecting such consignments.

Cultivation of lentils is mechanized in all the three lentil exporting countries mentioned. Lentil is a low-growing plant and harvested close to the ground using combines, which harvest irrespective of crop and the weed. This could be the possible reasons for interception of weed contaminants in the import shipments. Mack (2000) opined that no criteria have yet been agreed for the minimum damage, spread or size of population needed for an alien species to be considered invasive. Introduction, spread and establishment of invasive species is detrimental to the plants can have very significant economic consequences (Bhalla and Khetarpal 2009, Sushil *et al*. 2021). Interception of non-indigenous weeds in regularly imported shipments from most important trading partners is alarming though; subsequent establishment of an introduced pest depends on the availability of suitable host and environment. Quarantine is the first line of defence against invasion of non-indigenous pests, failure in the systems results entry of non-indigenous pest. India has witnessed number of invasions in past and it is quite difficult to pin-point the pathways of entry since India shares porous borders with many neighbouring countries. However, introduction of non-indigenous pests through well-defined trade would be failure of quarantine system. Plant quarantine officials at the port of entry should ensure proper inspection of imported consignments and mitigate the associated risk prior to release of consignments for use. In addition, trading partners should be alerted through notification of non-compliance as per guidelines given in International Standard for Phytosanitary Measure ISPM -13 (ISPM 2001). Such notifications enable the exporting country to carry out investigation and to take necessary corrective action to avoid such non-compliances in the future shipments. Furthermore, there is a need to better appreciate the indirect economic damage by invasive pests to natural and agro-biodiversity, ecosystem services which are critical for meeting the Sustainable Development Goals.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. N. K. Krishna Kumar, former Deputy Director General (Horticulture), ICAR, New Delhi for scientific scrutiny of the manuscript. We also thank the Plant Protection Advisor, Directorate of Plant Protection, Quarantine and Storage, Faridabad for facility and encouragement. H.M. Yeshwanth, Department of Entomology, University of Agricultural Sciences, GKVK, Bangalore prepared the images.

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Indian Journal of Weed Science **53**(4): 421–425, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Efficacy of pre-seeding application of two formulations of paraquat dichloride in managing weeds in dry direct-seeded rice

Tej Pratap*, V. Pratap Singh, S.P. Singh, Abnish Kumar, Soniya Saini and Neeta Tripathi
G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263145, India
Email: drtpsingh2010@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00077.0

Type of article: Research note

Received : 8 January 2021
Revised : 24 September 2021
Accepted : 27 September 2021

KEYWORDS

Dry direct-seeded rice (DSR), Formulations, Hand weeding, Paraquat dichloride, Phytotoxicity, Weed management

ABSTRACT

A field experiment was conducted at GBPUA&T, Pantnagar during *Kharif* (rainy) season of 2015 to evaluate and compare the efficacy of pre-seeding application, at 2 days before seeding (DBS), of two formulations of paraquat dichloride on weeds associated with dry direct-seeded rice (dry-DSR) and assess their possible phytotoxicity to rice crop. Two formulations of paraquat dichloride include: i. Sponsor sample (SS) (paraquat dichloride 45% SL) tested at 300, 450, 800, 1600 g/ha and ii. Commercially available paraquat dichloride market sample (MS) tested at 800 g/ha. The paraquat dichloride at 1600 g/ha provided 85-95% weed control efficiency at all crop growth stages. All the herbicidal treatments were found significantly superior over hand weeding twice [(before sowing and at 20 days after seeding (DAS)]. The highest grain yield (3.3 t/ha) was obtained with paraquat dichloride 1600 g/ha followed by 800 g/ha. No symptoms of phytotoxicity were observed on dry-DSR at any of the doses of both the formulations of paraquat dichloride applied two days before seeding rice. Paraquat dichloride (SS) efficacy at 1600 and 800 g/ha applied 2 DBS was at par with each other in effectively managing broad spectrum weeds in dry direct-seeded rice in *Tarai* water (lowland) region of Uttarakhand.

Rice (*Oryza sativa* L.) is the major staple crop of India accounting for 39.64% of total food grain production (284.83 million tons) during 2017-18 (DOES 2018). In India, rice occupies an area of 43.1 million hectares and its productivity is low (around 2.6 t/ha) (India Stat, 2017-18). To meet the future food demand, the productivity of rice in India is to be increased. The major challenge is to achieve higher grain yield with less water, labor, and chemicals, thereby ensuring long-term sustainability. Since rice is mostly grown under flooded condition in puddled soil by transplanting rice (PTR), which is highly cumbersome and laborious. Over the years, transplanted rice culture, a labour-intensive establishment system with high and stable yield was highly suited to the labour surplus in India till the fanged of late 20^{th} century. Eliminating manual transplanting operation which requires 238 man-hours/ha (Dixit and Khan 2011) could result in savings anywhere between ₹ 7500-10000/ha. To avoid nursery raising and transplanting of rice, direct-seeding of rice (DSR) by both dry- and wet-seeding methods have been considered good. Reduced duration of crop (7-12 days) under direct-seeding of rice adds to crop intensification in a year (Mondal *et al.* 2015). Thus, DSR is considered as the best alternative for transplanting (Kaur and Singh 2017). Heavy weed infestation is one of the major constraints for DSR adaptation.

In India, yearly loss of rice grain production is around 15 million tonnes due to heavy weed infestation (Singh *et al.* 2018). Weed management is considered as most critical in dry direct-seeded rice (dry-DSR) due to simultaneous emergence of crop and weeds (Rao *et al.* 2007). In DSR, the critical period of crop weed competition has been reported to be 14–41 days after sowing (Chauhan and Johnson 2011). Thus, in DSR it is important to minimize the crop-weed competition during the early stages of the crop before it forms a closed leaf canopy to reduce the weed competition and for effective utilization of available resources for enhanced productivity (Singh 2008). The manual weeding is the traditional method but increased wages and demand for labour at peak periods are major limitations of using hand weeding. Hence, chemical weed management was found to be highly efficient and cost-effective method of managing weeds in DSR. Keeping this in view, a field experiment was conducted to evaluate and compare the bio- efficacy of pre-seeding application of two formulations of paraquat dichloride on the weeds associated with dry-DSR and also to assess their possible phytotoxicity on rice.

The field experiment was conducted at GBPUA&T, Pantnagar (29ÚN latitude, 27.3ÚE longitude and at an altitude of 243.8 m above mean sea level) during *Kharif* (rainy) season of 2015. The climate of Pantnagar is very hot in summers and cold in winters. The soil of the experimental site is clay loam in texture. During crop growth period (July to November, 2015) the area received total rainfall of 769.9 mm and the average maximum and minimum temperatures were 31.5ºC and 21.0ºC, respectively. The experiment was laid out in randomized block design with three replications. Eight treatment combinations comprised of four doses (300, 450, 800 and 1600 g/ha) of sponsor sample of paraquat dichloride [paraquat dichloride 45% SL] (SS); commercially available paraquat dichloride market sample (MS) as standard check 800 g/ha; pendimethalin at 1000 g/ha, hand weeding twice (before sowing and at 20 DAS) and weedy check. Herbicides were applied with knapsack sprayer fitted with flat fan nozzle using 500-liter water/ha. For phytotoxicity study, SS (paraquat dichloride 45% SL) at 450, 800 and 1600 g/ha was applied two days before sowing of dry direct-seeded rice and compared with control. A rice variety '*Govind*' was sown manually with 20 x 10 cm planting geometry in a plot size of 5.0 x 4.0 m with seed rate of 50 kg/ha. Thinning was done manually to maintain plant population. Irrigation was applied in the field as per requirement. Recommended dose of fertilizer (70:60:40 kg NPK/ha) was applied as per package of practices of crop for the area. Both the formulations of paraquat and pendimethalin were sprayed 2 days before sowing.

Category-wise weed count (density) and their dry biomass accumulation (biomass) and total weed density and biomass were measured at 15, 30, 45 days after application (DAA) by placing a quadrate of 0.25 m^2 randomly at 3 places in each plot and were subjected to square-root transformation $(\sqrt{x+1})$ before analysis and weed control efficiency was calculated. Data were analyzed by using standard statistical techniques (STPR package). Treatment means were separated using the least significant difference (LSD) at the 5% level of significance. Differences were considered significant only at P=0.05. Crop was harvested on November 05, 2015 and left in the field for 5-7 days for sun drying. The number of panicles/m^2, grains/panicle, 1000 grain weight, grain yield and straw yield were recorded. Phytotoxic symptoms were recorded at 1, 3, 5, 7 and 10 days after application of paraquat dichloride 450, 800 and 1600 g/ha and were compared with weedy check. Carry over effect of applied herbicides were also observed on succeeding wheat crop by recording wheat yield parameters and yield at harvest of wheat grown in rotation in the experimental plots, using standard procedures.

Effect on weeds

The weed species observed in the experimental field at the time of herbicide application were; *Echinochloa colona*, *Eleusine indica*, *Panicum maximum*, *Digitaria sanguinalis*, *Dactyloctenium aegyptium* among the grasses; *Phyllanthus niruri* and *Ammania baccifera* among the broad-leaved weeds and *Cyperus iria*, *Cyperus halpans* and *Cyperus rotundus* among the sedges. Among all the weed species, *Echinochloa colona*, *Eleusine indica* and *Cyperus iria* were most predominant as reported earlier also by Maity and Mukherjee (2008).

The tested weed control treatments had significant effect on weeds density at 15, 30 and 45 days after application (DAA). There was considerable increase in the weed control efficiency of paraquat dichloride (SS) with the increase in rate from 300 to 1600 g/ha in reducing the density of all grassy and non-grassy weeds. *P. maximum*, *D. sanguinalis* and *D. aegyptium* among the grassy; *P. niruri* among the broad-leaf weeds and *C. iria* and *C. halpans* among the sedges were completely controlled with application of paraquat dichloride (SS) at 1600 g/ha and was at par with its lower dose (800 g/ha). At 45 DAA, *D. sanguinalis* was completely controlled with paraquat dichloride (SS) applied at 800 and 1600 g/ ha, which was also effective in reducing the density of other non-grassy weeds (**Table 1**-**3**). Being a non-selective contact-herbicides, paraquat dichloride (post-emergence) showed promising broad-spectrum control of diverse weeds by desiccation and defoliation during critical period of crop weed competition with an extended period of 30-40 days of crop establishment (Hofstra *et al.* 2001)**.**

The lowest total weed density was recorded with paraquat dichloride at 1600 g/ha and was significantly superior to rest of the herbicidal treatments at all stages of crop growth (**Table 4**). The lowest total weed biomass and highest weed control efficiency was recorded with application of paraquat dichloride 1600 g/ha followed by paraquat dichloride 800 g/ha, at all stages of crop growth (**Table 4**). This is due to the broad-spectrum control of weeds

Table 1. Effect of different treatments on weed density at 15 days after herbicide application

Treatment	Weed density (no./m^2)									
	Grassy					Broad-leaved		Sedges		
	E. colona	*E. indica*	*P. maximum*	*D. sanguinalis*	*D. aegyptium*	*P. niruri*	*A. baccifera*	*C. iria*	*C. halpans*	*C. rotundus*
Paraquat dichloride (SS) 300 g/ha 2 DBS	4.8 (21.7)	5.1(25.3)	2.5(5.3)	2.2(4.0)	2.2(4.0)	1.0(0.0)	3.0(8.0)	1.9(2.7)	1.3(0.8)	3.4(10.7)
Paraquat dichloride (SS) 450 g/ha 2 DBS	4.0(14.7)	2.8(6.7)	1.5(1.3)	1.7(2.0)	1.7(2.0)	1.0(0.0)	2.8(6.7)	1.0(0.0)	1.0(0.0)	2.8(6.7)
Paraquat dichloride (SS) 800 g/ha 2 DBS	3.4(10.7)	1.9(2.7)	1.0(0.0)	1.5(1.3)	1.0(0.0)	1.0(0.0)	2.6(6.0)	1.0(0.0)	1.0(0.0)	1.5(1.3)
Paraquat dichloride (SS) 1600 g/ha 2 DBS	3.3(10.0)	1.9(2.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.9(7.3)	1.0(0.0)	1.0(0.0)	1.6(1.7)
Paraquat dichloride (MS) 800 g/ha 2 DBS	4.9(17.3)	2.9(7.3)	1.0(0.0)	1.9(2.7)	1.5(1.3)	1.0(0.0)	2.5(5.3)	1.0(0.0)	1.0(0.0)	2.5(5.3)
Pendimethalin-1000 g/ha 2 DBS	4.5(19.3)	3.4(10.7)	2.9(7.3)	1.0(0.0)	1.0(0.0)	1.9(2.7)	2.5(5.3)	1.5(1.3)	2.1(3.2)	3.8(13.3)
Hand weeding twice before sowing and 20 DAS	2.8(6.7)	3.4(10.7)	1.8(2.7)	1.9(2.7)	2.8(6.7)	1.9(2.7)	2.8(6.7)	4.1(16.0)	1.7(2.0)	3.2(9.3)
Weedy check	7.7(58.0)	6.3(38.7)	4.4(18.7)	2.8(6.7)	4.3(17.3)	2.8(6.7)	4.3(17.3)	8.5(72.0)	6.7(44.0)	4.9(22.7)
LSD (p=0.05)	0.5	0.56	0.56	0.41	0.36	0.3	0.40	0.39	0.38	0.61

DBS: Days before rice sowing; DAS: Days after sowing; SS: Sponsor sample; MS: Market sample; Value in parentheses were original and transformed to square root ($\sqrt{x+1}$) for analysis

Table 2. Effect of different treatments on weed density at 30 days after herbicide application

Treatment	Weed density (no./m^2)									
	Grassy					Broad-leaved		Sedges		
	E. colona	*E. indica*	*P. maximum*	*D. sanguinalis*	*D. aegyptium*	*P. niruri*	*A. bacifera*	*C. iria*	*C. halpans*	*C. rotundus*
Paraquat dichloride (SS) 300 g/ha 2 DBS	5.4(28.7)	4.3(17.3)	3.0(8.0)	2.4(4.7)	1.9(2.7)	1.7(2.0)	2.9(7.3)	2.5(5.3)	1.0(0.0)	5.0(24.0)
Paraquat dichloride (SS) 450 g/ha 2 DBS	4.5(19.3)	3.2(9.3)	2.5(5.3)	1.5(1.3)	1.5(1.3)	1.0(0.0)	2.9(7.3)	1.5(1.3)	1.0(0.0)	4.9(22.7)
Paraquat dichloride (SS) 800 g/ha 2 DBS	3.6(11.7)	2.8(6.7)	2.2(4.0)	1.0(0.0)	1.5(1.3)	1.0(0.0)	3.0(8.0)	1.5(1.3)	1.0(0.0)	4.4(18.7)
Paraquat dichloride (SS) 1600 g/ha 2 DBS	3.2(9.3)	2.8(6.7)	2.1(3.3)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.8(6.7)	1.0(0.0)	1.0(0.0)	4.3(17.3)
Paraquat dichloride (MS) 800 g/ha 2 DBS	4.7(21.0)	3.4(11.0)	2.6(6.0)	2.1(3.3)	2.2(4.0)	1.4(1.0)	3.2(9.7)	2.0(3.0)	1.0(0.0)	5.2(26.0)
Pendimethalin-1000 g/ha 2 DBS	4.8(22.3)	3.6(12.0)	4.0(14.7)	1.5(1.3)	1.0(0.0)	2.2(4)	3.7(12.7)	3.5(11.7)	2.7(6.3)	4.9(22.7)
Hand weeding twice before sowing and 20 DAS	2.9(7.8)	2.1(3.3)	2.2(3.1)	1.7(2.0)	1.7(2.0)	1.5(1.3)	2.1(3.3)	2.2(3.1)	1.5(1.3)	3.5(11.6)
Weedy check	8.5(71.0)	7.2(51.3)	6.2(37.3)	3.3(9.7)	4.9(23.3)	3.2(9.3)	4.7(21.0)	8.9(79.0)	8.0(63.3)	7.2(50.7)
LSD (p=0.05)	0.33	0.44	0.3	0.65	0.42	0.3	0.3	0.49	0.14	0.76

DBS: Days before rice sowing; DAS: Days after sowing; SS: Sponsor sample; MS: Market sample; Value in parentheses were original and transformed to square root ($\sqrt{x+1}$) for analysis

Table 3. Effect of different treatments on weed density at 45 days after herbicide application

Treatment	Weed density (no./m^2)									
	Grassy					Broad-leaved		Sedges		
	E. colona	*E. indica*	*P. maximum*	*D. sanguinalis*	*D. aegyptium*	*P. niruri*	*A. bacifera*	*C. iria*	*C. halpans*	*C. rotundus*
Paraquat dichloride (SS) 300 g/ha 2 DBS	6.0(34.7)	4.8(21.7)	3.5(11.0)	2.4(5.0)	2.2(4.0)	2.1(3.3)	3.3(10.0)	3.4(10.7)	2.5(5.3)	5.4(28.7)
Paraquat dichloride (SS) 450 g/ha 2 DBS	4.7(21.0)	3.6(11.7)	4.4(18.7)	1.7(2.0)	1.8(2.3)	1.5(1.3)	3.2(9.3)	2.2(4.0)	1.9(2.7)	5.0(24.0)
Paraquat dichloride (SS) 800 g/ha 2 DBS	3.6(12.3)	3.0(8.0)	2.7(6.3)	1.0(0.0)	1.7(2.0)	1.3(0.7)	2.9(7.7)	2.1(3.3)	1.4(1.0)	4.6(20.3)
Paraquat dichloride (SS) 1600 g/ha 2 DBS	3.5(11.0)	2.9(7.3)	2.6(5.7)	1.0(0.0)	1.4(1.0)	1.3(0.7)	2.8(7.0)	1.9(2.7)	1.3(0.7)	4.2(17.0)
Paraquat dichloride (MS) 800 g/ha 2 DBS	4.8(22.7)	3.6(12.0)	3.1(8.7)	1.6(1.7)	1.6(1.7)	1.4(1.0)	3.4(10.3)	2.4(4.7)	2.0(3.0)	5.3(26.7)
Pendimethalin-1000 g/ha 2 DBS	5.2(26.3)	4.3(17.7)	4.6(20)	3.0(8.3)	2.1(3.3)	3.0(8.0)	4.0(15.3)	3.6(12.3)	3.5(11.7)	5.5(29.0)
Hand weeding twice before sowing and 20 DAS	4.2(16.7)	4.1(15.7)	4.4(18.3)	3.5(11.0)	3.5(10)	3.7(12.7)	4.0(15.0)	4.2(16.7)	2.8(7.0)	5.4(28.3)
Weedy check	8.2(66.0)	8.3(67.3)	7.0(48.3)	4.3(17.3)	6.3(39.0)	4.2(16.6)	6.3(39.3)	9.5(89.3)	8.5(70.6)	8.6(73.0)
LSD (p=0.05)	0.28	0.31	0.41	0.3	0.46	0.22	0.40	1.7	1.1	0.84

DBS: Days before sowing; DAS: Days after sowing; SS: Sponsor sample; MS: Market sample; Value in parentheses were original and transformed to square root ($\sqrt{x+1}$) for analysis

by paraquat dichloride (Singh *et al.* 2016). The highest herbicide efficiency index (HEI) was also observed (3.3%) with the paraquat dichloride 1600 g/ha followed by paraquat dichloride 800 g/ha. Application of pendimethalin (standard check) at 1000 g/ha obtained lowest weed persistence index (0.98%) followed by paraquat dichloride applied at 450 g/ha.

Effect on rice yield attributing characters and grain yield

The hand weeding twice (before sowing and at 20 DAS) was found to be superior in obtaining the highest rice grain yield and yield attributing characters (**Table 5**). However, among different herbicidal treatments, highest number of panicles/m^2, grains/panicle and 1000 grain weight was recorded with

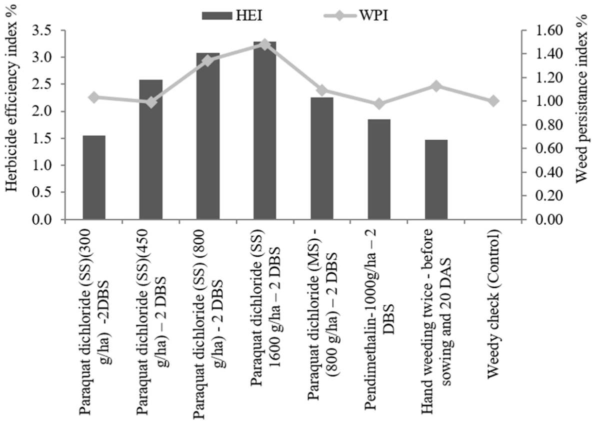

Figure 1. Effect of treatments on herbicide efficiency index (HEI) and weed persistence index (WPI)

paraquat dichloride (SS) at 800 g/ha, which was at par with all other herbicidal treatments except lower dose of paraquat dichloride 300 g/ha. These effects are mainly due to lower crop-weed competitions for various growth factors during the crop growth period.

Paraquat dichloride (SS) at higher dose (1600 g/ha) was found superior in achieving the highest rice grain (3.3 t/ha) and straw yield (5.2 t/ha), which was at par with its respective lower doses at 450 and 800 g/ha as well as MS at 800 g/ha. Maximum increase in rice grain yield (95.98%) over weedy check was recorded with paraquat dichloride (SS) at 1600 g/ha and next maximum increase was with 800 g/ha. This might be due to higher weed control efficiencies of these treatments that reduced the crop-weed competition for resources and allowed the crop to grow to its best potential which in turn positively influenced grain and straw yield of rice (Ganai*et al.* 2014).

Phytotoxicity

There were no phytotoxic symptoms observed on dry direct-seeded rice crop of SS (paraquat dichloride) applied 2 days before seeding at all three doses (450, 800 and 1600 g/ha), even when the herbicide was applied on emerging of weeds at 3-5 leaf stage.

Table 4. Effect of treatment on total weed density and biomass and weed control efficiency at different stages of dry direct-seeded rice

Treatment	Total weed density (no./m^2)			Total weed biomass (g/m^2)			Weed control efficiency (%)		
	15 DAA	30 DAA	45 DAA	15 DAA	30 DAA	45 DAA	15 DAA	30 DAA	45 DAA
Paraquat dichloride (SS) 300 g/ha 2 DBS	9.1(82)	10.0(100)	11.6(134)	8.08(64)	9.8(95)	11.0(121)	77.00	75.83	73.66
Paraquat dichloride (SS) 450 g/ha 2 DBS	6.4(40)	8.3(68)	9.9(97)	5.74(32)	7.5(55)	9.2(84)	88.59	86.13	81.73
Paraquat dichloride (SS) 800 g/ha 2 DBS	4.8(22)	7.3(52)	7.9(62)	4.62(20)	6.9(47)	8.6(72)	92.74	88.13	84.27
Paraquat dichloride (SS) 1600 g/ha 2 DBS	4.8(22)	6.7(43)	7.4(53)	4.52(19)	6.5(41)	8.3(69)	93.06	89.60	85.08
Paraquat dichloride (MS) 800 g/ha 2 DBS	6.8(45)	9.3(85)	10.9(101)	6.52(41)	9.0(79)	9.9(96)	85.16	79.91	79.01
Pendimethalin-1000 g/ha 2 DBS	8.0(63)	11.3(108)	13.3(125)	7.78(60)	9.5(90)	10.4(106)	78.68	77.12	76.85
Hand weeding twice before sowing and 20 DAS	8.2(66)	6.4(40)	15.9(151)	7.67(58)	6.0(35)	12.3(149)	79.33	91.10	67.52
Weedy check	17.4(302)	20.4(416)	23.0(526)	16.75(279)	19.9(394)	21.5(460)	-	-	-
LSD (p=0.05)	0.26	0.36	0.13	1.2	1.8	2.5	-	-	-

DBS: Days before sowing; DAS: Days after sowing; SS: Sponsor sample; MS: Market sample; Value in parentheses were original and transformed to square root $(\sqrt{x+1})$ for analysis

Table 5. Effect of treatments on yield and yield attributes of dry direct-seeded rice

Treatment	Panicles (no./m^2)	Grains/ panicle	1000 grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Percent increase in grain yield over weedy check (%)
Paraquat dichloride (SS) 300 g/ha 2 DBS	152	78.7	22.2	2.8	4.1	68.99
Paraquat dichloride (SS) 450 g/ha 2 DBS	162	86.7	22.6	3.2	5.0	88.96
Paraquat dichloride (SS) 800 g/ha 2 DBS	163	87.7	22.8	3.2	5.1	93.94
Paraquat dichloride (SS) 1600 g/ha 2 DBS	162	87.0	22.8	3.3	5.2	95.98
Paraquat dichloride (MS) 800 g/ha 2 DBS	160	87.0	22.6	3.2	5.0	89.62
Pendimethalin-1000 g/ha 2 DBS	151	86.7	22.6	2.9	4.3	74.99
Hand weeding twice before sowing and 20 DAS	170	89.0	22.9	3.2	5.3	90.94
Weedy check	70	61.7	21.6	1.7	2.5	-
LSD (p=0.05)	15.5	6.2	0.49	2.94	9.10	-

DBS: Days before rice sowing; DAS: Days after sowing; SS: Sponsor sample; MS: Market sample

Table 6. Effect of various doses of paraquat dichloride applied in dry direct-seeded rice on the succeeding wheat crop during the *Rabi* (rainy) season

Treatment applied in DSR	No. of wheat plants/ m^2 at 15 DAS	Wheat Spikes (no./m^2)	No. of grains/ spike of wheat	1000 grain weight of wheat (g)	Wheat grain yield (t/ha)	Wheat straw yield (t/ha)
Paraquat dichloride (SS) 300 g/ha 2 DBS	103.7	291	48.5	43.7	4.3	6.9
Paraquat dichloride (SS) 450 g/ha 2 DBS	91.7	292	48.1	42.8	4.3	6.9
Paraquat dichloride (SS) 800 g/ha 2 DBS	95.3	273	47.5	43.7	4.4	7.0
Paraquat dichloride (SS) 1600 g/ha 2 DBS	103.7	293	52.8	43.4	4.4	7.0
Paraquat dichloride (MS) 800 g/ha 2 DBS	91.0	277	51.8	44.7	4.5	7.2
Pendimethalin-1000 g/ha 2 DBS	94.0	268	52.2	42.8	4.2	7.0
Hand weeding twice before sowing and 20 DAS	82.0	279	49.4	43.1	4.4	7.1
Weedy check	89.7	285	47.1	43.4	4.4	7.0
LSD (p=0.05)	NS	NS	NS	NS	NS	NS

DBS: Days before rice sowing; DAS: Days after sowing; SS: Sponsor sample; MS: Market sample

Carryover effect

In succeeding wheat crop, the plant stands at harvest as well as wheat yield and yield attributing characters were not influenced significantly due to various weed control treatments applied during preceding rice crop and they were statistically similar to each other (**Table 6**). This concludes that pre-seeding application of paraquat dichloride in direct-seeded rice crop during *Kharif* (rainy) season was very safe for growing wheat crop during *rabi* season. No visual symptom of injury or phytotoxicity was observed due to any treatment used during the previous rice crop indicating their safety to wheat grown in rotation.

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Indian Journal of Weed Science **53**(4): 426–429, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Organic weed management in wet-seeded and transplanted aromatic rice

Yerradoddi Sindhu Sree*, Anjan K. Sarmah and I.C. Barua

Department of Agronomy, Assam Agricultural University Jorhat, Assam 785013, India

**Email: srisindhu4784@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00078.2

Type of article: Research note

Received : 27 July 2021
Revised : 20 November 2021
Accepted : 23 November 2021

KEYWORDS

Aromatic rice, Inter cropping, *Dhaincha*, Organic weed management, *Sesbania aculeata L.*, Transplanted rice, Wet-seeded rice

ABSTRACT

A field experiment was conducted during rainy (*Sali*) season of 2019 in organic block of Instructional-cum-Research farm of the Assam Agricultural University, Jorhat to study the effect of organic weed management practices on weeds, rice growth, yield attributes and yield of aromatic rice (*Oryza sativa* L. *cv Kola Joha)* established by wet-seeding and transplanting. The experiment was laid out in split-plot design with main plots of two rice establishment methods, *i.e*., direct wet-seeding (WSR), puddled transplanting (PTR) and sub plots of five organic weed management practices, *viz*. weedy check, hand weeding at 20 and 40 days after transplanting (DAT) / seeding (DAS), weeding with rotary weeder at 20 and 40 DAT/DAS, weeding with cono-weeder at 20 and 40 DAT/DAS and intercropping of *Sesbania* (*Sesbania aculeata L.*) and its incorporation at 40 DAT/DAS. The puddled transplanting method of rice establishment resulted significantly higher rice grain yield (1.82 t/ha), decreased weed density and biomass compared to the direct wet-seeding method. The hand weeding twice at 20 and 40 DAT/DAS produced the highest grain yield (2.19 t/ha), maximum weed control efficiency and weed control index. The next best was the intercropping of *Sesbania* and its incorporation at 40 DAT/ DAS (1.69 t/ha), which recorded the highest B:C ratio (2.61) under the puddled transplanting system of rice establishment.

Rice (*Oryza sativa L.*) is the major cereal crop feeding nearly half of the world's population. In India, rice is the most important and widely grown food crop occupying an area of 43.78 million hectares with a production of 118.43 million tons and productivity of 2705 kg/ha during 2019-2020 (Anonymous 2021). The labour intensive and time- consumption procedures involving nursery raising of seedlings and transplanting rice seedlings in the main field in conventional transplanted rice, the direct-seeding method of rice establishment is gaining popularity as a potential alternative to transplanting in many Asian countries since last two decades (Rao *et al*. 2017). The concept of DSR is relatively new to Assam, where rice is accounted for 96% of the state's total food grain production (Das 2021). In DSR weeds are one of the main biological constraints of successful rice production, particularly in the organic production system where the weeds cause yield reduction to the extent of 64-66% in wet- seeded rice and 57-61% in transplanted rice (Mukherjee *et al*. 2008). The organic rice systems are devoid of the herbicide usage. Thus, experiment was conducted to determine the influence of organic weed control methods on weeds, growth, yield attributes and yield of transplanted and wet- seeded aromatic rice.

A field experiment was conducted in Assam Agricultural University, Jorhat, at Instructional cum Research farm (26°45´N latitude, 94°12´E longitude with an elevation of 87 meters above mean sea level) during *sali* (*Kharif*) (rainy) season of 2019. The climatic condition of Jorhat is sub–tropical humid having hot summer and cold winter. Average annual rainfall is 204.20 cm and the mean maximum and minimum temperature during the crop growing period ranged from 25.8°C to 34.8°C and 14.6°C to 26°C, respectively. Weekly average relative humidity during the crop growing season ranged from 86 to 99 per cent during morning hours and 63 to 90% during afternoon hours. Experimental site was sandy loam in texture with pH 5.9, medium in organic carbon (0.58%), low in available N (242.5 kg/ha), low in available P (18.60 kg/ha) and medium in available K (140.6 kg/ha). The experiment was laid out in split-plot design with three replications. The size of each plot was 15 m^2 (5 x 3 m). The treatments consisted of rice established by two methods of establishment, *viz*. puddled transplanted rice (PTR) and direct wet-seeded rice (WSR) in the main plot and five organic weed management practices, *viz*. weedy check; hand weeding twice at 20 and 40 days after transplanting (DAT)/ seeding (DAS), weeding with rotary weeder at 20 and 40 DAT/DAS; weeding twice with cono-weeder at 20 and 40 DAT/DAS and intercropping of dhaincha (*Sesbania aculeata L.*) and its incorporation at 40 DAT/DAS in the sub-plots. Rice cultivar *'Kola joha'* (150-160 days duration) with seed rate of 40 kg/ha was line sown managing a spacing of 20 x 15 cm in wet-seeded rice. In case of transplanted rice, 25 days old seedlings were transplanted using 2-3 seedlings per hill with the recommended spacing of 20 cm x 15 cm. In intercropping treatment, dhaincha seeds were sown on the day of sowing and transplanting in between the rows of rice. There was one row of dhaincha between two rows of rice was maintained.

The recommended dose of N-P-K for traditional *sali* rice cultivar of Assam is 20- 10-10 kg/ha. Only the recommended dose of nitrogen 20 kg/ha was applied using combinations of three organic sources using 1/3rd each of farm yard manure, vermicompost, and mustard oil cake. Weed Density (no. of weeds/ m^2) at 30 and 60 DAT/DAS and at harvest was recorded by using two quadrats (50 x 50 cm) placed randomly in each plot. Weeds were uprooted from quadrats at 30, 60 DAT/DAS and at harvest, dried in shade after cleaning the soil particles adhered to the roots and oven dried at 60°C. Weed control efficiency and weed control index were calculated using the standard formulae. The observations on rice effective tillers per m^2, panicle length (cm), number of filled and unfilled grains per panicle, 1000 grain weight (g), grain yield (t/ha), straw yield (t/ha) and harvest index were recorded following standard methodologies. The intercropped dhaicha was incorporated manually with hoe at 40 DAT/DAS as per the treatments. The crop was infested with blast and brown spot diseases at tillering stage. The diseases were reasonably controlled by the application of fresh cow dung slurry prepared by mixing 3.0 kg fresh cow dung in 20.0 liters of water.

Effect on weed flora

The experimental field was infested by 12 weed species, of which, grass species *Echinochloa crusgalli* (L.) Beauv. and sedges: *Cyperus iria* L., *Cyperus difformis* L., *Fimbristylis littoralis* Gaudich. had emerged early and appeared in the field within the first fortnight. The broad-leaved weeds like *Monochoria vaginalis* (Burm.f.) C. Presl ex Kunth., *Sphenoclea zeylanica* Gaertn., *Acmella paniculata* (Wall. ex DC.) R.K.Jansen., *Hydrolea zeylanica* (L.) Vahl, *Sagittaria guyayanensis* Kunth. and grasses like *Isachne himalaica* Hook.f. and *Eragrostis japonica* (Thunb.) Trin. appeared at least 25 days after transplanting/sowing.

The weed density and biomass were the highest in wet-seeded rice than in puddled transplanted rice (**Table 1**). In wet-seeded rice the pre-germinated rice seeds were sown in main field and weeds emerged simultaneously with rice resulting in higher competition for growth factors between the WSR and weed than in transplanted field (Rao *et al*. 2007). In transplanting rice system, 25 days old seedlings raised in nursery established well and competed with emerging weeds. (Bhardwaj *et al*. (2018). During first three weeks after sowing high rainfall (409.8 mm) was received creating temporary inundation of plots which reduced the germination of weed seeds resulting lower weed density and biomass at 30 DAS.

Table 1. Effect of rice establishment methods and organic weed management treatments on weed density and weed biomass in aromatic rice

Treatment	Weed density (no./m^2)			Weed biomass (g/m^2)		
	30 DAT/DAS	60 DAT/DAS	Harvest	30 DAT/DAS	60 DAT/DAS	Harvest
Rice establishment method						
Transplanting	4.72(22.4)	6.00(38.2)	6.65(46.4)	7.51(58.5)	7.89(70.7)	8.10(72.2)
Direct-seeded (wet-seeding)	5.00(24.7)	8.29(69.8)	8.52(73.1)	4.72(22.5)	9.77(97.9)	11.79(146.2)
LSD (p=0.05)	0.26	0.38	0.27	0.55	0.13	0.34
Weed management						
Weedy check	5.54(30.3)	9.34(87.5)	9.29(88.2)	8.13(69.7)	12.55(157.2)	13.32(179.2)
Hand weeding twice at 20 and 40 DAT/DAS	4.32(18.3)	5.27(29.8)	5.77(35.0)	4.58(21.0)	6.07(42.1)	7.24(68.1)
Weeding by rotary weeder twice at 20 and 40 DAT/DAS	4.84(23.2)	6.94(48.7)	7.46(55.1)	6.12(38.7)	8.40(71.8)	9.22(88.2)
Weeding by cono-weeder twice at 20 and 40 DAT/DAS	5.23(27.0)	7.94(64.3)	8.34(69.3)	6.30(41.4)	9.98(99.3)	10.98(122.1)
Intercropping of *dhaincha* and its incorporation at 40 DAT/DAS	4.38(19.0)	6.23(39.8)	7.09(51.3)	5.45(31.8)	7.14(51.1)	8.99(88.4)
LSD (p=0.05)	0.43	0.29	0.51	0.26	0.17	0.27
Interaction effect						
LSD (p=0.05)	NS	0.51	NS	0.60	0.25	0.46

$\sqrt{x+0.5}$ transformed values original values in the parentheses, LSD + least significant difference at the 5% level of significance; DAS: Days after seeding; DAT: Days after transplanting

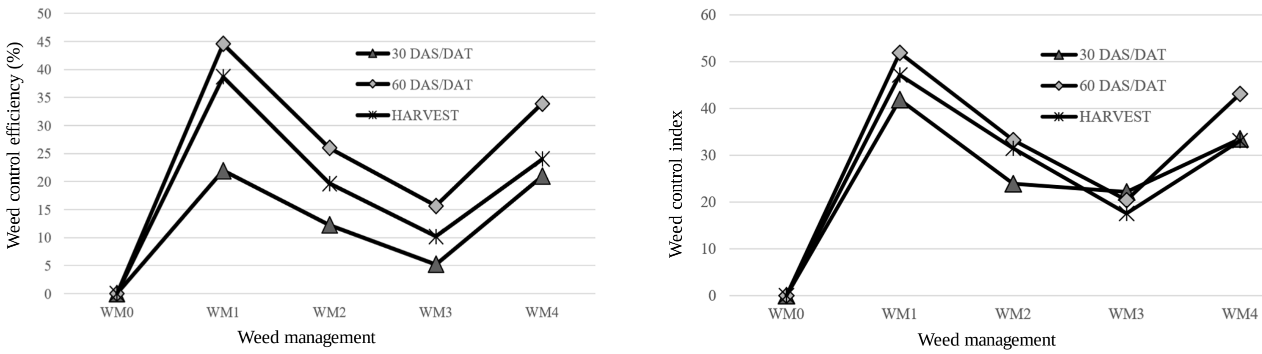

Figure 1. Weed control efficiency and weed control index of different weed management practices under two methods of aromatic rice establishment

Different weed management treatments significantly reduced weed density and biomass as compared to the weedy check. The least weed biomass at 30 and 60 DAT/DAS was recorded with hand weeding twice at 20 and 40 DAT/DAS followed by intercropping of dhaincha and its incorporation at 40 DAT/DAS. Hand weeding provided efficient weed control in comparison to other weed management practices causing reduced weed density and consequently reduced weed biomass as observed by Barla *et al.* (2016).

The rice establishment method had significant effect on WCE and WCI (**Figure 1**). The highest WCE (%) and WCI (%) were found in PTR. Among weed management practices, hand weeding twice at 20 and 40 DAT/DAS (WM1) resulted the highest WCE and WCI followed by intercropping of *dhaincha* and its incorporation at 40 DAT/DAS (WM4) at all observations.

Effect on rice

The effective tillers number/m^2, panicle length, panicle weight, filled grains per panicle and test weight, grain yield and straw yield (**Table 2**) were significantly higher in PTR as compared to WSR. Weeds compete in the crop field for the growth resources and crops get suffered due to this competition. The transplanted crop experienced late emergence of weeds coupled with less weed density which minimized the competition between crop and weed and thereby promoted the growth of different yield attributing characters of the transplanted rice crop.

Different weed management practices significantly influenced rice yield attributing characters and rice grain and straw yield. Hand weeding twice at 20 and 40 DAT/DAS enhanced rice effective tillers no./m^2, panicle length, panicle weight, number of filled grains per panicle, test weight, grain yield and straw yield as compared to the remaining treatments. The next best treatment was

Table 2. Yield attributes, yield and harvest index of aromatic rice as influenced by rice establishment methods and organic weed management treatments

Treatment	No. of effective tillers/m^2	Panicle length (cm)	Panicle weight (g)	Filled grains/ panicle	1000 grain weight (g)	Grain yield t/ha	Straw yield t/ha	Harvest index (%)
Rice establishment method								
Transplanting	207.00	24.16	1.25	103.6	11.85	1.82	3.01	37.23
Direct-seeded (wet-seeding)	159.00	22.68	1.07	98.06	10.86	1.11	2.06	34.00
LSD (p=0.05)	12.64	NS	NS	2.45	0.20	0.11	0.67	1.80
Weed management								
Weedy check	129.00	21.65	1.02	91.5	9.7	0.84	1.60	34.83
Hand weeding twice at 20 and 40 DAT/DAS	231.00	24.68	1.15	109	11.93	2.19	3.50	36.80
Weeding by rotary weeder twice at 20 and 40DAT/DAS	183.86	24.03	1.21	100.5	11.75	1.44	2.49	35.43
Weeding by cono-weeder twice at 20 and 40 DAT/DAS	176.00	23.57	1.09	97.80	11.63	1.16	2.15	35.32
Intercropping of *dhaincha* and incorporation at 40DAT/DAS	193.81	23.76	1.33	105.33	11.76	1.69	2.90	35.66
LSD (p=0.05)	6.92	1.58	NS	3.02	0.45	0.31	0.18	-
Interaction effect								
LSD (p=0.05)	14.46	NS	NS	NS	NS	0.40	0.68	-

LSD: Least significant difference at the 5% level of significance; DAS: Days after seeding; DAT: Days after transplanting

Table 3. Comparative economics of different organic weed management treatments under two establishment methods of aromatic rice

Treatment	Cost of cultivation (x10^3 `/ha)	Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)	B:C ratio
Transplanted rice				
Weedy check	29.14	53.39	24.25	0.83
Hand weeding at 20 and 40DAT/DAS	41.64	136.16	94.52	2.27
Weeding by rotary weeder at 20and 40 DAT/DAS	32.89	87.83	54.94	1.67
Weeding by cono-weeder at 20 and 40 DAT/DAS	32.89	66.06	33.17	1.00
Intercropping of *dhaincha* and its incorporation at 40 DAT/DAS	31.11	112.39	81.28	2.61
Direct wet-seeded rice				
Weedy check	22.64	32.57	9.92	0.44
Hand weeding twice at 20 and 40 DAT/DAS	35.14	82.82	47.68	1.36
Weeding by rotary weeder twice at 20 and 40 DAT/DAS	26.39	57.38	30.99	1.17
Weeding by cono-weeder twice at 20 and 40 DAT/DAS	26.39	52.67	26.28	0.99
Intercropping of *dhaincha* and its incorporation at 40 DAT/DAS	24.64	58.83	34.19	1.38

LSD: Least significant difference at the 5% level of significance; DAS: Days after seeding; DAT: Days after transplanting.

intercropping of dhaincha and its incorporation at 40 DAT/DAS. Intercropping dhaincha which is a green manure crop added not only valuable plant nutrient through atmospheric fixation of N, but also reduce the occurrence of weed by occupying the interspaces. Thus, led to increased grain yield and straw yield. Manual weeding has more advantage because of complete removal of weeds and helps in increasing grain yield and straw yield (Barla *et al.* 2016). Rice grain yield and weed biomass at 60 DAT / DAS had noticed a negative linear relationship with coefficient of determination of 0.844 was observed between rice grain yield and weed biomass at 60 DAT/DAS.Even though the highest grain yield was with the treatment hand weeding twice at 20 and 40 DAS/DAT (**Table 2**), the highest B:C ratio was recorded with intercropping of dhaincha and its incorporation at 40 DAS/ DAT, which was 2.61 and 1.38 with transplanted rice and wet seeded rice, respectively (**Table 3**). Hence, it may be concluded that for obtaining optimum grain yield and economic returns, intercropping of dhaincha and its incorporation at 40 DAT/DAS may be considered as one of the best options for organic weed management in aromatic rice.

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Indian Journal of Weed Science **53**(4): 430–432, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Weed management effect on weed growth and yield of foxtail millet [*Setaria italica* (L.) Beauv]

P. Sravani, D. Subramanyam[1*], A.V. Nagavani[2] V. Umamahesh and G. Karuna Sagar

Department of Agronomy, S.V. Agricultural College, Acharya N.G. Ranga Agricultural University, Tirupati, Andhra Pradesh 517502, India

[1]Agricultural Polytechnic, Punganur, Chittoor, Andhra Pradesh 517247, India

[2]DAATTC, Kalikiri, Chittoor, Andhra Pradesh 517234, India

**Email: subbuagro37@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00079.4

Type of article: Research note

Received : 9 July 2021
Revised : 25 September 2021
Accepted : 28 September 2021

KEYWORDS

Foxtail millet, Herbicides, Isoproturon, Pretilachlor, Pyrazosulfuron-ethyl, Weed management

ABSTRACT

A field experiment was conducted during (rainy season) *Kharif* 2020 at wetland farm of S.V. Agricultural College, Acharya N.G. Ranga Agricultural University, Tirupati, Andhra Pradesh, India to study the effect of different pre-emergence herbicides alone or in combination with inter-cultivation on weeds growth and yield of foxtail millet. The predominant weed flora associated with foxtail millet was *Digitaria sanguinalis* (L.) Scop. (42%), *Cyperus rotundus* L. (22%), *Cucumis callosus* (9%), *Boerhavia erecta* L. (6%), *Commelina benghalensis* L. (5%) and others (16%). The hand weeding (HW) twice at 20 and 40 days after seeding (DAS) resulted in lower density and biomass of all weeds with higher weed control efficiency, grain yield and benefit-cost ratio. Next best treatment was pre-emergence application of pretilachlor 500 g/ha or pyrazosulfuron-ethyl 15 g/ha followed by (*fb*) inter-cultivation at 20 DAS. The decrease in grain and straw yield due to weeds in unweeded check was 63.42 and 26.95% respectively, compared to HW twice.

Foxtail millet [*Setaria italica* (L.) Beauv] is grown as rainfed *Kharif* crop in India. Among agronomic practices, appropriate weed control is considered to be important aspect due to heavy losses caused by uncontrolled weeds (Munirathnam and Sawadhkar 2007). Weed flora associated with foxtail millet are highly diversified and vary depending upon the season, agroecological condition and level of management. The slow growing canopy of foxtail millet, during the initial growth, makes it susceptible to weed competition. Generally, small millets are relatively poor competitors for growth resources than weeds, especially during the early stages of the crop. Severe weed infestation is noticed in foxtail millet due to its slow growth at initial stages during rainy season. The initial period of 4-6 weeks after seedling emergence was considered as critical period for weed removal. Ning *et al.* (2015) stated that grain yield of foxtail millet was reduced by 56% due to presence of weeds throughout the crop season on calcareous soils. Pre-emergence herbicides improve the weed control and production efficiency in major millets due to their bigger seed size and comparatively deeper depth of sowing than small millets (Mishra 2016). The research findings on chemical weed management in foxtail millet are very meagre. In recent years, as the cost of hand weeding increased, farmers are inclined to use herbicides in small millet crops for effective control of weeds. Hence, the present study was undertaken to assess the efficacy of pre-emergence application (PE) of herbicide supplemented with inter-cultivation or post-emergence application (PoE) of penoxsulam for weed control with better selectivity in foxtail millet.

A field experiment was conducted during (rainy season) *Kharif* 2020 at wetland farm of S.V. Agricultural College, Acharya N.G. Ranga Agricultural University, Tirupati, Andhra Pradesh, India. The soil was sandy clay loam in texture, neutral in reaction, low in organic carbon and available nitrogen, medium in available phosphorus and available potassium. The experiment was laid out in a randomized block design with eleven treatments and replicated thrice. Foxtail millet was sown at a spacing of 30 x 10 cm on 14th August, 2020.The weed management treatments consisted of pre-emergence application (PE) of pretilachlor, isoproturon and pyrazosulfuron-ethyl 500, 500 and 15 g/ha, respectively; hand weeding twice and un-weeded check (**Table 1**). All the pre-emergence herbicides were supplemented with inter-cultivation or post-emergence application (PoE) of penoxsulam 20 g/ha, at 20 days after seeding (DAS). Pre-emergence herbicides were applied at 1 DAS and inter-cultivation/post-emergence herbicide, penoxsulam was applied at 20 DAS. All the pre-and post-emergence herbicides were applied with the help of knapsack sprayer fitted with flat fan nozzle and spray volume of 500 L/ha. Uniform dose of 20 kg N and 20 kg P was applied in the form of urea and single super phosphate, respectively to all the plots. Nitrogen was applied in two splits, *viz.* half of the dose as basal and the remaining half of the dose as top dressing at 30 DAS and entire dose of phosphorous was applied as basal at the time of sowing itself. The rest of the packages of practices were adopted as per recommendations of the Acharya N.G. Ranga Agricultural University. Category wise weed density and biomass were recorded randomly with the help of 0.25 m^2 quadrat. The data on weed density and biomass were transformed to square root $\sqrt{X+0.5}$ transformation to normalize their distribution. Weed control efficiency was computed as per the method suggested by (Mani *et al.* 1973). All the yield components, *viz.* number of panicles/m^2, grain weight/panicle and 1000-grain weight were recorded at harvest. Benefit-cost ratio was calculated after dividing gross returns with cost of cultivation. The crop was harvested on 5th November, 2020. The weed and crop data were analysed statistically by following the analysis of variance for randomized block design as suggested by Panse and Sukhatme (1985).

Effect on weed density and biomass

The predominant weed flora associated with foxtail millet was *Digitaria sanguinalis* (L.) Scop. (42%), *Cyperus rotundus* L. (22%), *Cucumis callosus* (9%), *Boerhavia erecta* L. (6%), *Commelina benghalensis* L. (5 %), *Cynodon dactylon* (L.) Pers. (5%), *Borreria hispida* (L.) K. Schum. (3%), *Cleome viscosa* L. (3%) and others (5%). All the weed management treatments significantly influenced the weed growth and yield of rainfed foxtail millet (**Table 1**). Among the weed management practices tested, the lowest density and biomass of grasses, sedges, broad-leaved weeds and total weeds as well higher weed control efficiency were obtained with pretilachlor 500 g/ha PE *fb* inter-cultivation at 20 DAS which was comparable with pyrazosulfuron-ethyl 15 g/ha PE *fb* inter-cultivation at 20 DAS and

Table 1. Weed density and biomass and weed control efficiency as influenced by different weed management treatments at harvest in foxtail millet

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)				WCE (%)
	Grasses	Sedges	BLWs	Total	Grasses	Sedges	BLWs	Total	
Pretilachlor (PE) 500 g/ha at 1 DAS	5.98 (35.33)	8.67 (74.67)	4.70 (21.67)	11.49 (131.67)	7.32 (53.67)	4.90 (24.43)	4.09 (16.27)	10.06 (94.37)	27.34
Isoproturon (PE) 500 g/ha at 1 DAS	6.04 (36.00)	8.69 (75.00)	4.78 (22.33)	11.57 (133.33)	7.39 (54.17)	4.94 (24.57)	4.21 (17.23)	10.14 (95.93)	26.13
Pyrazosulfuron-ethyl (PE) 15 g/ha at 1 DAS	6.01 (35.67)	8.68 (74.83)	4.74 (22.00)	11.53 (132.50)	7.38 (54.13)	4.88 (24.53)	4.16 (16.87)	10.12 (95.60)	26.39
Pretilachlor (PE) 500 g/ha *fb* IC at 1 + 20 DAS	4.18 (17.00)	6.40 (40.30)	3.58 (12.33)	8.36 (69.33)	3.69 (13.17)	3.48 (11.67)	2.77 (7.23)	5.70 (32.07)	75.31
Isoproturon (PE) 500 g/ha *fb* IC at 1 + 20 DAS	4.26 (17.67)	6.50 (41.33)	3.67 (13.00)	8.51 (72.00)	4.11 (17.33)	3.51 (11.87)	2.84 (7.57)	6.07 (36.77)	71.69
Pyrazosulfuron-ethyl (PE) 15 g/ha *fb* IC at 1 + 20 DAS	4.22 (17.33)	6.36 (40.00)	3.63 (12.67)	8.44 (70.67)	4.07 (16.93)	3.46 (11.53)	2.78 (7.27)	6.01 (35.73)	72.48
Pretilachlor (PE) *fb* penoxsulam (PoE) 500 + 20 g/ha at 1 + 20 DAS	5.36 (28.20)	7.76 (59.67)	4.12 (16.47)	10.24 (104.33)	6.15 (37.40)	4.39 (18.73)	3.57 (12.27)	7.39 (68.40)	47.33
Isoproturon (PE) *fb* penoxsulam (PoE) 500 + 20 g/ha at 1 + 20 DAS	6.63 (44.00)	9.51 (90.00)	5.24 (27.00)	12.70 (161.00)	8.02 (64.33)	5.47 (30.60)	4.64 (21.00)	11.56 (117.27)	9.70
Pyrazosulfuron-ethyl (PE) *fb* penoxsulam (PoE) 15 + 20 g/ha at 20 DAS	5.37 (28.33)	7.88 (61.67)	4.12 (16.50)	10.34 (106.50)	6.18 (37.80)	4.42 (19.13)	3.63 (12.67)	7.45 (69.60)	46.41
Hand weeding twice 20 and 40 DAS	2.74 (7.00)	3.53 (12.00)	1.68 (2.33)	4.67 (21.33)	1.67 (2.30)	2.2 (4.67)	1.42 (1.53)	2.98 (8.50)	93.45
Unweeded check	7.31 (53.00)	10.37 (107.0)	5.73 (32.33)	13.89 (192.33)	8.46 (71.13)	6.07 (35.33)	5.12 (25.73)	13.20 (129.87)	-
LSD (p=0.05)	0.54	0.78	0.44	1.06	0.60	0.44	0.40	0.84	

Data given in parentheses are original values. Original data subjected to square root transformation. WCE: weed control efficiency; IC: Intercultivation *fb*: followed by; PE: Pre-emergence; PoE: Post-emergence

Table 2. Yield components and yield as influenced by different weed management treatments in foxtail millet

Treatment	No. of panicles/ m^2	Weight of the panicle (g)	Grain weight panicle (g)	1000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Benefit-cost ratio
Pretilachlor (PE) 500 g/ha at 1 DAS	47.00	4.82	3.09	3.23	1309	3008	1.86
Isoproturon (PE) 500 g/ha at 1 DAS	47.00	4.51	3.04	3.21	1182	2962	1.68
Pyrazosulfuron-ethyl (PE) 15 g/ha at 1 DAS	47.00	4.52	3.07	3.21	1284	2.978	1.85
Pretilachlor (PE) 500 g/ha *fb* IC at 1 + 20 DAS	62.67	6.20	4.01	3.27	1961	3592	2.37
Isoproturon (PE) 500 g/ha *fb* IC at 1 + 20 DAS	56.00	6.06	3.59	3.17	1660	3348	2.11
Pyrazosulfuron-ethyl (PE) 15 g/ha *fb* IC at 1 + 20 DAS	58.33	6.13	3.74	3.18	1745	3435	2.14
Pretilachlor (PE) *fb* penoxsulam (PoE) 500 + 20 g/ha at 1 + 20 DAS	37.33	3.63	1.29	2.68	779	2438	1.09
Isoproturon (PE) *fb* penoxsulam (PoE) 500 + 20 g/ha at 1 + 20 DAS	32.00	3.39	1.24	2.52	690	2250	1.02
Pyrazosulfuron-ethyl (PE) *fb* penoxsulam (PoE) 15 + 20 g/ha at 20 DAS	33.33	3.54	1.21	2.67	724	2397	1.06
Hand weeding twice 20 and 40 DAS	70.00	7.06	4.61	3.64	2353	3944	1.92
Unweeded check	38.67	3.72	2.33	2.71	0861	2881	1.35
LSD (p=0.05)	6.72	0.75	0.42	0.42	0315	0419	0.17

IC: Intercultivation *fb*: followed by; PE: Pre-emergence; PoE: Post-emergence

isoproturon 500 g/ha PE *fb* inter-cultivation at 20 DAS which might be due to broad-spectrum and season long weed control as reported by Munirathnam and Sawadhkar (2007). However, all these treatments were significantly less effective in reducing weed growth than HW twice at 20 and 40 DAS.

Different weed management treatments in foxtail millet caused variation in number of panicles/ m^2, weight of the grains / panicle, 1000-grain weight, grain and straw yield (**Table 2**). Significantly higher number of panicles/m^2, weight of the grains / panicle grain and straw yield were recorded with HW twice and it was closely followed by pre-emergence application of pretilachlor 500 g/ha *fb* inter-cultivation at 20 DAS due to reduced competition for growth resources, which in turn increased the translocation of photosynthates to developing grains. These results were in agreement with the findings of Yathisha *et al.* (2020) in direct-seeded finger millet. All the above weed management treatments were at par with each other with respect to test weight of foxtail millet. Sequential application of pre-emergence herbicides at recommended doses followed by application of penoxsulam at 20 DAS applied plots registered the lowest values of all the yield components and yield due to phytotoxicity effect of penoxsulam. The decrease in grain and straw yield due to heavy weed infestation in unweeded check was 63.42 and 26.95 per cent, respectively, compared to best weed management practice. Among all the weed management practices, the highest benefit-cost ratio was realized with pre-emergence application of pretilachlor 500 g/ha *fb* inter-cultivation at 20 DAS and it was closely followed by pre-emergence application of pyrazosulfuron-ethyl 15 g/ha *fb* inter-cultivation at 20 DAS. Hand weeding twice recorded lesser benefit-cost ratio than all treatments constituting the pre-emergence herbicides application supplemented with inter-cultivation at 20 DAS, due to increased cost of manual weeding. Thus, under labour scarce situations, pre-emergence application of pretilachlor 500 g/ha *or* pyrazosulfuron-ethyl 15 g/ ha supplemented with inter-cultivation at 20 DAS may be used for broad-spectrum weed control and higher grain and straw yield as well as benefit-cost ratio in foxtail millet on sandy clay loam soils.

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Indian Journal of Weed Science **53**(4): 433–435, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Effect of different doses of fomesafen + fenoxaprop + chlorimuron-ethyl (ready-mix) against weeds in soybean

Rajendra Patel, Jitendra Patidar* and K.K. Jain

Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh 482004, India

**Email: jitendrapatidar90-coaagr@pau.edu*

Article information

DOI: 10.5958/0974-8164.2021.00080.0

Type of article: Research note

Received : 12 June 2021

Revised : 18 October 2021

Accepted : 21 October 2021

KEYWORDS

Chlorimuron-ethyl, Fomesafen, Fenoxaprop, Ready-mix formulation, Soybean, Weed management

ABSTRACT

Field experiment was conducted at Research Farm, Department of Agronomy, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) during (rainy season) *Kharif* 2018. Ten weed control treatments comprising of five doses of ready-mix formulation (ready-mix) of fomesafen + fenoxaprop + chlorimuron-ethyl (187, 234, 280, 327 and 584 g/ha), imazethapyr (100 g/ha) alone and combined with fluazifop-p-butyl + fomesafen (222 g/ha) as early post-emergence (PoE), hand weeding (HW) twice at 15 and 30 days after seeding (DAS), weed free and weedy check were laid out in randomized complete block design with three replications. The fomesafen + fenoxaprop + chlorimuron-ethyl (ready-mix) 327 g/ha as early post-emergence (early PoE) recorded lower weed density and biomass, with 98.0 and 99.0% weed control efficiency (WCE) of monocot and dicot weeds, respectively. The higher seed yield (1.91 t/ha) was recorded with fomesafen + fenoxaprop + chlorimuron-ethyl 327 g/ha and it was at par with HW twice (2.11 t/ha) and weed free plots (2.15 t/ha). The highest dose of fomesafen + fenoxaprop + chlorimuron-ethyl (584 g/ha) was found effective against monocot and dicot weeds but caused phytotoxicity on crop and reduced seed yield marginally (1.73 t/ha).

Weed infestation is the major constraint in soybean [*Glycine max* (L.) Merrill] production in rainy season (Vollmann *et al.* 2010). The lack of weeds control during critical period of crop-weed competition (20-40 DAS) results in appreciable loss in the yield (58-85%) of soybean, depending upon type and weed intensity (Kewat *et al.* 2000). Although hand weeding is an effective weed control measure, it is very costly which farmers could not afford. Herbicide usage is one of the alternate options for control of weeds. In the recent past, the ready-mix of herbicides comprising of two molecules like fomesafen + fenoxaprop-p-ethyl, quizalofop-p-ethyl + fomesafen and fomesafen + clodinafop are widely used for controlling the weeds in soybean. Currently, ready-mix of three herbicide molecules are also available and being used for effective control of mixed weed flora in the soybean crop. Thus, the present study was conducted to evaluate the efficacy of ready-mix fomesafen + fenoxaprop + chlorimuron-ethyl to manage weeds in soybean.

A field experiment was conducted at Research Farm, Department of Agronomy, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) during (rainy season) *Kharif* 2018. Ten weed control treatments comprising: fomesafen 12.5% + fenoxaprop 10% + chlorimuron-ethyl 0.9% micro encapsulated (ME) (ready-mix) five doses *i.e.*, 187, 234, 280, 327 and 584 g/ha; imazethapyr at 100 g/ha; fluazifop-p-butyl 11.1% SL + fomesafen11.1% SL (ready-mix) at 222 g/ha; hand weeding twice at 15 and 30 days after seeding (DAS); weed free and weedy check control. The soil of the experimental field was sandy clay loam in texture, neutral in reaction (7.1) and medium in organic carbon (0.60%). The five doses of fomesafen + fenoxaprop + chlorimuron-ethyl (ready-mix) were used as early post-emergence application (early PoE) (at 15 DAS at 3-4 leaf stage). Herbicides were applied at a volume of 500 litres of water/ha at 15 DAS using knapsack sprayer fitted with flat fan nozzle in water (500 litre/ha). The observations on weeds were recorded at 30 days after herbicide application (DAA). Weeds were counted using quadrat of 0.25 square meter (0.5 x 0.5 m), and data obtained were expressed as density (numbers/m^2). The percent composition of weed flora was estimated from weedy check plot. The relative density of individual weed was estimated using formula of Mishra (1968). The weed dry weight (weed biomass) from different treatments plots under all the treatments was recorded by removing weeds (counted for weed density) species wise from of 0.25 square meter quadrat by placing it at four places in each plot. The weeds thus obtained were first sun dried and thereafter kept in paper bags and dried in oven at 60 ^{0}C for 48 hours till constant weight is obtained, dry weight was recorded and expressed as weed biomass (g/m^2). The data on weed density and biomass were subjected to square root transformation to normalize their distribution (Gomez and Gomez 1984).

Effect on weeds

The weeds infested in experiment field mainly comprised of monocots: *Echinochloa colona*, *Cyperus iria* and dicots: *Sida acuta*, *Mollugo pentaphylla*, *Phyllanthus urinaria.* The density and biomass of all the weeds were maximum in weedy check at all the growth intervals (**Table 1** and **2**) due to continues growth of weeds as no weed control measures were adopted. The fomesafen + fenoxaprop + chlorimuron-ethyl (ready mix) at the lowest dose (187 g/ha) early PoE caused appreciable reduction in density and biomass of grassy and broad- leaved weeds **(Table 1** and **2)** but reduction was more pronounced when fomesafen + fenoxaprop + chlorimuron-ethyl ready mix was applied at higher rate *i.e.* from 234 to 584 g/ha was applied. The hand weeding twice at 15 and 30 DAS reduced the density and biomass of weeds to the maximum extent, when compared to herbicide-based treatments, due to removal of all catogories of weeds during the course of hand weeding as observed earlier by Singh and Jolly (2004), Sharma *et al.* (2017) and Gidesa and Kebede (2018).

Weed control efficiency (WCE) of a treatment has strong negative correlation with weed biomass. Therefore, the trend of treatments for increased WCE was in order of weed biomass. The highest weed control efficiency (98.24%) was attained with fomesafen + fenoxaprop + chlorimuron-ethyl (ready-mix) 584 g/ha early PoE **(Table 3)** followed by application of fomesafen + fenoxaprop + chlorimuron-ethyl (ready-mix) 327 g/ha early PoE (97.19%) due to lower weed biomass. The WCE was also higher (98.18%) with hand weeding twice.

Effect on soybean

Among the yield attributes, namely pods per plant were higher in the weed free plot and two hand weeding at 15 and 30 DAS followed by combined application of fomesafen + fenoxaprop +

Table 1. Effect of weed control treatments on weeds density in soybean at 30 days after herbicide application

Treatment	Weed density (no./m^2)				
	Echinochloa colona	*Cyperus iria*	*Sida acuta*	*Mollugo pentaphylla*	*Phyllanthus urinaria*
Fomesafen + fenoxaprop + chlorimuron-ethyl 187 g/ha early PoE	3.41(10.67)	2.64(6.00)	1.99(3.00)	1.91(2.67)	1.63(1.67)
Fomesafen + fenoxaprop + chlorimuron-ethyl 234 g/ha early PoE	3.00(8.00)	2.30(4.33)	1.82(2.33)	1.72(2.00)	1.52(1.33)
Fomesafen + fenoxaprop + chlorimuron-ethyl 280 g/ha early PoE	2.08(3.33)	1.88(2.67)	1.63(1.67)	1.52(1.33)	1.28(0.67)
Fomesafen + fenoxaprop + chlorimuron-ethyl 327 g/ha early PoE	1.72(2.00)	1.52(1.33)	1.38(1.00)	1.41(1.00)	1.14(0.33)
Fomesafen + fenoxaprop + chlorimuron-ethyl 584 g/ha early PoE	1.28(0.67)	1.38(1.00)	1.28(0.67)	1.14(0.33)	1.14(0.33)
Imazethapyr 100 g/ha early PoE	1.99(3.00)	2.29(4.33)	1.72(2.00)	1.91(2.67)	1.72(2.00)
Fluazifop-p-butyl + fomesafen 222 g/ha early PoE	1.82(2.33)	1.82(2.33)	1.52(1.33)	1.82(2.33)	1.38(1.00)
Hand weeding twice at 15 and 30 days after sowing	1.63(1.67)	1.52(1.33)	1.49(1.33)	1.61(1.67)	1.52(1.33)
Weed free	1.00(0.00)	1.00(0.00)	1.00(0.00)	1.00(0.00)	1.00(0.00)
Control (weedy check)	6.73(44.33)	6.53(41.67)	4.97(23.67)	9.49(89.00)	4.16(16.33)
LSD (p=0.05)	0.34	0.44	0.44	0.35	0.42

*Figure in parentheses is the original values

Table 2. Influence of weed control treatments on weeds biomass in soybean at 30 days after herbicide application (DAA)

Treatment	Weed biomass (g/m^2)				
	Echinochloa colona	*Cyperus iria*	*Sida acuta*	*Mollugo pentaphylla*	*Phyllanthus urinaria*
Fomesafen + fenoxaprop + chlorimuron-ethyl 187 g/ha early PoE	4.68(20.9)	3.58(11.88)	2.42(4.92)	1.56(1.44)	1.82(2.37)
Fomesafen + fenoxaprop + chlorimuron-ethyl 234 g/ha early PoE	3.88(14.08)	2.99(8.06)	2.18(3.78)	1.36(0.88)	1.71(1.97)
Fomesafen + fenoxaprop + chlorimuron-ethyl 280 g/ha early PoE	2.49(5.20)	2.34(4.75)	1.64(1.70)	1.25(0.56)	1.33(0.82)
Fomesafen + fenoxaprop + chlorimuron-ethyl 327 g/ha early PoE	1.84(2.48)	1.79(2.25)	1.37(0.96)	1.19(0.42)	1.17(0.42)
Fomesafen + fenoxaprop + chlorimuron-ethyl 584 g/ha early PoE	1.33(0.83)	1.58(1.68)	1.27(0.65)	1.06(0.13)	1.15(0.37)
Imazethapyr 100 g/ha early PoE	2.60(5.88)	3.17(9.19)	2.06(3.36)	1.53(1.36)	1.89(2.64)
Fluazifop-p-butyl + fomesafen 222 g/ha early PoE	2.25(4.11)	2.29(4.29)	1.82(2.37)	1.49(1.21)	1.50(1.40)
Hand weeding twice at 15 and 30 days after sowing	1.72(1.98)	1.53(1.36)	1.36(0.91)	1.15(0.33)	1.27(0.61)
Weed free	1.00(0.00)	1.00(0.00)	1.00(0.00)	1.00(0.00)	1.00(0.00)
Control (weedy check)	11.95(141.9)	9.23(84.17)	5.55(29.82)	7.26(51.67)	4.98(23.85)
LSD (p= 0.05)	0.48	0.64	0.49	0.17	0.51

*Figure in parentheses is the original values

Table 3. Influence of weed control treatments on the weed control efficiency, yield attributes, yields, weed index and benefit-cost ration of soybean

Treatment	WCE (%)		Pods/ plant (no.)	Seed yield (t/ha)	Stover yield (t/ha)	Weed index (%)	B:C ratio
	Monocot	Dicot					
Fomesafen + fenoxaprop + chlorimuron-ethyl 187 g/ha early PoE	89.00	90.02	31.79	1.24	2.56	42.41	1.37
Fomesafen + fenoxaprop + chlorimuron-ethyl 234 g/ha early PoE	92.00	92.43	34.89	1.41	3.00	34.48	1.56
Fomesafen + fenoxaprop + chlorimuron-ethyl 280 g/ha early PoE	95.95	94.94	40.51	1.68	3.22	21.90	1.83
Fomesafen + fenoxaprop + chlorimuron-ethyl 327 g/ha early PoE	97.97	97.19	51.59	1.91	3.65	11.03	2.08
Fomesafen + fenoxaprop + chlorimuron-ethyl 584 g/ha early PoE	98.73	98.24	41.77	1.73	3.57	19.48	1.87
Imazethapyr 100 g/ha early PoE	94.42	91.60	36.33	1.43	3.11	33.62	1.60
Fluazifop-p-butyl + fomesafen 222 g/ha early PoE	97.02	94.68	47.99	1.88	3.56	12.59	2.06
Hand weeding twice at 15 and 30 days after sowing	98.91	98.15	57.76	2.11	4.04	1.72	1.73
Weed free	100.00	100.00	60.59	2.15	4.15	0.00	1.14
Control (weedy check)	-	-	27.05	1.04	2.63	51.72	1.20
LSD (p=0.05)	-	-	2.61	0.11	0.21	-	-

chlorimuron-ethyl (ready-mix) 327 g/ha PoE. Excellent growth and development of soybean plants under these treatments environment during critical period of crop growth might have resulted in superior yield attributes with these treatments as compared to other treatments which had greater crop weed competition right from early growth stages and ultimately resulted in lesser values of yield attributes as observed by Raghuwanshi *et al.* (2005), Shete *et al.* (2007) and Kadam *et al.* (2018).

Among all the treatments, the minimum number of seed and stover yield was recorded under weedy check plot (1.04 and 2.63 t/ha) where weeds were allowed to grow throughout crop season. The higher seed and stover yield were recorded when fomesafen + fenoxaprop + chlorimuron-ethyl (ready-mix) applied at 327 g/ha early PoE (1.91 and 3.65 t/ha), which was significantly superior over check herbicide imazethapyr 100 g/ha and lower doses of the ready- mix herbicide. The application of fomesafen + fenoxaprop + chlorimuron-ethyl at highest dose (584 g/ha) gave effective control of weeds which resulted in lower density and biomass of weeds but also reduced soybean yield marginally (1.73, 3.57 t/ha seed and stover yield, respectively) due to phytotoxicity of it on soyabean plants. However, all the herbicidal treatments were found to be inferior to weed free and hand weeding twice which recorded maximum seed and stover yield (2.15 and 4.15, 2.11 and 4.04 t/ha, respectively).

The maximum reduction in yield (51.72%) due to weed competition occurred in weedy check plots, where weeds were not controlled throughout the crop season. Application of fomesafen + fenoxaprop + chlorimuron-ethyl (ready-mix) at 327 g/ha recorded lower yield reduction (11.03%) due to weed competition and was superior over other treatments except hand weeding twice that recorded 1.72% reduction due to weed competition. The application of fomesafen + fenoxaprop + chlorimuron-ethyl (ready-mix) at 327 g/ha early PoE recorded maximum B: C ratio (2.08).

It was observed that application of fomesafen + fenoxaprop + chlorimuron-ethyl (ready-mix) at 327 g/ha as early-post-emergence application gave effective control of diverse weed flora, and was more remunerative without any phytotoxicity on soybean crop.

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Indian Journal of Weed Science **53**(4): 436–439, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Weed smothering efficiency and cotton equivalent productivity of Bt cotton based intercropping systems

R. Veeraputhiran* and K. Sankaranarayanan[1]

Cotton Research Station, TNAU, Srivilliputtur, Tamil Nadu 626135, India

[1]ICAR- Central Institute of Cotton Research, RS, Coimbatore, Tamil Nadu 641003, India

**Email: veeraagri@yahoo.co.in*

Article information

DOI: 10.5958/0974-8164.2021.00081.2

Type of article: Research note

Received : 1 July 2021
Revised : 24 November 2021
Accepted : 27 November 2021

KEYWORDS

Cotton, Intercropping, Seed cotton yield, Weed density, Weed smothering efficiency

ABSTRACT

A field experiment was conducted at Cotton Research Station, (TNAU), Srivilliputtur under winter irrigated condition from September 2020 to February 2021. The objective of the study was to identify a suitable intercropping system with higher weed smothering efficiency and cotton productivity. The experiment was carried out in a randomized block design with ten treatments replicated thrice. The weed density and biomass were reduced by all the intercropping systems when compared to sole cropping. Among the intercrops, cluster bean, blackgram and greengram were more efficient in reducing the weed density than onion and coriander. The seed cotton equivalent yield was highest with intercropping of paired row planted Bt cotton with one row each of onion and cluster bean (3.75 t/ha) followed by two rows of cluster bean (3.70 t/ha) and two rows of onion intercropping (3.69 t/ha) as compared sole cotton (2.39 t/ha), cotton + blackgram (2.55 t/ha) and cotton + greengram intercropping system (2.56 t/ha).

Cotton also known as "white gold" and "king of fibre crops" is an important fibre cum cash crop of India and Tamil Nadu as well. India has the largest area (41.3%) of cotton in the world, but, due to its lower productivity, it's share to the total world cotton production is only 25.4%. In Tamil Nadu, cotton is cultivated in an area of 1.55 lakh ha during 2020-21 with a production of 5.0 lakh bales and productivity of 548 kg/ha, which is below the world average yield of 768 kg/ha (Anonymous 2021). Intercropping has been recognized as potentially beneficial and economic system of crop production to increase the cropping intensity and resource utilization for efficient management of inputs (Singh and Singh 2016). As cotton is a relatively longer duration and its slow growth during earlier stage offer vast scope for intercropping. Weeds, when uncontrolled, removed 32.6:3.33:18.46 kg NPK/ha by reducing the cotton nutrient uptake by 94 to 96% (Ayyadurai and Poonguzhalan 2010). Cotton is very sensitive to crop-weed competition due to slow growth during early stage and wider spacing (Kalaichelvi 2008). Intercropping and crop rotations will help in the ecological intensification of cotton-based cropping systems (Matloob *et al*. 2020). Intercropping of short duration field crops (Rajput *et al*. 2016) and vegetable crops (Rajput *et al*. 2018) has the potential to smother the weeds in the cotton based intercropping system. Selection of suitable intercropping system is paramount importance to realize higher productivity and also effective reduction of weed growth (Giri *et al*. 2006). Thus, an experiment was conducted to identify weed smothering intercrops for managing weeds and obtain higher productivity of irrigated Bt cotton.

A field experiment was conducted at Cotton Research Station, (TNAU), Srivilliputtur under winter irrigated condition from September 2020 to February 2021. The objective of the study was to identify a suitable intercropping system with higher weed smothering efficiency and cotton productivity. The experiment was carried out in a randomized block design with three replications. The treatments consisted of: sole Bt cotton; paired row planting of Bt cotton with two rows of onion; paired row planting of Bt cotton with two rows of cluster bean; paired row planting of Bt cotton with two rows of coriander; paired row planting of Bt cotton with one of row onion + one row cluster bean; paired row planting of Bt cotton with one row of cluster bean + one row coriander; paired row planting of Bt cotton with one row of coriander + one row onion; paired row planting of Bt cotton with one row each of onion

+ cluster bean + coriander; Bt cotton at normal spacing with 2 rows of blackgram and Bt cotton at normal spacing of with 2 rows of greengram. The sowing of experimental crop was taken up on 02.09.2020. The soil of the experimental field was clay loam with a pH of 8.26 dSm/m. The available soil nutrient status was low in N (196 kg/ha), high in P (40 kg/ha) and also high in K (496 kg/ha). The varieties used for the intercrops were *CO5* (small onion), *CO1* (cluster bean), *CO4* (coriander), *VBN8* (blackgram) and *CO8* (greengram). Normal spacing of 120 x 60 cm was followed in sole Bt cotton and blackgram and greengram intercropping. For other treatments, paired row planting of 80 x 60 cm for cotton and 50 x 10 cm for 2 rows intercropping and 40 x 10 cm for three rows of intercropping were followed. A fertilizer recommendation of 120: 60: 60 kg NPK/ha was applied for all the treatments and no additional fertilizers or pesticides were applied to intercrops. Hand hoeing twice on 25 days after seeding (DAS) and 45 DAS were undertaken for all the treatments. The data on weed density and biomass were recorded at 20 and 40 DAS. The weed smothering efficiency (WSE) was calculated and the seed cotton yield and yield of intercrops were also recorded. The seed cotton equivalent yield (SCEY) was calculated by multiplying the yield of intercrop with the market price of cotton and dividing with the market price of intercrop.

Effect on weeds

The weed density was lower during the early stage (20 DAS) than the later stage (40 DAS) of crop growth (**Table 1**). All the intercropping systems reduced the weed density compared to sole crop and among the intercrops cluster bean, blackgram and greengram were more efficient in reducing the weed density than onion and coriander during both the stages of observation. At 20 DAS, significant reduction in weed density was observed under the intercropping of cotton with two rows of cluster bean, blackgram, greengram, one row each of onion and cluster bean, cluster bean + coriander and one row each of cluster bean, coriander and onion intercropping with cotton than sole of cotton. At 40 DAS also, all the intercropping systems reduced the weed density significantly than pure cotton except two rows of onion intercropping with cotton. The lower weed density recorded under cotton with pulses and cluster bean intercropping systems was due to production of high foliage of pulses in the system; which suppressed weeds growth efficiently than intercropping of onion and coriander with cotton. Reduced weed density under Bt cotton inter cropped with pulses, cluster bean and coriander are in conformity with the findings of Sankaranarayanan *et al* (2012) and Harisudan (2019), Sivakumar and Subbain (2010)

The weed biomass followed a similar trend as that of weed density. All the intercropping systems significantly reduced the weed biomass than pure crop of cotton alone except cotton intercropping with two rows of onion, two rows of coriander and one row each of cotton + coriander at 20 DAS. At 40 DAS also, all the intercropping systems except cotton

Table1. Weed density, weed biomass and weed smothering efficiency as influenced by inter cropping in Bt cotton

Treatment	Weed density (no./m^2)		Weed biomass (kg/ha)		Weed smothering efficiency (%)	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
Sole Bt cotton	153(12.4)	231(15.2)	402(20.1)	890(29.8)	--	--
Paired row planting of Bt cotton with two rows of onion	151(12.3)	212(14.6)	397(19.9)	842(29.0)	1.31	5.39
Paired row planting of Bt cotton with two rows of cluster bean	142(11.9)	176(13.3)	304(17.4)	726(26.9)	6.54	18.41
Paired row planting of Bt cotton with two rows of coriander	149(12.2)	205(14.3)	393(19.8)	830(28.8)	2.61	6.74
Paired row planting of Bt cotton with one row onion + one row of cluster bean	140(11.8)	164(12.8)	293(17.1)	711(26.7)	8.50	20.15
Paired row planting of Bt cotton with one row of cluster bean +one row of coriander	137(11.7)	161(12.7)	284(16.9)	702(26.5)	10.46	21.13
Paired row planting of Bt cotton with one row of coriander + one row of onion	146(12.1)	204(14.3)	387(19.7)	817(28.6)	4.58	8.20
Paired row planting of Bt cotton with one row each of onion + cluster bean + coriander	124(11.2)	146(12.1)	276(16.6)	685(26.2)	18.95	23.08
Normal spacing of Bt cotton with 2 rows of black gram	129(11.4)	151(12.3)	295(17.2)	713(26.7)	15.68	19.94
Normal spacing of Bt cotton with 2 rows of greengram	132(11.5)	153(12.4)	308(17.6)	727(27.0)	13.73	18.33
LSD (p=0.05)	8.65	23.7	39.0	63.5	-	-

Figures in parentheses indicate transformed $\sqrt{x+0.5}$ values

+ 2 rows of onion registered significantly lesser weed biomass than sole cropping. The lesser weed biomass recorded in cotton intercropped with cluster bean and pluses was due to the corresponding lower weed growth and also higher foliage production as compared to onion and coriander. A similar reduction in weed biomass was reported earlier with the intercropping of cotton with cluster bean and coriander (Sankaranarayanan *et al.* 2012) and pulses (Sivakumar and Subbaian 2010).

Effect on weed smothering efficiency

Weed smothering efficiency (WSE) indicates the percentage of weed biomass suppression by the treatment than control. In the present study, all the intercropping systems smothered the weeds, compared to sole crop during both the stages of observation (**Table 1**). Moreover the WSE was higher at 40 DAS than at early stage of 20 DAS. Among the intercropping systems, cotton intercropped with three crops of onion, cluster bean, and coriander smothered the weeds more efficiently with the higher WCE of 18.95 and 23.08%, respectively during 20 and 40 DAS. The next efficient treatments were cotton intercropped with two rows of blackgram (15.68%) at 20 DAS. At 40 DAS, intercropping of one row each of cluster bean and coriander (21.13%), two rows of cluster bean (20.15%) followed by two rows of blackgram (19.94%) with greater WSE. The higher weed smothering efficiency with above intercropping systems might be due to better utilization of light, water and nutrients by the intercrops through greater competition with weeds and also by suppressing the germination of weeds (Altieri and Liebman 1986). In addition, more foliage producing capacity of intercrops resulted in high light interception and suppressed underground weed growth. The higher WSE was reported earlier too in cotton intercropped with cluster bean and coriander (Sankaranarayanan *et al.* 2012, Harisudan 2019), short duration vegetables (Gadade *et al.* 2006) and pulses (Giri *et al.* 2006, Sivakumar and Subbaian 2010).

Effect on seed cotton yield and seed cotton equivalent yield (SCEY)

The seed cotton yield was not influenced by different treatments **(Table 2**). However, all the intercrops studied had equally increased the seed cotton yield indicating the complementary effect without competition during the growth and development of main cotton crop. Among them, intercropping of Bt cotton with one row each of onion, cluster bean, coriander recorded highest seed cotton yield (2.46 t/ha) followed by that of one row each of onion and cluster bean (2.45 t/ha) and intercropping of two rows of cluster bean (2.44 t/ha). Similar result of non- significant response between sole crop and intercropping of cotton was reported by Sankaranarayanan *et al.* (2012) and Maitra *et al.* (2001). The intercropped legumes (cluster bean, greengram, blackgram) might have improved the soil health and soil fertility as reported by Sankaranarayanan *et al.* (2010) and Rao *et al.* (2009).

Table 2. Seed cotton yield and seed cotton equivalent yield as influenced by inter cropping in Bt cotton

Treatment	Seed cotton yield (t/ha)	Intercrop yield (t/ha)	Seed cotton equivalent yield* (t/ha)
Sole Bt cotton	2.39	--	2.39
Paired row planting of Bt cotton with two rows of onion	2.42	Onion 1.81	3.69
Paired row planting of Bt cotton with two rows of cluster bean	2.44	Cluster bean 3.14	3.70
Paired row planting of Bt cotton with two rows of coriander	2.43	Coriander 1.13	2.84
Paired row planting of Bt cotton with one row of onion + one row of cluster bean	2.45	Onion 1.01 Cluster bean 1.49	3.75
Paired row planting of Bt cotton with one row of cluster bean +one row of coriander	2.44	Cluster bean 1.38 Coriander 0.61	3.21
Paired row planting of Bt cotton with one row of coriander + one row of onion	2.43	Onion 0.85 Coriander 0.56	3.23
Paired row planting of Bt cotton with one row each of onion + cluster bean + coriander	2.46	Onion 0.74 Cluster bean 1.14 Coriander 0.46	3.60
Normal spacing of Bt cotton with 2 rows of black gram	2.41	Black gram 0.13	2.55
Normal spacing of Bt cotton with 2 rows of greengram	2.42	Greengram 0.13	2.56
LSD (p=0.05)	NS	-	-

*****Price of produces (₹/kg): cotton = 51, onion=35, cluster bean=20, vegetable coriander= 18, greengram and blackgram= 55

The clusterbean (1:1) intercropping system recorded higher seed cotton yield than cotton + blackgram (1:1) and cotton + greengram (1:1) intercropping system as reported by Ravindra Kumar *et al.* (2017).

The total productivity in terms of seed cotton equivalent yield (SCEY) increased with all the intercrops studied (**Table 2**). Among them, the highest total SCEY was with intercropping of one row each of onion and cluster bean with cotton (3.75 t/ha) followed by two rows of cluster bean (3.70 t/ ha) and two rows of onion (3.69 t/ha). The next higher total SCEY was observed with intercropping of Bt cotton with three crops (onion, cluster bean and coriander) (3.60 t/ha). The higher SCEY with these intercropped treatments were due to additional yield of intercrops obtained and also prevailing remunerative market price. The higher SCEY was also reported earlier in cotton intercropped with cluster bean (Ravindra Kumar *et al.* 2017, Sankaranarayanan *et al.* 2012), onion (Maitra *et al* 2001), coriandar (Sankaranarayanan *et al.* 2012) and pulses (Pandagale *et al.* 2019, Khagkharate *et al.* 2014). The lesser total SCEY under pulses intercropping was a result of lower grain yield of pulses than vegetables.

It may be inferred from this study that cotton based intercropping system including cotton intercropped with one row each of cluster bean and onion and with two rows of cluster bean may be recommended for reducing weeds growth with enhanced weed smothering efficiency and attain higher seed cotton equivalent yield.

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