Indian Journal of Weed Science

Print ISSN 0253-8040
Online ISSN 0974-8164

Volume – 53 | Number – 1
January – March, 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

Volume 53 | Number 1 | January – March, 2021

Review articles

Research articles

Research notes

The papers published in this journal are selectively abstracted and indexed in Google Scholar, CABI, Crossref, Efita.org, OAJI.net, Research Bible, Citefactor, CNKI Scholar, EBSCO Discovery, Summon Proquest, Indian Citation Index (ICI), Indian Science Abstracts, J-Gate and other major abstracting services of the world. Each paper bears a DOI number to facilitate online identity and access.

After consulting instructions on link http://isws.org.in/IJWSn/Journal.aspx, authors should submit their articles online only. Articles are not accepted through email or post. Please log directly on to http://isws.org.in/login_IJWS.aspx and upload your manuscript following the on-screen instructions.

Membership rates of Indian Society Weed Science (for the year 2020)		
	INDIA	FOREIGN
Individual (Annual)	` 500.00	US$ 50.00
Individual (Life)	` 6,000.00	US$ 300.00
Institution Libraries	` 10,000.00	US$ 300.00
Sustaining industries (Annual)	` 20,000.00	-
Sustaining industries (Life)	` 50,000.00	-
Please submit form online: http://isws.org.in/Member_r.aspx		

Indian Journal of Weed Science **53**(1): 1–13, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Economic threshold concept for weed management in crops: Usefulness and limitation

T.K. Das, Suman Sen*, Rishi Raj, Sonaka Ghosh, Biswaranjan Behera and Arkaprava Roy
Division of Agronomy, ICAR – Indian Agricultural Research Institute, New Delhi 110 012, India
**Email: sumansen.agri@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00001.0

Type of article: Review article

Received : 26 December 2020
Revised : 10 February 2021
Accepted : 12 February 2021

Key words
Decision support system
Economic threshold
Herbicide
Hyperbolic regression model
Weed management

ABSTRACT

The economic threshold (ET) is one of the major decision-making frameworks for rationalizing herbicides use for better weed management while reducing environmental impacts. The ET is the density of weeds at which the cost of control equals the benefits obtained under particular weed control measure adopted. The ET rejects complete eradication of weeds, but advocates regulating weed populations at economically optimum levels. Control measure is adopted only when weed competition goes beyond a certain limit, thus, it uses certain damage levels for making cost-efficient weed management decisions. Several decision-making models on ET are available with high to low degree of precision. Despite potentials, the adoption of ET models as the major criterion for cost-effective herbicide use has been low. Limitations are building up of seed bank by residual weeds, complexity in estimating ET density, patchy weed distribution, and limited validity in cropping systems with multiple weed species. Yet, the ET-based decision has great potential in designing weed management under single weed dominance in crops. Information on weeds population dynamics in cropping system, biology, ecology and spatial heterogeneity would make determination of ET more precise and reliable, and managing weeds using integrated approach more successful.

INTRODUCTION

Weed management has been primarily focused on selective herbicides since the inception of herbicides. But, the indiscriminate and increasing trend in herbicides use is a primary concern in present agriculture. Excess consumption of herbicides can be reduced by making rational decisions on weed management (Das *et al.* 2010). Making appropriate decision on the use of herbicides requires development of weed management decision models (Coble and Mortensen 1992). The development of weed management decision models is possible by through determining the ET of weeds, which assesses whether a treatment against weeds is necessary and economical (Cousens *et al.* 1986, Cousens 1987, Wilkerson *et al.* 2002). The ET concept is the principal guideline of pest/weed management that largely avoids eradication of pest(s) to regulate their populations at economically optimum levels (Coble and Mortensen 1992, Wilkerson *et al.* 2002, Das *et al.* 2014a). The ET for weed control or the "break-even point" is the level of weed infestation at which the cost of weed control operations is equal to the benefits obtained as a result of controlling the weeds (Cousens 1987, Hazra *et al.* 2011). Thus, the ET is primarily a binary decision-making concept ('control' or 'not control') that justifies adoption of control measures (Auld *et al.* 1987) or decides the weed density at which weed control becomes economically worthwhile (Cousens *et al.* 1988).

The ET concept was first introduced by Stern *et al.* (1959) and was defined as "the density at which control measures should be adopted to prevent an increasing pest population from reaching the economic injury level (EIL)." The EIL represents "the lowest population density of pests that can cause economic damage to crops." Stern *et al.* (1959) opined that the ET should be lower than the EIL, which provides sufficient time for the control measures to take action before the population reaches EIL. Initially, entomologists adopted ET in the early 1970s (Stern 1973, Wilkerson *et al.* 2002). Weed scientists adopted this later as the decision-making tool/ process for weed management. Coble and Mortensen (1992) and Thornton and Fawcett (1993) reported that this concept was the basis of majority of weed management decision models available to farmers. The ET-based weed management may lead to rationalization of herbicide use, which can reduce herbicide cost and environmental pollution while maintaining farm profitability (Swanton and Weise 1991, Jones and Medd 2000, Thomas *et al.* 2011). Besides, Norris (1992) opined that the ET-based concept can reduce future weed populations by reducing weed seed rain through control measure adopted when there is above-ET weed density. But, there may be chance of carry-over effect of the sub-ET weed density (when no control measure adopted) on weed seed bank over the years. However, most ET research, being a short-term approach, has overlooked this. Several competition thresholds, *viz*., period threshold, quantity threshold, damage threshold, economic threshold, action threshold, ecological threshold (Coble and Mortensen 1992, Das 2008) have been used for managing pests. Some of these thresholds can be applied to weed science for managing weeds in crops.

Determination of economic threshold (ET)

Determining ETs or action thresholds of weeds involves methods that can measure and predict the level of weed infestation. The level of weed infestation can be quantified in terms of weed population per unit area (Cousens 1985a, Cousens 1985b), relative leaf area *i.e*., proportion of leaf area of a weed species to the total leaf area of that weed and crop (Kropff and Spitters 1991, Kropff and Lotz 1993, Lotz *et al.* 1996), per cent ground cover of broad-leaved weeds (Gerowitt and Heitefuss 1990) or biomass of weeds. However, quantifying weed density for use in decision models by far has been the most common approach and simplest of all (Marra and Carlson 1983, Cousens 1987, Gerowitt and Heitefuss 1990, Coble and Mortensen 1992, Mortensen *et al.* 1993, Swinton and King 1994, Wilkerson *et al.* 2002). Usually, the density per unit area or relative leaf area of an individual weed is used in equations to predict yield loss. The gain or loss in crop values is generally estimated in terms of increase or decrease in crop yields. A weed-crop model developed across cropping systems can predict yield loss due to weeds or yield gain as a result of managing weeds. There are multiple simulation models available for this and for working out ET of weeds.

Economic threshold based on density-yield model

The relationship between crop yield/yield loss and weed density is worked out using a non-linear regression model derived from a rectangular hyperbola (**Eq. 1, Table 1**) (Cousens 1985a, Cousens 1985b, Norris 1999). The data and fitted curves are presented in terms of per cent yield loss using Eq. 2 (**Table 1**). This equation serves as the basis of many other models developed for ET calculation. A quadratic equation (**Eq. 3**; **Table 1**) is used for determining the ETs of different weed species based on their respective weed density (Cousens 1987).

Economic threshold based on yield-relative leaf area model

The empirical model (**Eq. 4; Table 1**), which relates crop yield loss to early observation on relative leaf area (*i.e.* proportion of leaf area of a weed species to the total leaf area of that weed and crop) can also be used to evaluate crop yield loss owing to weed density (Kropff and Spitters 1991, Kropff and Lotz 1993).

Economic thresholds based on other models

Economic threshold can also be derived from other models and empirical equations and a brief account of those models has been given in Eq.5 to Eq.15 (**Table 1**). These models have been successful in simulating crop yields and/or yield losses in concurrence with that of the observed field values.

Economic thresholds using crop yield loss

The ET based on economics of Cussans *et al.* (1986) and Cousens (1987) provides baseline information for making weed control decisions and plays a role for setting up an integrated weed management. However, several researchers have also estimated the ET of a weed considering its densities and threshold yield reduction ($\leq$10%) without using models. For this, a relationship between weed density and crop yield was established using linear equation (Moorthy and Das 1998) or exponential equation (Sinha *et al.* 2009). Then, a weed density causing $\leq$10% yield loss was considered as the ET of that weed. This ET, however, is not much reliable since it does not consider other factors of production except the yield loss. Besides, the threshold yield reduction of $\leq$10% considered in these cases is not accepted across situations/sites. To mention, the farmers of the developed countries with high technical skills, and having access to improved methods of weed control, *e.g*., herbicides may not allow losing 10% yield or even lesser reduction than this. The reverse may be true to the farmers of the developing countries, operating with low technical skills and less/no improved methods to whom even a 10% yield loss may be acceptable or is of usual occurrence.

Economic threshold research and applications

Experiments have been conducted across the globe (Mamun *et al.* 2013a, 2013b, Das *et al.* 2014b,

Table 1. Different models used for predicting economic threshold of weeds

SN	Model	Reference
1.	**Yield simulation using rectangular non-linear hyperbolic regression model:** $Y = Ywf\left[1 - \frac{id}{100\left(1 + \frac{id}{A}\right)}\right]$ ……(1) Percent yield loss (Y_L) $Y_L = \frac{id}{\left(1 + \frac{id}{A}\right)}$ …...(2) where, Y = observed yield; Ywf = estimated weed-free crop yield; i = percent yield loss per unit density as density (d) approaches to zero; and A = the asymptotic value of maximum yield loss in percent as density (d) approaches to infinity	Cousens (1985a, 1985b)
2.	**ET of weeds determination by using the quadratic equation:** $1 + (i/A)\,[2 - H - (YPAH/C)]T + (i/A)^2\,(1 - H)T^2 = 0$ …...(3) Where, Y = weed-free yield; P = unit price of produce; H = efficiency of herbicide; C = cost of weed control; T = economic threshold density; I and A values as per Eq. 2	Cousens (1987)
3.	**Empirical model to relate crop yield loss to relative leaf area of weeds:** $Y_L = \frac{qLw}{1 + (q - 1)Lw}$ …...(4) Where, Y_L = relative yield loss; Lw = relative leaf area of weed (i.e., leaf area of weed divided by the total leaf area of crop and weed per unit area); q = relative damage coefficient	Kropff and Spitters (1991), Kropff and Lotz (1993)
4.	Proportion of yield lost: $Y = ad^b$ …...(5) Yield: $y = y_{wf}\,(1 - ad^b)$ ……(6) Where, y_{wf} = weed-free crop yield; d = weed density; a, b = arbitrary parameters	Marraand Carlson (1983)
5.	**Certainty model:** $ET = \frac{Ca + Ch}{Lw \times Ps \times Hc}$ ……(7) Where, ET = economic threshold (number of weeds/l0 row meters); Ca = herbicide application cost per ha including labour and machinery costs; Ch = herbicide cost per ha for recommended dose; Lw = yield loss (kg/ha) per equidistantly spaced weed per 10 m of crop row; Ps = price of crop per kg; Hc = expected percent control with the given herbicide dose	Marraand Carlson (1983)
6.	$ET = \frac{Ch + Ca}{Ywf \times P \times L \times H}$ …...(8) Where Ch = herbicide cost (Rs/ha); Ca = herbicide application cost (Rs/ha); Ywf = weed-free crop yield (t/ha); P = price per unit of crop (Rs/t); L = proportional loss per unit weed density; H = herbicide efficacy (a proportional reduction in weed density by herbicide treatment)	Cousens (1987)
7.	**Step 1:** $y = \frac{(HM + UM)}{(OV \times UF)} \times 100$ …...(9) where, y = % yield loss associated with weed density (m^2); OV= average of expected maximum grain yield in weed-free plots (kg/ha); UF = price of grain (Rs/kg), HM= cost of herbicide (Rs/ha); and UM= application costs (Rs/ha) **Step 2:** Value of economic threshold is quantified by calculating y in the above equation and then replacing in a linear regression model, Y = a + bX where, Y = % loss of yield according to density in m^2, X = number of weeds in m^2 (economic threshold), b = regression coefficient	Uygur *et al.* (1999)
8.	$ET = \frac{Cc}{\left[R \times P \times \left(\frac{i}{100}\right) \times \left(\frac{H}{100}\right)\right]}$ ……(10) Where, ET= economic threshold (weeds/m^2), Cc=cost of control per ha (herbicide and application cost); R= yield (ton/ha); P = price of produce per tonne; i = yield losses (%) per unit of weed when the value of the variable approaches zero (Eq. 2); H = herbicide efficiency (%)	Lindquist and Kropff (1996)
9.	**Break-even yield loss (BEyl):** $BEyl = 100 - \left[\frac{YP - H}{YP}\right] \times 100$ ……(11) **Marketable break-even yield loss level (MBEyl):** $MBEyl = 100 - \left[\frac{YP - (H - Q)}{YP}\right] \times 100$ ……(12) Where, Y = predicted weed-free crop yield (t/ha), P= expected price of produce per ha, and H = price of herbicide per ha; Q = cost associated with dockage and drying of grains per ha	Weaver (1991)
10.	**Step 1:** Step 1 involves estimation of predicted crop yield (Y) based on Eq. 1. **Step 2:** $ET = \left[\frac{1 - (CP - H)/CP}{(r - s) + s\,\{(CP - H)/CP\}}\right]$ ……(13) Where, ET = economic threshold weed density (weeds/m^2); C = expected weed-free crop yield (ton/ha); P = crop price (Rs/ton); H= herbicide and application cost (Rs/ton); r = i/100 and s = i/A (values of i and A as per Eq. 1)	O'Donovan (1991)
11.	ET = Gain threshold/ Regression coefficient ……(14) where, gain threshold = cost of weed control (herbicide and application cost) per unit price of produce, and regression coefficient is the outcome of a simple linear relationship between yield (Y) and weed density/ biomass (x), Y = a + bx	Stone and Pedigo (1972)
12.	$Y = [\{(100/He \times Hc) + Ac\}/(Gp \times Yg)] \times 100$ ……(15) Where, Y = percent yield losses at a weed density; He = herbicide efficiency; Hc = herbicide cost; Ac= herbicide application cost; Gp = grain price and Yg = weed-free crop yield	Uygur and Mennan (1995)

Westendorff *et al.* 2014, Li *et al.* 2016, Tironi *et al.* 2016, Mehmood *et al.* 2018, Du *et al.* 2019, Galon *et al.* 2019, Raj *et al.* 2020) for determining ET values of weed species and predicting yield losses using various decision models to facilitate easier weed management decisions. A model usually describes the crop yield and/or yield loss as a function of weed competition (Cousens 1985a).The concept of thresholds has been successfully implemented by developing certain computer-based economic decision models or software. An effective decision model should take economics as well as biological factors into account, *viz.* nature of weed populations existing in the field, expected crop yield loss due to weed interference and potential economic returns for each control measure (Wilkerson *et al.* 2002). Thus, these decision models enable the growers in prior determination of economic and other effects of any weed control decision, and provide more efficient, reliable, and precise weed control (Coble and Mortensen 1992). A number of computerized decision-aid models (**Table 2**) available across the globe can help making weed management decisions by predicting yield losses due to weeds interference. These models consider factors that influence efficacy (weed species and their growth stages, climatic conditions) and cost-effectiveness of weed control options (mainly, herbicides), and, therefore, assist in selection of best weed-control option (Wilkerson *et al.* 2002). They may become important weed management tools and can potentially reduce prophylactic herbicide application, and herbicide loads into environment. However, these models over-simplify the complex weed-crop environment (Wilkerson *et al.* 2002), and hence, cannot simulate actual field condition perfectly, although the predictive capability can be improved with concurrent advances in computer technology. Scott

Table 2. Decision support systems/ tools for better weed management

Decision support systems/ tools	Description	Reference
HERB™	ET software application for soybean; includes many post-emergence herbicides; yield loss prediction using competitive index (CI) of weed species, higher values indicating more competitive weeds; estimates crop loss accurately at low weed densities, but overestimate at higher densities.	Wilkerson *et al.* (1991) Coble and Mortensen (1992)
NebHERB	ET software application used by Nebraska (USA) farmers; helps in post-emergence herbicide recommendations for soybean; crop loss (without weed control) is estimated using rectangular hyperbola regression equation.	Mortensen *et al.* (1993)
GWM (General weed management)	A bio-economic simulation model and decision support system (DSS) that can evaluate soil-applied and post-emergence weed management options in row crops; predicts the effect of management on weeds and crop yield in single season; parameterized to evaluate weed management as in two existing models (WEEDHA4; WEEDCAM) and for dry bean production.	Wiles *et al.* (1996)
HADSS™ (Herbicide application decision support system)	A desktop program for weed control/herbicide recommendation; information on crop, expected weed-free yield, crop sale price, estimated weed density, field history, field size, soil organic matter content, texture are required for pre-plant incorporation (PPI)/pre-emergence (PE) treatment; additional information on weed size, soil moisture content, density of each weed species are also required for post-emergence (POE) treatment.	Sturgill *et al.* (2001)
WeedSOFT™	WeedSOFT makes weed management decisions; yield loss estimated using CI of each weed species; provides fast, accurate solutions to specific weed problem; further more addresses environmental issues including ground water and surface water contamination and herbicide carry-over.	Mortensen *et al.* (1999), Krishnan *et al.* (2001)
GESTINF	Developed in Italy for making weed control decisions for soybean and winter wheat using observed weed densities, weed-free crop yield and grain price as input data; can estimate yield loss caused by weeds surviving the treatment; and consider environmental factors, thus, select treatment based on economics and environment.	Berti and Zanin (1997)
WEEDSIM	A bio-economic decision-aid model of weed management in corn and soybean; a multivariate hyperbolic yield equation; accommodates multiple weed species and multiple control measures like mechanical, chemical (PPI, PE and POE herbicides); includes estimated weed density, and predicted germination (for weed seed density estimates), weed control efficacy, yield loss, and seed production; recommends an optimal weed control strategy for a two-year time horizon and result in lower ET values than one year decision rule.	Swinton and King (1994)
SELOMA	An Italian computer program evaluates weed competitiveness and helps weed management recommendations in wheat, barley, oat, rye, sugar beet, corn, and sorghum; requires data on weed density, crop, weed growth stage and height, ET, and herbicide efficacy; recommends mechanical, chemical measures, and best herbicide.	Stigliani and Resina (1993)

et al. (2002) reported that the post-emergence herbicides recommended by HADSS™ in peanut resulted in better weed control, higher yield, and profitability than those with standard post-emergence herbicide. Hazra *et al.* (2011) used the rectangular non-linear hyperbolic regression model (weed density *vs*. crop yield; model 1; Eq. 1 and 2) and empirical model (*i.e.,* relative leaf area *vs*. crop yield; model 2; Eq. 4) in a field experiment to predict soybean yields and yield losses across the densities of *Trianthema portulacastrum* L. (horse purslane). Both the models could simulate soybean yield losses better due to horse purslane densities with $R^2 = 0.85$ (Model 1) and $R^2 = 0.91$ (Model 2). The obtained residuals/ deviations between the predicted and observed yield losses ranged from -0.3 to -1.4% in the weed density *vs*. crop yield model; and from -0.5 to -2.7% in the relative leaf area *vs*. crop yield model (Hazra *et al.* 2011). In another experiment, Hussain *et al.* (2014) determined wheat yield losses that economically justifies control of *Phalaris minor* Retz. (littleseed canary grass) by correlating per cent yield losses obtained through equation proposed by Uygur *et al.* (1999) to weed density using a linear regression model (model 7; step 1 and 2). They found that the linear regression model was effective in predicting wheat yield losses across the densities of *P. minor* and the regression equations showed good fit to observed data. The ET level of *P. minor* was estimated at 6-7 plants/m^2 for mid-sown and 2.2-3.3 plants/m^2 for late-sown wheat crop. The model predicted a yield loss to the tune of 4% at 5 plants/m^2 of *P. minor*. Similarly, using various other models, the ETs of *Chenopodium album* L. (common lambsquarters) in wheat (Dodamani and Das 2013) and of *Cyperus rotundus* L. (nutsedge) in soybean (Das *et al*. 2014b) in India; of *Bromus japonicus* (japanese brome) in wheat (Li *et al*. 2016) and of *C. rotundus* in groundnut (Du *et al*. 2019) in China were determined.

The ET values of some important weeds have been determined across the crops through several studies in the world (**Table 3**). Below the ET value, certain amount of weed interference and crop loss can be tolerated considering the unavailability of adequate human labourers, resources, and inputs required for crop production. Boz (2005) reported that control measure or herbicide application should be advocated when the economic loss caused by weeds is greater than the cost of control. Moorthy and Das (1998) reported that a density of 40 plants/ m^2 of *Cyperus iria* (umbrella sedge) with a dry matter production of 0.3 t/ha was the threshold level of this weed for adopting control measure in upland direct-seeded rice. Similarly, using empirical models, the ET of *T. portulacastrum*, the most widely distributed rainy season (*Kharif*) weed in India was found to be 6, 5 and 4 plants/m^2, considering the 70, 80, and 90% control efficiencies of the herbicide lactofen, respectively (Hazra *et al.* 2011). In India now-a-days *P. minor*. has become the most important weed in wheat, causing significant yield loss, which demands for prompt control measures. Sinha *et al*. (2009) estimated the threshold density of *P. minor* in wheat to be 25 plants/m^2 in North Bihar, India. In contrast, using a rectangular non-linear hyperbolic regression model, Raj *et al*. (2020) found that the mean ET of *P. minor* over the years was 6, 8 and 10 plants/m^2 at 100, 150 and 180 kg N/ha, respectively in New Delhi, India. The model took several production factors into consideration for estimating ET, which can make the ET of *P. minor* more precise, reliable and the *P. minor* management decision more economical. This would be useful for making *P. minor* control decision and fitting models. This also holds great potential in designing weed management strategies for other crops/cropping systems, where single weed species is dominant in crops (Raj *et al*. 2020). This may delay the likelihood of development of herbicide-resistance in weeds as well. In another study, the ET value of *C. rotundus* in soybean was estimated to be 19-22 plants/ m^2, considering a post-emergent treatment of imazethapyr with 70% efficiency (Das *et al*. 2014b). Similarly, Dodamani and Das (2013) observed that the ET of *C. album* in wheat was 6-7 plants/m^2 and the simulation of yields and yield losses using the yield-density model was better at lower weed densities up to 16 plants/m^2 than at higher densities (32, 64 and 128 plants/m^2). In Bangladesh, Mamun *et al*. (2013a) found that weed dry matter-crop yield model (Cousens 1985a) was effective in predicting yield losses over a wide range of *Scirpus maritimus* (saltmarsh bulrush) dry matter in winter rice and 10-18 g/m^2 dry matter of *S. maritimus* (or 2-4 weeds/m^2) could be allowed without economic yield loss. Similarly, the ET of different weeds have been estimated across crops in different parts of the world, such as: 1.79 plants of *Xanthium pensylvanicum* (common cocklebur) per 10 m row as ET in soybean in USA (Marra and Carlson 1983); 7.1 plants/m^2 of *Bromus sterilis* as ET in winter wheat in England (Cousens *et al*. 1988); 6 plants/m^{2}of *Ammi majus* (bishop's weed) and 4 plants/m^2 of *C. album* as ET in sunflower in Italy (Onofri and Tei 1994); 1.8-2.0 plants/m^2 of *Raphanus raphanistrum* (wild radish) as ET in wheat in Turkey (Boz 2005); 0.40-14.0 plants/ m^2 (for conventional tillage) or 0.13-3.13 plants/m^2 (for no-tillage) of *Abutilon theophrasti* (velvet leaf) as ET in maize in USA (Cardina *et al*. 1995); 5-7 plants/ m^2 of *S. maritimus* and *C. difformis* as ET in direct-

Table 3. Economic thresholds of weed species in different crops

Crop	Weed species	ET value and yield loss (%)	Country	Reference
Upland rice	*Cyperus iria* L. (umbrella sedge)	40 plants/m^2 with dry-matter accumulation of 0.3 t/ha and 11.2% yield loss	India	Moorthy and Das (1998)
Winter rice	*Scirpus maritimus* L. (saltmarsh bulrush)	2-4 plants/m^2 (or 10-18 g/ m^2)	Bangladesh	Mamun *et al*. (2013a)
Direct-seeded rice	*Scirpus maritimus* L. (saltmarsh bulrush) and *Cyperus difformis* L. (small-flowered nutsedge) (80% of total weed population)	5-7 weeds/m^2	Bangladesh	Mamun *et al*. (2013b)
Rice	*Cyperus esculentus* L. (yellow nutsedge)	2 and 13 plants/m^2 for the first (14 days) and second (21 days) period of irrigation, respectively	Brazil	Westendorff *et al*. (2014)
Rice	*Alternanthera philoxeroides* (Mart.) Griseb. (alligator weed)	1.3-1.5 plants/m^2	Pakistan	Mehmood *et al*. (2018)
Direct-seeded rice	Mixed population of weeds, particularly dominated by grass weeds	9 plants/m^2	India	Sen *et al*. (2020)
Wheat	*Bromus japonicus* Houtt. (japanese brome)	4-5 plants/m^2 at 80% efficiency of flucarbazone with 2.11-2.24% yield loss at 4 plants/ m^2	China	Li *et al*. (2016)
Wheat	*Phalaris minor* Retz. (littleseed canarygrass)	6, 8 and 10 plants/m^2 at 100, 150 and 180 kg N/ha, respectively (1.6-2.0% yield loss at 10 plants/m^2 with 180 kg N/ha)	India	Raj *et al*. (2020)
Wheat	*Lolium multiflorum* Lam. (ryegrass)	8-48 plants/m^2	Brazil	Galon *et al*. (2019)
Wheat	*Phalaris minor* Retz. (littleseed canarygrass)	6-7 and 2.2-3.3 plants/m^2 in mid- (20 November) and late-sown (10 December) wheat crop, respectively (4% yield loss at 5 plants/m^2)	Pakistan	Hussain *et al*. (2014)
Wheat	*Avena* spp. (wild oats)	39 weed seeds/m^2 or equivalent to 10.1 seedlings/m^2	Australia	Jones and Medd (2000)
Wheat	*Phalaris minor* Retz. (littleseed canarygrass)	ET ranged from 13-19.7 plants/m^2 (but, 17 and 15 plants/m^2 at 80 and 90% efficiencies of isoproturon, respectively)	India	Duary and Yaduraju (2005)
Wheat	*Raphanus raphanistrum* L. (wild radish)	1.8 to 2.0 plants/m^2	Turkey	Boz (2005)
Wheat	*Phalaris minor* Retz. (littleseed canarygrass)	25 plants/m^2 with 12.4% yield loss.	India	Sinha *et al*. (2009)
Wheat	*Chenopodium album* L. (common lambsquarters)	6–7 plants/m^2 with 3.4-4.3% yield loss.	India	Dodamani and Das (2013)
Wheat	*Avena sterilis* ssp. *ludoviciana* (Dur.) Nym. (wild oats)	1.2-2.1 plants/m^2 for isoproturon; 3.2-6.6 plants/m^2 for diclofop-methyl; 2.0-4.1 plants/m^2 for manual weeding	India	Thomas (1996) Thomas *et al*. (2000)
Winter wheat	*Avena fatua* L. (wild oats)	2-3 seedlings/m^2	England	Cousens *et al*. (1986)
Winter wheat	*Bromus sterilis* L. (barren brome)	7.1 plants m^2	England	Cousens *et al*. (1988)
Maize	*Abutilon theophrasti* Medic. (velvet leaf)	0.3 to 2.4 plants/m^2 depending upon the kill rate (from 0.6 to 1.0)	Italy	Zanin and Sattin (1988)
Maize	*Abutilon theophrasti* Medic. (velvet leaf)	0.40-14.0 plants/m^2 (conventional tillage); 0.13-3.13 plants/m^2 (no-tillage)	USA	Cardina *et al*. (1995)
Soybean	*Xanthium pensylvanicum* Wallr. (common cocklebur)	1.79 weeds per 10 row metre	USA	Marra and Carlson (1983)
	Ipomoea purpurea (L.) Roth (tall morning glory)	1.53 weeds per 10 row metre		
	Amaranthus hybridus L. (smooth pigweed)	2.92 weeds per 10 row metre		
	Ambrosia artemisiifolia L. (common ragweed)	5.19 weeds per 10 row metre		
	Polygonum pensylvanicum L. (pennsylvania smartweed)	3.00 weeds per 10 row metre		
Soybean	*Abutilon theophrasti* Medic. (velvet leaf)	0.66- 4.34 plants/m^2	Italy	Sartorato *et al*. (1996)
	Amaranthus cruentus L. (red amaranth)	0.34-1.05 plants/m^2		
	Datura stramonium L. (jimsonweed)	0.15-3.10 plants/m^2		
	Panicum miliaceum L. (wild proso millet)	0.67-4.18 plants/m^2		
	Solanum nigrum L. (black nightshade)	2.19-2.61 plants/m^2		
Soybean	*Trianthema portulacastrum* L. (horse purslane)	6, 5 and 4 plants/m^2 at 70, 80 and 90% efficiencies of lactofen, respectively	India	Hazra *et al*. (2011)
Soybean	*Cyperus rotundus* L. (purple nutsedge)	19-22 (~mean 21) plants/m^2 at 70% efficiency of imazethapyr with 9.1-11.5% yield loss	India	Das *et al*. (2014b)
Sunflower	*Ammi majus* L. (bishop's weed)	6 plants/m^2 (mechanical weed control by hoeing at 70% killing rate)	Italy	Onofri and Tei (1994)
	Chenopodium album L. (common lambsquarters)	4 plants/m^2 (mechanical weed control by hoeing at 70% killing rate)		
	Sinapis arvensis L. (wild mustard)	• 4 plants/m^2 (mechanical weed control by hoeing at 70% killing rate) • 6 plants/m^2 at 95% efficacy of imazamethabenz		
Sugarcane	*Brachiaria brizantha* (A. Rich.) Stapf. (signal grass)	0.33-0.66 *B. brizantha*/m^2 for various cultivars	Brazil	Tironi *et al*. (2016)
Peanut	*Cyperus rotundus* L. (purple nutsedge)	4-5 plants/m^2 at 90% efficiency of imazapic with 3.68-3.97% yield loss	China	Du *et al*. (2019)

seeded rice in Bangladesh (Mamun *et al.* 2013b); 1.3-1.5 plants/m^2 of *Alternanthera philoxeroides* (alligator weed) as ET in rice in Pakistan (Mehmood *et al.* 2018); 2 and 13 plants/m^2 during the first (14 days) and second (21 days) irrigation, respectively, of *C. esculentus* as ET in rice in Brazil (Westendorff *et al.* 2014); 4-5 plants/m^2 of *Bromus japonicus* as ET in wheat in China (Li *et al.* 2016); 8-48 plants/m^2 of *Lolium multiflorum* (ryegrass) as ET in wheat in Brazil (Galon *et al.* 2019); 0.33-0.66 plant/m^2 of *Brachiaria brizantha* (signal grass) in sugarcane as ET in Brazil (Tironi *et al.* 2016); and 4-5 plants/m^2 of *C. rotundus* as ET in peanut in China (Du *et al.* 2019).

Impact of weed interference on crop is a cumulative and collective effect of a large number of weeds (~composite weeds) present in crop fields except where there is abundance/dominance of single/ specific weed. Measuring the effect of single weed density, however, may not reflect total weed impact accurately (Radosevich and Holt 1984). The weed biomass per unit area could be more appropriate in determining ET values, but there is lack of models. The ET models or formulae based on composite weed density are hardly available. Moreover, it is difficult to establish a widely applicable and reproducible ET model based on composite weed density due to inherent patchy distribution, inconsistent and variable composition and population of weed species in crops across fields/locations (Das 2001) and times. Weeds also vary in their growth habits. In these situations, statistical transformation is envisaged to reduce variation in weed population for a meaningful conclusion of the treatments' effects (Das 1999). The transformed weed densities may be used for determining ET, the results of which, however, still remain uncertain. Therefore, the determination of ET is usually based on specific weed infestation in certain crops. The ET values calculated based on this method can be extended for other crop situations, having similar infestation of that weed.

Factors affecting economic threshold (ET)

Like the period threshold (*i.e.*, critical period of weed interference), the ET is a dynamic concept (Das 2008). Several factors such as weed, crops and crops varieties, nutrients (especially N), soil and climate, relative times of crop and weed emergence, herbicides cost and efficacy, cost of control and market price of produce, crop growing time (season, year) can influence crop-weed interference and thereby ET.

Weed, crop and crops cultivars

Crops and weed based on their architecture differ considerably in their ability to compete with each other (Coble and Mortensen 1992, Das and Yaduraju 1995, Das and Yaduraju 1996, Hazra *et al.* 2011, Dodamani and Das 2013, Mamun *et al.* 2013b, Hussain *et al.* 2014, Das *et al.* 2014b, Dass *et al.* 2017). Even the cultivars of a crop may have difference in their competitiveness against weed. Therefore, the ET of certain weed may vary across crops, and even between the cultivars of a crop, depending on the competitive abilities of crops or cultivars. Similarly, different weeds have different competitive abilities in a crop or across crops. Galon *et al.* (2016) determined the ET of *Bidens pilosa* L. (beggartick) in six black bean cultivars, ranging from 0.59-8.72 plants/m^2. The difference in ET was attributed to the intrinsic growth habit of each cultivar, reflecting plant stature, leaf size, branching capacity, which could influence light entry into soil, thus, weed infestation, and yields of cultivars (Mason *et al.* 2007). Furthermore, tolerance of crops against weed pressure is associated with its ability to acquire resources including water, nutrients and light, and allelopathic effects on weeds. Usually, competitive cultivars have vigorous growth that can suppress weeds efficiently through reducing the supply of resources to weeds (Buhler 2002, Dass *et al.* 2017). These effects minimize weed interference and subsequent crop yield loss, thereby significantly influencing the ET of a weed.

Climate, soil and cropping season

Composition and distribution of weed species are influenced by the changes in physical and biotic pressures of the environments (mainly, climate and soil) in which they grow. This influences ET and makes it dynamic is influenced by them. An alteration (permanent or temporary) in any of the environmental factors, biotic or abiotic, or introduction of new factors may considerably alter the abundance, composition and distribution of weed species in given area (Stern *et al.* 1959). Optimal climatic and edaphic factors, such as temperature, soil moisture and fertility can have more significant effects on optimal crop plant density relative to weeds (Walker and Buchanan 1982) and influence ET of weed considerably. Moreover, soils with relatively higher amounts of organic matter and clay content show carry-over effects of control measures, mainly herbicides from the preceding crops that may result in lowering ET values. The time of weed control operations, for example, application of herbicides is crucial for effective weed control that may significantly influence ET. The warm and humid conditions during rainy season favours weeds more relative to crops, and weeds grow more rapidly and vigorously during rainy season than winter. This can influence weed interference and ET. Similarly, weather/climatic variations that have direct effect on crop and weed growth over the years can also influence ET. The best time of weed control, *i.e.*, the length of critical period of crop-weed competition also depends on other conditions such as time of weed emergence, density and competitive ability of weeds and environmental factors. Controlling weeds during the critical period helps in minimizing higher crop-weed interference and avoids significant yield loss (Das 2008, Nazarko *et al.* 2005). Weed control operations outside this period (too early or too late) may have little effect on weed management or crop yield. Moreover, herbicide applications at the appropriate time may help farmers save one spray operation thereby reducing the cost of weed control and ET.

Nutrients

Crop-weed interference *vis-à-vis* ETs are considerably influenced by the availability of nutrients, especially N, depending on weed species and their composition and distribution (Das and Yaduraju 1999, Blackshaw *et al.* 2004, Das and Yaduraju 2007, Das and Yaduraju 2011). Certain weed growth and consequent yield losses due to interference could be reduced by applying higher doses of N (Das and Yaduraju 1999, 2007, 2011). Raj *et al.* (2020) reported that the higher N doses, 150 and 180 kg N/ha could lead to 25% and 43% reduction in *P. minor* density, respectively compared to 100 kg N/ha. Moreover, the yield reduction at a higher density of 80 *P. minor* plants/m^2 was substantially lower due to 180 kg N/ha (~1.1 t/ha) compared to 100 and 150 kg N/ha (*i.e.*, 1.7 and 1.3 t/ha, respectively). In a similar study, it was observed that the growth of *C. album* and wheat increased gradually with the increase in N level from 0 to 120 kg N/ha, but the application of 120 kg N/ha favoured wheat growth more than that of weed, resulting in greater crop-weed balance compared to sub-optimal dose of 60 N kg/ha (Dodamani and Das 2013). Thus, the nutrients, particularly N could be a management option for weeds in wheat, resulting in higher ET values (Das and Yaduraju 1999; Raj *et al.* 2020).

Crop yield and price, herbicide efficacy and cost of control

The ET values of a weed could be different in the same crop at various yield levels due to differential weed interference. Hussain *et al.* (2014) reported a lower ET of *P. minor* (~2.2 - 3.3 plants/m^2) in late-sown wheat compared to 6-7 plants/m^2 in timely-sown crop, primarily owing to high weed pressure and lower grain yield. Similarly, higher growth of *C. album* and consequently lower wheat yield could reduce ET slightly compared to normal (Dodamani and Das 2013). Efficiency of herbicides is another profound factor influencing ET. Generally, higher the herbicide efficiency, lower is the ET (Hazra *et al.* 2011).Galon *et al.* (2019) made a comparison between the ETs across herbicide efficiencies and found that the ETs of ryegrass were 12.5% higher and 9.8% lower at 80% and 100% herbicide efficiencies, respectively compared to that at 90% herbicide efficiency. The ET of weeds is usually lower in crops with higher market price, and even a small yield loss could be an economic loss under this situation (Hazra *et al.* 2011, Dodamani and Das 2013, Li *et al.* 2016, Du *et al.* 2019). There is implication that an increase in cost of weed control will lead to increase ET, indicating greater number of weeds/m^2 to justify adoption of control measures. Hand weeding may have higher ET value than herbicidal treatment due to higher wage. Furthermore, any increase in crop yield and price, degree of weed control, or crop loss per unit weed density will lower ET, other factors being constant (Coble and Mortensen 1992). Thus, the variations in crop and weed growth/vigour, cost of weed control, price of produce, and herbicide efficiency across locations and time (Fischer *et al.* 2004, Duary and Yaduraju 2005, Cheema and Akhtar 2006, Hazra *et al.* 2011, Dodamani and Das 2013) are responsible for variations in ET.

Usefulness and limitation of ET

In weed science, the ET concept has been advocated as a decision-making tool to farmers for determining whether or not to adopt weed control (i.e., when weed populations exceed a certain level). The ET provides a base for rational use of weed control measures/operations by excluding unnecessary control operations (especially herbicide use), thereby increasing the effectiveness of weed management. Thus, ET-based weed management strategy may lead to the rationalization and reduction of herbicide use (both amount and cost) and environmental damage (*i.e.*, pesticides loads) while maintaining farm productivity and profitability as well as sustainability of chemical weed management. Despite of numerous potential benefits, the adoption of ET for weed control has been low among the growers. The concept of ET has been criticized for a number of reasons: (i) Proven *et al.* (1991) opined that the methods for ET determination are generally too laborious to be adopted by farmers. Factors like herbicide and its application cost, unit crop value involved in estimating ET, can be estimated accurately, but the potential crop yield (weed-free yield), per cent yield loss, weed density and herbicide efficacy are comparatively more difficult to determine owing to spatial heterogeneity (inherent patchiness) of weed population and variability associated with weed composition, weather, and cropping systems effects on these variables (Auld and Tisdell 1987, Auld *et al.* 1987, Mortensen and Coble 1989, Proven *et al.* 1991, Coble and Mortensen 1992). These make accurate estimation of ET difficult; (ii) assessment of yield losses due to weeds is based on simple weed densities but several factors influence yield losses including weather conditions, relative time of crop and weed emergence, crop stand and potential yield, crop value and cost of weed control. The crop-weed interactions depend greatly on weather conditions that even may differ for the same crop-weed pair (O'Donovan 1996, Hall *et al.* 2000, O'Donovan and McClay 2002).The ET however largely ignores these factors and over-simplifies the estimation; (iii) weed control decision-making through ET is largely a single-season approach. It simply overlooks the carry-over effects of residual weeds at sub-threshold densities. These 'escapes' may return large amounts of weed seed (weed seed rain) to the seed bank, creating seed bank build-up in soil and potential future weed problems (Cousens 1987, Buhler *et al.* 1997, Norris 1999). This may increase the cumulative herbicide use over the years (10-15 years) for controlling weeds resulting from sub-threshold residual weeds (Pandey and Medd 1990). The ET also does not consider the carryover effects of residual herbicides in soil. This interrupts the decision-making in future years. Economic optimum threshold (EOT) has been suggested as an improved and preferred tool over the ET as this takes into consideration the future weed population dynamics and seed production (Cousens 1987). Several studies have found that the EOT of weed was considerably lower than that of ET when future population dynamics/ effects were taken into account (Cousens *et al.* 1986, Doyle *et al.* 1986, Bauer and Mortensen 1992, Swinton and King 1994). In a study, weed population dynamics was incorporated into a dynamic, multiple species, multiple control 2-year bio-economic model (WEEDSIM) that resulted in a significantly lower ET for 3-weed species than one year decision rule (Swinton and King 1994). The EOTs of two weed species were 7.5-fold and 3.6-fold lower than their respective ET in a continuous soybean system (Bauer and Mortensen 1992). Therefore, seed production by uncontrolled weeds would result in lowered population threshold over a period of years than those computed on weed interference alone. Thus, the use of EOT (with very low values) may not result in a significant reduction in herbicide use and consequent economic gain (Jones and Medd 2000, Nazarko *et al.* 2005); (iv) most ETs have been estimated based on single crop-weed interaction. Research on ET with multiple weed species is limited especially in cropping systems containing diverse weed species with different competitive abilities (Hall *et al.* 2000, Nazarko *et al.* 2005). Moreover, most of the research assumed the impact of multiple weed species on crop yield to be additive, which is not always true (Swanton *et al.* 1999); (v) The ET concept considers a fixed dose of single herbicide as the only weed control option with little information on variable herbicide rates depending upon weed density and environmental conditions. It precludes the opportunity of incorporating other chemical and non-chemical options for integrated weed management (Jones and Medd 2000). Optimal dose rate (ODR) has been proposed as an improved framework of variable herbicide rates over the existing fixed rate (Deen *et al.* 1993, Pannell 1995). However, ODR still ignores the residual weed densities and carry-over effects of herbicides (Jones and Medd, 2000); (vi) the ET advocates leave some weeds below the threshold levels in the field. But, high level of weed control and a weed-free crop (for ease of harvest and grain quality) are the primary desires of a farmer that might not happen by using ET concept; (vii) applicability of ET concept is to be restricted while dealing with the management of herbicide-resistant weeds. Seeds produced from the sub-ET density of herbicide-resistant weeds may cause severe weed menace in future and failure of existing weed management practices. The ETs are mainly suitable under low weed pressure situation. Therefore, combinations of practices that reduce weed densities or competitiveness are particularly important for realizing the potential of reducing herbicide use through ET (Nazarko *et al.* 2005).

Long-term approach for economic threshold

Weed control using ET is largely a single-season and short-term approach, which may lead to build up seed bank in soil over the years (discussed above). A model based on long-term weed populations considering the weed seed bank may be used as an alternative to the single-season approach of weed control decisions making (Jones and Medd 2000). Depletion of weed seed bank in soil over the years should be the primary aim of this approach while maximizing the long-term farm profitability. However, this approach needs a comprehensive understanding of weed population dynamics and the use of integrated weed management strategies. This approach was applied to a model for controlling wild oat in spring wheat and as a result of this wild oat seed bank in soil reduced to almost zero owing to low tolerance for weeds in the first few years (Jones and Medd 2000). The adoption of integrated weed management practices took only seven years to deplete the weed seed bank while it took nearly 15 years for the same when only chemical weed control was used (Jones and Medd 2000). Herbicide use was higher during the initial years to deplete seed bank, yet the total herbicide consumption of 20 years was much lower compared to controlling weeds according to ET (Jones and Medd 2000). Thus, lower tolerance for weeds during the initial years is important for depleting weed seed bank more quickly and lowering herbicide use and delaying resistance development in weeds against herbicide.

Conclusions

The ET can be a major decision-making framework for effective and profitable weed management while ensuring rationalization of herbicides use and environmental security. The ET-based decision holds great potential in designing weed management framework for a single-season cropped situation and in crops where single weed species dominates. Prediction of yield loss due to single weed species may not reflect weed impacts adequately in the long-run, especially in cropping systems having multiple diverse weed species. Moreover, this approach does not consider the long-term effect of residual weeds on seed bank. Therefore, adoption of ET by farmers has been low, despite the availability of several models. More information on crop-weed interactions using current crop production systems and cultivars, weed emergence patterns, and the spatial heterogeneity of weeds is needed to improve the determination of economic or action thresholds. An alternative could be using a model based on long-term weed populations that aims to deplete weed seed bank while optimizing farm profitability. While developing these models, more comprehensive information including weed population dynamics in cropping pattern, biology of weed species such as weed reproduction and seed dormancy, vegetative allocation patterns of both weeds and crops, integrated weed management strategies, *etc* must be considered. This would lead to making an economical, reliable and precise weed control decision that may reduce future weed problems and environmental footprints of herbicides.

REFERENCES

Auld BA and Tisdell CA. 1987. Economic thresholds and response to uncertainty in weed control. *Agricultural Systems* **25**(3): 219–227.

Auld BA, Menz KM and Tisdell CA. 1987. *Weed Control Economics*. Applied botany and crop science series. Academic Press, London, 177p.

Bauer TA and Mortensen DA. 1992. A comparison of economic and economic optimum thresholds for two annual weeds in soybeans. *Weed Technology* **6**(1): 228–235.

Berti A and Zanin G. 1997. GESTINF: a decision model for post-emergence weed management in soybean (*Glycine max* (L.) Merr.). *Crop Protection* **16**(2): 109–116.

Blackshaw RE, Molnar LJ and Janzen HH. 2004. Nitrogen fertilizer timing and application method affect weed growth and competition with spring wheat. *Weed Science* **52**: 614–622.

Boz Ö. 2005. Economic threshold for wild radish (*Raphanus raphanistrum* L.) control in wheat fields. *Turkish Journal of Agriculture and Forestry* **29**: 173–177.

Buhler DD, Hartzler RG and Forcella F. 1997. Implications of weed seedbank dynamics to weed management. *Weed Science* **45**(3): 329–336.

Buhler DD. 2002. Challenges and opportunities for integrated weed management. *Weed Science* **50**(3): 273–280.

Cardina J, Regnier E and Sparrow D. 1995. Velvetleaf (*Abutilon theophrasti*) competition and economic thresholds in conventional-and no-tillage corn (*Zea mays*). *Weed Science* **43**(1): 81–87.

Cheema MS and Akhtar M. 2006. Evaluation of economic threshold level of wild oat (*Avena fatua* L.) in wheat under super imposed application of fenoxaprop-p-ethyl. *Pakistan Journal of Weed Science Research* **12**(4): 257–264.

Coble HD and Mortensen DA. 1992. The threshold concept and its application to weed science. *Weed Technology* **6**: 191–195.

Cousens R, Doyle CJ, Wilson BJ and Cussans GW. 1986. Modelling the economics of controlling *Avena fatua* in winter wheat. *Pesticide Science* **17**: 1–12.

Cousens R, Firbank LG, Mortimer AM and Smith RG. 1988. Variability in the relationship between crop yield and weed density for winter wheat and *Bromus sterilis*. *Journal of Applied Ecology* **25**: 1033–1044.

Cousens R. 1985a. A simple model relating yield loss to weed density. *Annals of Applied Biology* **107**: 239–252.

Cousens R. 1985b. An empirical model relating crop yield to weed and crop density and a statistical comparison with other models. *Journal of Agricultural Science* **105**: 513–521.

Cousens R. 1987. Theory and reality of weed control thresholds. *Plant Protection Quarterly* **2**: 13–20.

Cussans GW, Cousens RD and Wilson BJ. 1986. Thresholds for weed control – the concepts and their interpretation. Pp. 253–260. In: *Proceedings of the 5th European Weed Research Society Symposium on Economic Weed Control* (Stuttgart-Hohenheim, Germany, 1986). European Weed Research Society, Oxford.

Das TK and Yaduraju NT. 1995. Crop-weed competition studies in some *kharif* crops. Part II. Nutrient uptake and yield reduction. *Annals of Plant Protection Sciences* **3**(2): 95–99.

Das TK and Yaduraju NT. 1996. Crop-weed competition studies in some *Kharif* crops. Part I. Physiological parameters. *Indian Journal of Agricultural Research* **30**(3): 235–241.

Das TK and Yaduraju NT. 1999. Effect of weed competition on the growth, nutrient uptake and yield of wheat as affected by irrigation and fertilizers. *The Journal of Agricultural Science* (Cambridge) **133**: 45–51.

Das TK and Yaduraju NT. 2007. Effect of irrigation and nitrogen levels on grassy weed competition in wheat and comparative eco-physiology of *Phalaris minor* Retz. And *Avena sterilis* ssp. *ludoviciana* Dur. in wheat. *Indian Journal of Weed Science* **39**: 178–184.

Das TK and Yaduraju NT. 2011. Effects of missing-row sowing supplemented with row spacing and nitrogen on weed competition and growth and yield of wheat. *Crop and Pasture Science* **62**: 48–57.

Das TK, Ahlawat IPS and Yaduraju NT. 2014a. Littleseedcanarygrass (*Phalaris minor*) resistance to clodinafop-propargyl in wheat fields in north-western India: Appraisal and management. *Weed Biology and Management* **14**: 11–20.

Das TK, Paul AK and Yaduraju NT. 2014b. Density-effect and economic threshold of purple nutsedge (*Cyperus rotundus*) in soybean. *Journal of Pest Science* **87**: 211–220.

Das TK, Sakhuja PK and Zelleke H. 2010. Herbicide efficacy and non-target toxicity in highland rainfed maize of eastern Ethiopia. *International Journal of Pest Management* **56**: 315–325.

Das TK. 1999. Is transformation of weed data always necessary? *Annals of Agricultural Research* **20**: 335–341.

Das TK. 2001. Towards better appraisal of herbicide bio-efficacy. *Indian Journal of Agricultural Sciences* **71**: 676–678.

Das TK. 2008. *Weed Science: Basics and Applications*. 1st Edition, Jain Brothers Publishers, New Delhi, India, 901p.

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

Deen W, Weersink A, Turvey CG and Weaver S. 1993. Weed control decision rules under uncertainty. *Review of Agricultural Economics* **15**(1): 39–50.

Dodamani BM and Das TK. 2013. Density and nitrogen effects on interference and economic threshold of common lambsquarters in wheat. *Journal of Pest Science* **86**: 611–619.

Doyle CJ, Cousens R and Moss SR. 1986. A model of the economics of controlling *Alopecurus myosuroides* Huds. in winter wheat. *Crop Protection* **5**(2): 143–150.

Du L, Li X, Chen J, Jiang X, Ju Q, Qu C and Qu M. 2019. Density effect and economic threshold of purple nutsedge (*Cyperus rotundus* L.) in Peanut (*Arachis hypogaea* L.). *International Journal of Plant Production* **13**(4): 309–316.

Duary B and Yaduraju NT. 2005. Estimation of yield losses of wheat (*Triticum aestivum* L.) caused by little seed canary grass (*Phalaris minor* Retz.) competition. *Journal of Crop and Weed* **2**: 8–12.

Fischer DW, Harvey RG, Bauman TT, Phillips S, Hart SE, Johnson GA, Kells JJ, Westra P and Lindquist J. 2004. Common lambsquarters (*Chenopodium album*) interference with corn across the northcentral United States. *Weed Science* **52**(6): 1034–1038.

Galon L, Basso FJ, Chechi L, Pilla TP, Santin CO, Bagnara MA, Franceschetti MB, Castoldi CT, Perin GF and Forte CT. 2019. Weed interference period and economic threshold level of ryegrass in wheat. *Bragantia* **78**(3): 409–422.

Galon L, Forte CT, Gabiatti RL, Radunz LL, Aspiazú I, Kujawinski R, David FA, Castoldi CT, Perin GF, Radunz AL and Rossetti J. 2016. Interference and economic threshold level for control of beggartick on bean cultivars. *Planta Daninha* **34**(3): 411–422.

Gerowitt B and Heitefuss R. 1990. Weed economic thresholds in cereals in the Federal Republic of Germany. *Crop Protection* **9**: 323–331.

Hall JC, Van Eerd LL, Miller SD, Owen MD, Prather TS, Shaner DL, Singh M, Vaughn KC and Weller SC. 2000. Future research directions for weed science. *Weed Technology* **14**(3): 647–658.

Hazra D, Das TK and Yaduraju NT. 2011. Interference and economic threshold of horse purslane (*Trianthema portulacastrum*) in soybean cultivation in northern India. *Weed Biology and Management* **11**: 72–82.

Hussain S, Khaliq A, Matloob A, Fahad S and Tanveer A. 2014. Interference and economic threshold level of little seed canary grass in wheat under different sowing times. *Environmental Science and Pollution Research* **22**: 441–449.

Jones RE and Medd RW. 2000. Economic thresholds and the case for longer term approaches to population management of weeds. *Weed Technology* **14**: 337–350.

Krishnan G, Mortensen DA, Martin AR, Bills LB, Dieleman A and Neeser C. 2001. WeedSOFT: a state of the art weed management decision support system. P. 41. In: *Weed Science Society of America Abstract.*

Kropff MJ and Lotz LAP. 1993. Empirical models for crop weed competition. Pp. 9–24. In: *Modelling Crop–Weed Interactions*. Kropff MJ and van Laar HH (Eds). CAB International and IRRI, Manila, Philippines.

Kropff MJ and Spitters CJT. 1991. A simple model of crop loss by weed competition from early observations on relative leaf area of the weeds. *Weed Research* **31**: 97–105.

Li Q, Du L, Yuan G, Guo W, Li W and Wang J. 2016. Density effect and economic threshold of Japanese brome (*Bromus japonicus* Houtt.) in wheat. *Chilean Journal of Agricultural Research* **76**(4): 441–447.

Lindquist JL and Kropff MJ. 1996. Applications of an ecophysiological model for irrigated rice (*Oryza sativa*)-*Echinochloa* competition. *Weed Science* **1**: 52–56.

Lotz LA, Christensen S, Cloutier D, Quintanilla CF, Legere A, Lemieux C, Lutman PJ, Iglesias AP, Salonen J, Sattin M and Stigliani L. 1996. Prediction of the competitive effects of weeds on crop yields based on the relative leaf area of weeds. *Weed Research* **36**: 93– 101.

Mamun MAA, Shultana R, Rana MM and Mridha AJ. 2013b. Economic threshold density of multi species weed for direct seeded rice. *Asian Journal of Agriculture and Rural Development* **3**: 523–531.

Mamun MAA, Shultana R, Roy BC, Parvez A and Mridha AJ. 2013a. Determination of yield loss and economic threshold density of *Scirpus maritimus* in winter rice. *Academia Journal of Agricultural Research* **1**: 211–219.

Marra MC and Carlson GA. 1983. An economic threshold model for weeds in soybeans (*Glycine max*). *Weed Science* **31**: 604–609.

Mason H, Navabi A, Frick B, O'Donovan J and Spaner D. 2007. Cultivar and seeding rate effects on the competitive ability of spring cereals grown under organic production in northern Canada. *Agronomy Journal* **99**(5): 1199–1207.

Mehmood A, Tanveer A, Javed MM, Nadeem MA, Naeem M and Abbas T. 2018. Estimation of economic threshold level of alligator weed (*Alternanthera philoxeroides* (Mart.) Griseb.) to tackle grain quality and yield losses in rice. *Archives of Agronomy and Soil Science* **64**: 208–218.

Moorthy BTS and Das TK. 1998. Threshold level of weed umbrella sedge (*Cyperus iria*) in upland rice (*Oryza sativa*) under rainfed direct-seeded condition. *Indian Journal of Agricultural Sciences* **68**: 7–8.

Mortensen DA and Coble HD. 1989. The influence of soil water content on common cocklebur (*Xanthium strumarium*) interference in soybeans (*Glycine max*). *Weed Science* **37**(1): 76–83.

Mortensen DA, Martin AR, Roeth FW, Harvill TE, Klein RW, Milner M, Wicks GA, Wilson RG, Holshouser DL, Lyon DJ and Shea PJ. 1999. *WeedSOFT Version 4.0 User's Manual*. Lincoln, NE: Department of Agronomy, University of Nebraska.

Mortensen DA, Martin AR, Roeth FW, Harvill TE, Klein RW, Wicks GA, Wilson RG, Holshouser DL and McNamara JW. 1993. Nebraska HERB *Version 3.0 User's Manual*. Lincoln, NE: Department of Agronomy, University of Nebraska.

Nazarko OM, Van Acker RC and Entz MH. 2005. Strategies and tactics for herbicide use reduction in field crops in Canada: a review. *Canadian Journal of Plant Science* **85**(2): 457–479.

Norris RF. 1992. Case history for weed competition/population ecology. Barnyard grass (*Echinochloa crusgalli*) in sugarbeet (*Beta vulgaris*). *Weed Technology* **6**: 220–227.

Norris RF. 1999. Ecological implications of using thresholds for weed management. *Journal of Crop Production* **2**: 31–58.

O'Donovan JT and McClay AS. 2002. Relationship between relative time of emergence of Tartary buckwheat (*Fagopyrum tataricum*) and yield loss of barley. *Canadian Journal of Plant Science* **82**: 861–863.

O'Donovan JT. 1996. Weed economic thresholds: useful agronomic tool or pipe dream? *Phytoprotection* **77**: 13–28.

O'Donovan JT. 1991. Quackgrass (*Elytrigia repens*) interference in canola (*Brassica campestris*). *Weed Science* **39**: 397–401.

Onofri A and Tei F. 1994. Competitive ability and threshold levels of three broadleaf weed species in sunflower. *Weed Research* **34**: 471–479.

Pandey S and Medd RW. 1990. Integration of seed and plant kill tactics for control of wild oats: an economic evaluation. *Agricultural Systems* **34**(1): 65–76.

Pannell DJ. 1995. Optimal herbicide strategies for weed control under risk aversion. *Review of Agricultural Economics* **17**: 337–350.

Proven MJ, Courtney A, Picton J, Davies DH and Whiting AJ. 1991. Cost-effectiveness of weed control in cereals-systems based on thresholds and reduced rates. pp. 1201–1208. In: Proceedings of Brighton Crop Protection Conference-Weeds.

Radosevich SR and Holt JS. 1984. *Weed Ecology: Implications for Vegetation Management*. 1st Edition, John Wiley and Sons Inc. New York.

Raj R, Das TK, Kaur R, Shekhawat K, Singh R and Singh VK. 2020. Effects of nitrogen and densities on interference and economic threshold of *Phalaris minor* in wheat. *Crop Protection* **8**: 105215.

Sartorato I, Berti A and Zanin G. 1996. Estimation of economic thresholds for weed control in soybean (*Glycine max* (L.) Merr.). *Crop Protection* **15**(1): 63–68.

Scott GH, Askew SD, Wilcut JW and Bennett AC. 2002. Economic evaluation of HADSS™ computer program in North Carolina peanut. *Weed Science* **50**(1): 91–100.

Sen S, Kaur R and Das TK. 2020. Weed management in dry direct-seeded rice: Assessing the impacts on weeds and crop. *Indian Journal of Weed Science* **52**(2): 169–174.

Sinha NK, Singh D and Roy DK. 2009. Economic threshold levels of littleseed canary grass in wheat in north Bihar. *Indian Journal of Weed Science* **41**(3&4): 154–156.

Stern VM, Smith RF, van den Bosch R and Hagen KS. 1959. The integration of chemical and biological control of the spotted alfalfa aphid: The integrated control concept. *Hilgardia* **29**: 81–101.

Stern VM. 1973. Economic thresholds. *Annual Review of Entomology* **18**: 259–280.

Stigliani L and Resina C. 1993. SELOMA: expert system for weed management in herbicide-intensive crops. *Weed Technology* **7**(3): 550–559.

Stone JD and Pedigo LP. 1972. Development and economic injury level of the green clover worm on soybean in Iowa. *Journal of Economic Entomology* **65**: 197–201.

Sturgill MC, Wilkerson GG, Wilcut J, Bennett AC and Buol GS. 2001. HADSS 2001 User's Manual. Research Bulletin 192. Raleigh, NC: Crop Science Department, North Carolina State University.

Swanton CJ and Weise SF. 1991. Integrated weed management: the rationale and approach. *Weed Technology* **5**: 657–663.

Swanton CJ, Weaver S, Cowan P, Acker RV, Deen W and Shreshta A. 1999. Weed thresholds: theory and applicability. *Journal of Crop Production* **2**: 9–29.

Swinton SM and King RP. 1994. A bioeconomic model for weed management in corn and soybean. *Agricultural Systems* **44**(3): 313–335.

Thomas AG, Légère A, Leeson JY, Stevenson FC, Holm FA and Gradin B. 2011. Weed community response to contrasting integrated weed management systems for cool dryland annual crops. *Weed Research* **51**: 41–50.

Thomas CG, Yaduraju NT and Sreekumar J. 2000. Estimation of yield losses of wheat caused by wild oats (*Avena sterilis* spp. *ludoviciana*) competition. *Indian Journal of Weed Science* **32**: 44–50.

Thomas CG. 1996. Eco-physiological analysis of competition between wild oats [*Avena sterilis* spp. *Ludoviciana* (Dur.) Nym.] and wheat [*Triticum aestivum* (L.)]. *Ph. D. Thesis*. Indian Agricultural Research Institute, New Delhi. 129p.

Thornton PK and Fawcett RH. 1993. Weed control and the economic threshold. In: *Proceedings on International Symposium on "Integrated weed management for sustainable agriculture*" held during 18-20 November, Indian Society of Weed Science, Hisar, India. pp. 17–27.

Tironi SP, Galon L, Silva AA, Barbosa MH, Silva AF and Ferreira EA. 2016. Economic threshold levels for signal grass control in sugarcane cultivars. *Planta Daninha* **34**: 649–656.

Uygur FN and Mennan H. 1995. A study on economic threshold of *Galium aparine* L. and *Bifora radians* Bieb., in wheat fields in Samsun-Turkey. pp. 347-354. In: *ANPP SeizièmeConférence Du ColumaJournéesInternationale Sur la LutteContre Les Mauvaises Herbes 6-8 décembre. Conference Proceedings* Volume 1.

Uygur FN, Kadioglu I, Boz O and Mennan H. 1999. Economic threshold of weeds and application in the world and Turkey. Bitki Korumada Ekonomik Zarar Esigi Modellerive Uygulamas. Workshop, 8–9 September 1999. Samsun, Turkey. pp. 170–225.

Walker RH and Buchanan GA. 1982. Crop manipulation in integrated weed management systems. *Weed Science* **30**: 17–24.

Weaver SE. 1991. Size-dependent economic thresholds for three broadleaf weed species in soybeans. *Weed Technology* **5**: 674–679.

Westendorff ND, Agostinetto D, Ulguim AD, Perboni LT and Silva BM. 2014. Yield loss and economic thresholds of yellow nutsedge in irrigated rice as a function of the onset of flood irrigation. *Bragantia* **73**: 32–38.

Wiles LJ, King RP, Schweizer EE, Lybecker DW and Swinton SM. 1996. GWM: general weed management model. *Agricultural Systems* **50**(4): 355–376.

Wilkerson GG, Modena SA and Coble HD. 1991. HERB: decision model for postemergence weed control in soybean. *Agronomy Journal* **83**(2): 413–417.

Wilkerson GG, Wiles LJ and Bennett AC. 2002. Weed management decision models: pitfalls, perceptions, and possibilities of the economic threshold approach. *Weed Science* **50**: 411–424.

Zanin G and Sattin M. 1988. Threshold level and seed production of velvetleaf (*Abutilon theophrasti* Medicus) in maize. *Weed Research* **28**: 347–352.

Indian Journal of Weed Science 53(1): 14–29, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Weeds as alternate and alternative hosts of crop pests

Sushil Kumar*, Malay K. Bhowmick[1] and Puja Ray[2]

ICAR-Directorate of Weed Research, Maharajpur, Jabalpur, Madhya Pradesh 482004, India

[1]Directorate of Agriculture (Government of West Bengal), Kolkata, West Bengal 700001, India

[2]Department of Life Sciences, Presidency University, Kolkata, West Bengal 700073, India

**Email: sknrcws@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00002.2

Type of article: Review article

Received : 7 January 2021
Revised : 10 March 2021
Accepted : 13 March 2021

Key words

Alternate host

Alternative host

Insect pest

Mites

Nematode

Plant pathogen

Weed

ABSTRACT

Weeds pose a perpetual menace both in cropped and non–crop areas. They provide food, shelter and reproductive sites for various pest organisms (plant pathogens, insect pests, mites, nematodes, rodents and others), and thereby play a key role to serve as alternate as well as alternative hosts. Many plant pathogens (fungi, bacteria and viruses) may also have either narrow or wide host range on which they pass at least a part of their life cycle. Alternate hosts from plant families other than the family of main (primary) host help a crop pest not only to complete its life cycle, but also support the crop pest to survive under unfavourable conditions and non–availability of main host. Alternative (collateral) hosts of similar plant family as of primary host help a crop pest to survive during the periods when main hosts are not seasonally available, and while the pests subsequently migrate back onto the main host plants. Although there are some similarities, differences between alternate and alternative hosts are aptly justified, signifying the relative importance of alternative hosts over the alternate ones. There may also have the possibilities of an elevated weed status from its indirect role as alternate and alternative hosts to directly as the main host under certain circumstances. However, eliminating harmful weeds (alternate and alternative hosts) from the margins of crop fields as well as non–crop areas at the extent possible or feasible is imperative to preventing continued infection and infestation of crop plants from different pest organisms.

INTRODUCTION

Weeds have been viewed as a perpetual menace towards successful crop production, independent of other concerns. They compete with crop plants for various growth–limiting resources like water, nutrients, sunlight, root space *etc.*, causing significant reduction in crop growth, yield and quality (Anwar *et al.* 2009, Ramachandra Prasad and Sanjay 2016). Crop losses due to weeds (33%) are more than the losses caused by pathogens (26%), insect pests (20%), storage pests (7%), rodents (6%) and others (8%) in India (Yaduraju *et al.* 2015, Yaduraju and Mishra 2018). Although competition is the primary impact that weeds have on crop production (Davis and Webster 2005, Anwar *et al.* 2009). Weeds become a part of the field ecosystem by maintaining the population levels of other pest organisms and can have other less obvious (indirect) effects such as serving as alternate and alternative hosts. Invasive weeds in natural areas may alter ecosystem processes, and exert the potential to displace the native biodiversity. They often support populations of non–native organisms, hybridize with native species and subsequently alter gene pools (Yandoc–Ables *et al.* 2006). However, weeds provide food, shelter and reproductive sites for various organisms *i.e.* plant pathogens (Gonzalez *et al.* 1991, Marley 1995, Ramappa *et al.* 1998, Singh *et al.* 2010, Rathore *et al.* 2012, Webb *et al.* 2012), insect pests (Bernays and Chapman 1994, Marshall *et al.* 2003, Penagos *et al.* 2003, Capinera 2005, Singh *et al.* 2010, Duary *et al.* 2014, Singh and Singh 2016), mites (Gupta 1985, Kreiter and Tixier 2002, Steinkraus *et al.* 2003, Nair *et al.* 2005, Mamun and Ahmed 2011, Ito *et al.* 2012, Vasquez *et al.* 2015, Chandrasena *et al.* 2016, Rathee and Dalal 2018, Mishra *et al.* 2019), nematodes (Bélair and Benoit 1996, Davidson and Townshend 1967, Tedford and Fortnum 1988, Venkatesh *et al.* 2000, Davis and Webster, 2005, Thomas *et al.* 2005, Anwar *et al.* 2008, Singh *et al.* 2010), rodents (Fulk *et al.* 1981, Parshad *et al.* 1991, Jain *et al.* 1993, Malhi and Parshad 1994, Islam 2001, Htwe *et al.* 2019) *etc.* Thus, they serve in both the ways as alternate and alternative (collateral) hosts (reservoirs) for these organisms that adversely affect crop production system (Ampong–Nyarko and De Datta 1991, Rao 2000, Bhowmick 2002, Norris and Kogan 2005, Thomas *et al.* 2005, Bhowmick *et al.* 2012, 2016, Beasley 2013, Das, 2015, Ntidi 2018, Saeed *et al.* 2015, Mishra 2018, Ramachandra Prasad and Sanjay 2016, Rao *et al.* 2018). Consequently, weed hosts have an economic impact on crop production (Bendixen 1988). In recent years, the increasing trends of certain pernicious weeds in non–crop areas jeopardize the natural environment (Ghosh *et al.* 2002, Bhowmick *et al.* 2005, Yaduraju *et al.* 2015). There is no better example to this in India than the way *Parthenium hysterophorus* has become a serious menace in vacant and uncultivated areas including roadsides, railroads, industrial sites, and airfields (Sushilkumar 2009, 2014, Duary *et al.* 2005, Sushilkumar and Varshney 2010, Mondal and Duary 2014, Sushilkumar and Duary 2015). Out of several noxious characteristics, there lies the importance of recognizing weeds both as alternate and alternative hosts. It is vital to keep them managed in the margins of crop fields as well as non–crop areas at the possible or feasible extent so as to prevent continued infection and infestation of crop plants from different pest organisms.

Importance of weeds as alternate and alternative hosts

The terms 'alternate' and 'alternative' have often been used casually and interchangeably although they have literally different uses and meanings. The term 'alternate' refers to "one that substitutes for or alternates with another", "happening, occurring or succeeding by turns" or "serving in place of another", and is used as a synonym of "substitute" or "replacement". The term 'alternative' is used for referring to "one of two or more available possibilities or options" or "an option or a choice that stands instead of the other".

An alternate host is a host that comes from a different family compared to the family of the main (or primary) host and helps a crop pest to complete its life cycle. Moreover, it supports the crop pest for survival under unfavourable conditions. Many plant pathogens (fungi, bacteria and viruses) have several alternate hosts on which they pass at least a part of their life cycle. The ubiquitous nature of the invasive weed species ascertains the continuity of infection chains for a diverse group of pathogens between weeds and crop hosts (White 1970). It will be clear from a typical example of heteroecious rust pathogen (*Puccinia graminis* var. *tritici*) which causes black or stem rust in wheat (*Triticum* spp. Poaceae family) and survives on barberry (*Barberis vulgaris*, Berberidaceae family). Two independent hosts, primary and alternate, are indispensable for completion of its (pathogen) life cycle. Wheat crop is its primary host plant where uredia, uredospores, telia and teliospores are produced. Barberry, the only other species (other than wheat) affected by the pathogen, is its alternate host plant, which is indispensable for the life cycle and survival of the pathogen. Reproductive structures like pycnia, pycniospores, aecia and aeciospores are established on the alternate hosts (barberry). Such transfer of inoculum is obligatory and essential for the survival and perpetuation of the pathogen.

Diverse weed flora plays a key role on the concept that more the diversity, more the stability holds true. Because, diverse system may provide alternate hosts as source of food, over wintering sites, refuges *etc*. However, weed flora varies from season to season, year to year and/or location to location in different agro–climatic regions. In a competitive environment, weeds potentially have higher proficiency to survive, compete, and reproduce (Schroeder *et al.* 2005). Under adverse growing conditions, hardy (tolerant) species of weeds are likely to predominate.

An alternative host can also be a collateral host that belongs to the same family of the primary host and helps a crop pest to survive when the main host is not available (McMaugh 2005, Nutter 2007, Sileshi *et al.* 2008). The epidemiological significance of alternative hosts of phytopathogens is that they can serve as an over–seasoning bridge from one crop growing season to a susceptible crop in next season, providing a localized source of initial inoculum for the next susceptible crop (Bendixen 1988, Clementine *et al.* 2005, Nutter 2007). They further serve as a source of initial inoculum by producing dispersal units (spores, sclerotia, viruliferous insects, *etc.*), thus aiding in the spread of infection when they come in contact with another susceptible crop or weed host species under favourable environmental conditions (Nutter 2007). Thus, collateral hosts aid to bridge the gap between two crop seasons. For example, the phytopathogenic fungi causing blast disease [*Pyricularia grisea* (Teleomorph: *Magnaporthe grisea*)] in rice (Poaceae) infects the grasses like *Brachiaria mutica*, *Digitaria marginata*, *Dinebra retroflexa*, *Echinochloa crus–galli*, *Leersia hexandra*, *Panicum repens etc.* belonging to same family, and survives on these grassy weeds in absence of rice crop. During the subsequent rice season, the conidia (inocula) gets liberated from the weed hosts, grown on bunds or adjacent areas and disseminated by wind or other media to infect the fresh crop through initiation of the disease in rice nursery and/or main field. The alternative hosts susceptible to the phytopathogens of crop plants facilitate continuous growth and multiplication/reproduction of these pathogens during non–cropping season.

Highly preferred alternative hosts can be sometimes used as trap crops to attract herbivores away from less preferred crops. Identifying the entire host range is particularly important for early detection surveys of exotic pests as well as delimiting surveys investigating the extent of a pest incursion (McMaugh 2005).Similarities of alternate and collateral hosts are that both are the secondary (not the main, primary or principal) hosts on which a parasite, insect, pathogen or other pests can survive. Both the types of weed hosts are important in maintaining and building up the initial inoculum for the next crop. They determine the course and intensity of an epidemic. But the role of alternate hosts is not as significant as that of collateral (alternative) hosts. When a pathogen has a very wide host range (*Sclerotium rolfsii, Alternaria alternata, Rhizoctonia solani, Fusarium* spp. *etc*.) and is tolerant to a wide range of environmental conditions, the alternate hosts become essential source of survival for the pathogen, aiding in completion of the life cycle of heteroecious rust pathogens. In temperate regions, barberry bush as an alternate host plant of black/stem rust pathogen for wheat is, therefore, naturally found established along with the cultivated host, wheat. In such areas, the wild host barberry is crucial for survival of the fungus. This helps in the completion of a diverse infection chain of the rust fungus. Thus, the terms 'alternate' (replacement for the original) and 'alternative' (another option to the original) hosts should rightly be used.

Weeds appear on field bunds/margins, waste lands, irrigation and drainage channels, fence lines, pastures, shelterbelts, riparian areas, *etc.* during off–season and/or in–season of crop plants. Their presence under these sites or situations is highly objectionable as they harbour a number of pest organisms which may either spread to neighbouring fields to easily infest the crop plants during cropping season (Bhowmick 2002) or maintain pest populations to cause infection to the succeeding crops (Anwar *et al*. 2009, Ntidi 2018). Thus, alternate and alternative hosts, which are often weeds, provide a means for crop pests (pathogens, insects, mites, nematodes, rodents) to survive and multiply. Complete eradication of these weed hosts (alternate and alternative) that serve as potential sources of inoculum in field sites, is an important principle of disease and insects management as well (Nutter 2007). Because, removal and destruction of these hosts along with volunteer plants and crop residues (field sanitation) help either in the life cycle completion of pest organisms under adverse condition (Schroeder *et al.* 2005) or reducing their carry–over from one season to another (Levins and Miranda 2007, Singh *et al*. 2009). For example, white flies in cotton crop can be controlled by eradicating their alternate weed hosts like common Indian shrub (*Abutilon indicum*), suryavarti (*Chrozophora rottleri*), black nightshade (*Solanum nigrum*) and white wild musk mallow (*Hibiscus ficulneus*) from the fields and neighbouring areas to maintain field sanitation and avoid pest infestation. Weeds like heartleaf hempvine (*Mikania cordata*), yellow flowered blackjack (*Bidens biternata*), red tassel flower (*Emilia sonchifolia*), Chinese knotweed (*Polygonum chinense*) and common lantana (*Lantana camara*) offer excellent hiding places and serve as alternate hosts for the tea mosquito bug (*Helopeltis theivora*) in tea. Growth of these weeds and wild host plants in and around tea fields can be controlled to reduce the growth of tea mosquito bug population (TBI 2019).

However, the presence of low levels of pest populations *vis–a–vis* alternate and alternative hosts may sometimes be necessary to keep the natural enemies available in a particular area or location (Levins and Miranda 2007, Naveed *et al.* 2007, Saeed *et al.* 2015). Weed hosts like coat buttons (*Tridax procumbens*), goat weed (*Ageratum* sp.,) joyweed (*Alternanthera* sp.) *etc.* act as nectar source for natural enemies when primary hosts like wheat are not available (GoI 2014). Thus, alternate and alternative host plants in the vicinity of crop fields provide both advantages and disadvantages across agro–ecosystems.

Weed host–pathogen relationship

A disease generally develops from an interaction of three components; the host, the pathogen, and the environment. Plant diseases are caused by plant pathogens including bacteria, mollicutes, viruses, viroids, fungi, *etc*. These plant pathogens form an intimate relationship with their host plants in gaining access to host resources through a process called pathogenesis which involves infection, colonization, reproduction and spread. As a result, they prevent plants from performing to their maximum potential and can have devastating ecological, economic and social consequences globally (Velásquez *et al.* 2018). A plant disease may be endemic or sporadic, and may assume an epidemic or epiphytotic form under special circumstances which are governed by nature of host, nature of pathogen, and environment. Abundance of susceptible hosts in a particular area is one of the major causes for the spread of infection, leading to epidemics under favourable environmental conditions. Plant pathogens are often hardy and have evolved to survive for a prolonged period under unfavourable weather condition. They are capable of continual evolution through mutation leading to novel and dangerous strains enabling them to shift or expand host or emerge as a more virulent and resistant to abiotic stresses and environmental changes. Plant diseases are persistent threat to food and cash crops critical for global food security contributing to widespread poverty, hunger and malnutrition (Records *et al.* 2020). For example, potato late blight in Ireland in 1846 was caused by *Phytophthora infestans*, and it had an enormous socio–economic impact on the country with millions of people dead or emigrated (Nelson and Ristaino 2011). The phytopathogenic fungus *Cochliobolus miyabeanus* (formerly known as *Helminthosporium oryzae*) was largely responsible for the Bengal famine in 1943 (Padmanabhan 1973). It was reported to cause about 50–90% yield losses in rice production in the region.

In tropical regions where year–round cropping of plant species such as rice and root crops (cassava, sweet potato, taro and yams) are a common practice, the continuous presence of host plants enables parasites to survive by continuously infecting new hosts. In temperate regions, it is not uncommon for self–sown, volunteer crop plants to grow along roadsides, fence lines and irrigation channels and as weeds in paddocks during periods when the main crop is absent. These self–sown plants enable pathogens to survive during intercrop periods and serve as sources of inoculum when the main crop is grown. Black rot bacterium of Brassicaceae plants (*Xanthomonas campestris* pv. *campestris*) is known to survive on related weed species such a wild radish (Brown 1997).

Phytopathogens are not always host–specific. Most of them have the ability to infect a wide range of plants over same or different family (Linde *et al.* 2016). Weeds associated with crops often come from same family as the crop, thus sharing several botanical similarities possibly making them susceptible to the same pathogen(s). Weeds are likely to be more genetically diverse than their cultivated counterparts, and thus, become less susceptible to diseases themselves. But many weed species in addition to being pests themselves, have been reported as reservoirs or obligate hosts of many plant pathogens associated with crops (Wisler and Norris 2005, Singh *et al.* 2010). Unlike crops, weeds being hardy can survive throughout the year, and hence, often act as over–summering or overwintering hosts for a range of plant pathogens and their carrier arthropods (Webb *et al.* 2012). Thus, weeds can act as source to serve initiation of epidemics in crops and can elevate the existing problems of disease management. Presence of phytopathogens on weed hosts may not be always obvious, and it is possible that the symptoms normally associated with the disease may remain asymptomatic, making disease management in crop more challenging (Shrestha *et al.* 2016). For example, common dicotyledonous weeds in soybean fields can serve as asymptomatic hosts of the blight pathogen (*Fusarium oxysporum*), which retains pathogenicity for soybean (Helbig and Carroll 1984). Linde *et al.* (2016) suggested that pathogen population from a genetically diverse host could be more virulent than those from a monoculture crop that weedy or wild relative could play a major role in pathogen evolution. Hence, management of diseases on crops must include the management of weedy hosts or wild relatives, which might harbour disproportionate supplies of virulent pathogen strains (Linde *et al.* 2016). Further, weeds are prolific seed producers. Seeds may act as passive carriers of pathogens across vast distances and may even be responsible for the emergence of diseases in new areas (Darrasse *et al.* 2010).

Phytopathogenic bacteria and weed association: A diverse range of bacteria are associated with many wild hosts and weeds, and their presence increases the risk of infecting many cultivated crops (Kyrkou *et al.* 2018). Banana wilt (*Xanthomonas campestris* pv. *musacearum*) is known to severely affect the production of banana (*Musa* spp.). Studies showed that few weeds and crops associated with banana can significantly influence the *Xanthomonas* wilt dynamics either through spread and survival of the pathogen or supporting pathogen survival and perpetuation of the disease (Ocimati *et al.* 2018). *Xylella fastidiosa* causes pierce's disease (PD) of grapevines. Bermuda grass has been reported as a favoured host of the main PD vectors (Hopkins and Purcell 2002). Important vascular wilt pathogen in the tropics is *Pseudomonas solanacearum* which causes bacterial wilt in a wide range of crops and has been isolated from several weed species belonging to Solanaceae and Asteraceae families, being relatively susceptible and often displaying visible symptoms.

Phytopathogenic fungi and weed association: Several grasses are collateral hosts of *Sclerospora sacchari*, *S. philippinensis* (downy mildews), *Pyricularia oryzae* (rice blast) and *Ustilago scitaminea* (sugarcane smut), which can produce abundant inoculum, leading to epidemics. Such outbreak of heteroecious blister rust of pine (*Cronartium ribicola*) in Europe and the U.S.A took place due to import or introduction of eastern white pine (*Pinus strobus*) from the USA. de Oliveira *et al.* (2018) evaluated health of some weed seeds and the pathogenicity of fungi associated with economically important crop plants. They observed a positive correlation between their ability to carry several species of phytopathogenic fungi with potential to cause disease on cultivated plants. Evans (1971) reported a fungus *Verticillium dahliae* that was probably introduced along with weed seed, and then increased on natural dicotyledonous weeds, from which it spread to the introduced crops such as cotton. The fungus was isolated from stems and roots of twenty–six weed species of the region out of which several of weeds were not reported as hosts of the pathogen from other weed infested areas. Weedy barley grass with high genetic diversity and population size is a well–known carrier of phytopathogenic fungus, *Rhynchosporium commune* which causes leaf blotch on cultivated barley (King *et al.* 2013). Soybean rust caused by *Phakopsora pachyrhizi* is an exceptionally aggressive global concern for soybean worldwide causing yield losses up to 80% in susceptible cultivars (Chander *et al.* 2019). The pathogen is known to overwinter on kudzu, a noxious weed, in the southern United States, thus keeping it alive under unfavourable conditions (Ward *et al*., 2012). A part of life cycle of wheat rust is completed on wild ber (*Zizyphus rotundifolia*) when the wheat crop is not in the field (Bhowmick *et al.* 2016). Southern cutgrass, locally known as nylon grass (*Leersia hexandra*), is a potential source of *Bipolaris oryzae* causing brown spot disease in rice. *Phytophthora capsici* is known to successfully survive on weeds, making it a difficult–to–control pathogen that can utilize weed as a host in absence of a host crop, making it difficult to utilize cultural control measures for this serious vegetable pathogen. Many rust pathogens also overwinter on reservoir hosts. Pathogens of various diseases rest on *Trianthema* spp. of ice plant family (Aizoaceae). The spores of *Alternaria* blight of Indian mustard survive on scarlet pimpernel (*Anagallis arvensis*) of Primulaceae family, field bindweed (*Convolvulus arvensis*) of Convolvulaceae and lambsquarters (*Chenopodium album*) of Chenopodiaceae (Rathore *et al.* 2012).

Phytopathogenic viruses and weed association: Several authors (Aguiar *et al.* 2018, Mouhanna *et al.* 2008, Papayiannis *et al.* 2011, Wisler and Norris 2005) reported weeds as alternate hosts and sources of inoculum for a wide range of plant pathogenic viruses of crops. The plant viruses that can not be directly transmitted from an infected plant to another plant of the same species must alternate between two completely unrelated biological species. They can only be transmitted through a vector, often an insect. The phytopathogenic viruses live either in collateral hosts or arthropod vectors in absence of suitable crop hosts. These viruses are secondarily spread by insect vectors feeding generally on both cultivated plant and associated weeds. Thus, weeds also act as alternate or intermediate hosts of vectors of viral diseases (Shrestha *et al.* 2016). Wisler and Norris (2005) observed that weeds inspite of being reservoirs of plant viruses often do not show disease symptoms, making management efforts even more challenging. Many weeds serve as alternative hosts for the beet necrotic yellow vein virus (BNYVV), beet soil–borne virus (BSBV), and their common vector a plasmodiophorid, *Polymyxa betae* (Mouhanna *et al.* 2008). The host–pathogen relationships were confirmed using enzyme–linked immunosorbent assay (ELISA), internal transcribed spacer (ITS) sequence and northern blot analysis, and also positive spread of the viruses by their vector from infected weed roots to sugar beet crops. Squash vein yellowing virus (SqVYV), disseminated by the whitefly Middle East–Asia Minor 1 (MEAM1) [formerly *Bemisia tabaci* biotype B] causes devastating disease on Florida watermelon, *Citrullus lanatus* (Webb *et al.* 2012). In few transmission experiments (Adkins *et al.* 2008, Shrestha *et al.* 2016), common cucurbit weeds including smell melon (*Cucumis melo* var. *dudaim*) and wild bitter melon (*Momordica charantia*) were distinguished as natural hosts of the virus. Shrestha *et al.* (2016) further observed egg–laying preference of the whitefly on uninfected plants and on virus infected ones raising the possibilities of rapid spread of the virus in the agro–ecosystem.

Different wild grasses, crops and grassy weeds are known to host wheat streak mosaic virus (WSMV) and its vector, the wheat curl mite (Ito *et al.* 2012). In India, the chilli mosaic has been found to be due to a number of different viruses, each of which may have different host range (Dasgupta 1988), indicating practical difficulty in implementing such measures. Wild and weedy rice are the important hosts of Rice Yellow Mottle Virus in Africa (Johnson *et al.* 1999, Rodenburg and Johnson 2009). Though many examples can be cited, all those discussed so far indicates how weeds aid in propagating plant pathogens, which they render more destructive and more difficult–to–control. An understanding of the mechanisms involved in the different steps of plant disease epidemiology is essential to develop new control strategies (Darrasse *et al.* 2010). Cropping techniques are crucial in diminishing the plant disease risks. There is a need to undertake integrated management of weeds and crop pathogens in order to get rid of the source. Papayiannis *et al.* (2011) suggested new weed control strategies to be introduced focusing on the control of alternate pathogen/ pest hosts during the growing and non–growing seasons of crops.

Weeds often as a pest itself, vector or reservoir of a pathogen, can significantly influence disease incidence (Wisler and Norris 2005). The role of alternate hosts is especially more important where the pathogen has a wide host range and rotation is the main cultural method of disease management. Even crop rotation with non–host plants is the first general agronomic rule to avoid soil–borne diseases, and certain recommended rotations have been designed as decision support tools (Rouxel *et al.* 1991, Ratnadass *et al.* 2012). Alternative weed hosts among the weed flora then need to be removed if rotation with a non–host (immune) crop is to be fully effective as a control measure. Grasses such as mouse barley grass (*Hordeum leporinum*) and common wheat grass (*Agropyron scabrum*) can serve as alternative hosts to various special forms of the rust fungus *Puccinia graminis*. A similar infection chain occurs with other pathogens of wheat. Many plant pathogens survive intercrop periods by infecting alternative hosts. For example, the black rot bacterium (*Xanthomonas campestris* pv. *campestris*) of crucifers can survive on related weed species such as horse radish (Vicente and Holub 2013). Eradication of over–wintering hosts breaks the chain in the completion of the life cycle of the pathogen (Bhowmick *et al.* 2012). For example, barberry eradication in temperate countries helps to control the black or stem rust of wheat. There may have certain scope in reducing the incidence of viral diseases by eradicating their weed (reservoir) hosts and symptom–less carriers. Even weeds in non–crop areas assume profuse growth owing to their prolific seed producing ability, easy sprouting and/or regenerating ability through underground rhizomes, tubers or runners with roots at each node. Some others may have definite perennating mechanisms. All these call for a thorough study and better understanding about the host–pathogen relationship before taking any attempts for the management of weeds in both cropped and non–crop areas.

Weed host–insect pest relationship

The relationship between insects and host plants varies largely from very specialized to generalized feeding behaviours (Capinera 2005). Phytophagous insect species locate their host plants from mixed vegetation when they face the dangers of annihilation by various abiotic and biotic agents. Hence, the damage caused by insects is quite limited in natural ecosystem. In contrast, natural regulating factors play only a limited role in agro–ecosystem, and insect pest outbreaks are quite frequent (Sharma *et al.* 2017). However, there is a continuous spectrum between insect species that feed only on one plant species and others that feed on a very wide range of plants under a number of families. Weeds in particular harbour many insect pests during crop season as well as off–season. Many insects feed exclusively, or nearly so, on weeds. Depending on their host–plant ranges and feeding behaviour, the insects are categorized as: monophagous, oligophagous and polyphagous although there are certain alternative terms of occasional use as stenophagous insects with a restricted host–plant range and euryphagous insects with a broad host–plant range.

Monophagous insects: Monophagous insects generally feed on only one plant species and also include the species feeding on plants within a single genus. Some examples are spotted alfalfa aphid (*Therioaphis maculata*) feeding only on alfalfa (*Medicago sativa*), and brown planthopper (*Nilaparvata lugens*) feeding on rice throughout south and South-east Asia. Klamath weed beetle (*Chrysolina quadrigemina*) is another example which is a monophagous insect herbivore used for the selective biological control of Klamath weed (*Hypericum perforatum*) in California. Only hosts of the European spruce sawfly (*Diprion hercyniae*) are spruce trees in north–temperate regions of Europe and America (Bernays and Chapman, 1994). Such insects possibly diapause during non–availability of their host plant.

Oligophagous insects: Oligophagous insects feed on a number of plants, usually in different genera within a plant family (Bernays and Chapman 1994, Capinera 2005). Sometimes an insect may be associated with a small number of plant species from different families. For example, Colorado potato beetle (*Leptinotarsa decemlineata*) feeds mostly on about 14 plants in the genus *Solanum* under the Solanaceae family. The reddish potato beetle (*Leptinotarsa rubiginosa*) is more restricted in feeding on solanaceous plants, including only on two species of *Physalis* and two of *Solanum*. However, many grasshoppers like migratory locust (*Locusta migratoria*) feed on different grasses with common features (Bernays and Chapman 1994). So weeds and wild plants from same genera or family act as alternative hosts for these insects in absence of the preferred host plant.

Polyphagous insects: Polyphagous insects feed on a relatively large number of plants from different families (Bernays and Chapman 1994). Even they often have a well–defined preferential hierarchy, feeding on alternative host only when preferred hosts are unavailable (Capinera 2005). A number of aphid species, including green peach aphid (*Myzus persicae*) and potato aphid (*M. euphorbiae*), are known to colonize potato plants. These aphids are typically polyphagous as they feed on hundreds of host plants in multiple plant families, including both cultivated and alternate weed hosts (Singh and Singh 2016). Cotton leaf hopper (*Amrasca devastans*) is the most devastating major insect pest of cotton and a well–known polyphagous herbivore on wide range of plant species, that remains active throughout the year due to uninterrupted availability of alternative host plants (Saeed *et al*. 2015). Common vetch (*Vicia sativa*) in chickpea provides shelter to *Helicoverpa armigera*, a major pest of chickpea (Chauhan *et al.* 1991). The weed *Amaranthus* gives shelter to many caterpillars (Rathore *et al.* 2012) which are highly polyphagous in nature. Tropical armyworm (*Spodoptera litura*) is a serious polyphagous pest as it prefers to consume the leaves of weed hosts like *Alternanthera philoxeroides*, *Euphorbia hirta*, *Eichhornia crassipes*, *Trianthema portulacastrum*, *P. hysterophorus*, *Cichorium intybus*, *Rumex obtusifolius* and *Ipomoea fistulosa* (*Ipomoea carnea*). Of these, weed species, *T. portulacastrum* has been found to be the most suitable food plant (Sushilkumar and Ray 2007). Grassy weeds like *Brachiaria ramosa*, *Cynodon dactylon*, *Echinochloa colona*, *Digitaria sanguinalis* and *Leptochloa chinensis* of Poaceae family provide alternate shelter to rice mealybugs for their survival and multiplication during off–season (Mishra *et al.* 2019).

In agricultural systems, weeds directly serve as important food sources or provide other ecosystem resources for herbivorous arthropods, and indirectly serve carnivorous (beneficial) arthropods by providing food and shelter to their prey. Weeds can serve as potential alternative hosts for insect pests and beneficial arthropods when their preferred crop host is absent (Capinera 2005, Norris and Kogan 2005). For example, black–jack (*Bidens pilosa*) is an alternative host to common bean insect pests during the off–season (Laizer *et al*. 2019). Wild and weedy rice are the only alternative hosts of African rice gall midge in rice (Johnson *et al.* 1999, Rodenburg and Johnson 2009). Weeds may also impact the propensity of dispersing insects to locate crop plants (Capinera 2005). Like many other natural enemies, predaceous ground beetles do not disperse far from their overwintering sites due to an easy access to permanent habitat near or within the field that gives them a jump–start on early pest populations. Weeds that are closely related to crops are explicitly predominant in harbouring insects that attack those crops. Thus, there are some weeds which may distract beneficial insects such as pollinators during the flowering stage (Laizer *et al.* 2019) and certain others which attract. Alternate hosts have also been reported to serve as trap crops. Insects may use these plants as alternate habitat until an appropriate crop occurs in a nearby field. Napier grass (*Pennisetum purpureum*) is an example that can defend itself against the pest onslaught. Once attacked by a borer larva, it secretes sticky substance that physically traps the pest and effectively limits its damage. When insects have a broad host range (oligophagous to highly polyphagous), they may move from weeds to crop plants and cause crop damage. Then, it may be advisable to keep weed populations at check, not only within the crop field, but also in the adjacent areas like irrigation channels, field bunds, fence rows, *etc.* as a common source in view of either reducing the level of crop damage or maintaining natural enemies of crop pests. Thus, taxonomic similarity between weeds and crop plants are essential in forecasting possible damage to crops by weed–feeding insects (Capinera 2005). Farmers should also be careful in assessing the potential threat from insect pests before weeding out or removing any plants.

Weeds not only harbour insect pests that cause insect damage to crop plants, they sometimes also play a key role by harbouring insect vectors responsible for causing crop diseases and thereby, subjecting the crop plants to serious damage with conjoint or multiple attack of crop enemies. The American palm cixiid (*Myndus crudus*) is the most abundant potential vector on coconut palms. Populations of leaf hoppers (*Cicadellidae*) and plant hoppers (*Flugoroidea*) also become much higher in areas of high lethal yellowing incidence than disease–free areas in West Africa. Guinea grass (*Panicum maximum*), a perennial tufted grass, is the most abundant host of these vector insects responsible for causing lethal yellowing disease in coconut palms (Eziashi *et al*. 2013).

In India, carrot weed or congress grass (*Parthenium hysterophorus*) has already been reported as an alternate host of striped mealybug (*Ferrisia virgata*) in the states of Punjab and Haryana and cerembycid borer (*Nupserha* sp.) at Jabalpur and Vindhyanagar in Madhya Pradesh (Sushilkumar 2009). Many other insects like aphids, cotton bollworm (*H. armigera*), bagworm (*Clania crameri*), hairy caterpillar (*Dicrasia oblique*), mealybugs and grasshoppers have also been reported feeding on *P. hysterophorus* (Sushilkumar 2009). Besides, *P. hysterophorus* has been reported as the most preferred host for both the grubs and adults of host–specific leaf–feeding Mexican beetle, *Zygogramma bicolorata* (Sushilkumar and Bhan 1998, Sushilkumar *et al*. 1995 and 1997) while the wasteland weed (*Xanthium strumarium*) acts as an alternate host of *Z. bicolorata* (Sushilkumar and Bhan 1996). Considering the huge importance of *P. hysterophorus* for the survival and multiplication of *Z. bicolorata*, the Mexican beetle is often referred to as the parthenium beetle. As a weed of international importance, *P. hysterophorus* is, thus, an important example to cite and elevate the status of weeds from their indirect role as alternate and alternative hosts to the direct role as main host.

Weed host–mite relationship

Among phytophagous mites belonging to the families of Tetranychidae, Tuckerellidae, Tenuipalpidae, Nalepellidae, Eriophyidae, Rhyncaphytoptidae and Tarsonemidae, eriophyoid mites are host–specific (Gupta 1985, Vásquez *et al*. 2015), whereas those belonging to Tetranychidae, Tenuipalpidae and Tarsonemidae are not host–specific (Gupta 1985). Some polyphagous mites may occur on a wide variety of plants (Gupta 1985).

Mites under the families of Eriophyiidae and Tetranychidae have emerged as major pests of bean, brinjal, cotton, cucurbits, okra, apple, ber, citrus and mango in Northern India (Rathee and Dalal 2018). Eriophyoid mites (gall mites) are characterized by an intimate relationship with their host plants and restricted range of plants upon which they reproduce (Vásquez *et al*. 2015). Among the tetranychids, some are quite specific as to the type of host (Gupta 1985). *Schizotetranychus* species mostly occur on monocotyledons with the exception of *S. baltazari* which is an injurious pest of citrus (Gupta 1985). *Platytetranychus* species generally occurs on conifers, whereas *Oligonychus*, *Eotetranychus* and *Tetranychus* occur on a diverse group of plants (Gupta 1985). Even mites may have a certain level of preference for a particular type of microhabitat within a particular host plant (Gupta 1985). For example, mango spider mite (*Oligonychus mangiferus*) occurs only on the upper leaf surface of grape vine while lower surface of same leaf may be infested by *Eotetranychus truncatus* (Gupta 1985). Sugarcane and sorghum are the alternate hosts of *Oligonychus indicus* while *Dicanthium annulatum* is the primary host as the mite occurs on that host even during the rainy season (Khan and Murthy 1956). Alternate hosts of date palm mite (*Oligonychus afrasiaticus*) belong only to the families of Arecaceae and Poaceae, and include *Hyphaene thebaica*, *Phoenix canariensis* (Arecaceae), *Cenchrus ciliaris*, *Dichanthium annulatum*, *Hilaria* sp., *Hyparrhenia hirta*, *Pennisetum ciliarae*, *P. divisum*, *Pennisetum* sp. and *Aeluropus littoralis* (Poaceae) in Saudi Arabia (Alatawi 2020). Two phytophagous mites, *Eutetranychus orientalis* and *E. palmatus* (Tetranychidae), and the predatory mite, *Spinibdella cronini* (Bdellidae) remain associated with the date palm mite on date fruits, whereas the phytoseiid mite, *Cydnoseius negevi* remains on the grasses growing under the trees (Alatawi 2020).

Under field conditions, air–borne adults of tomato russet mite (*Aculops lycopersici*) may begin to infest tomatoes from perennial alternate hosts shortly after transplanting. When the primary host dies, some of the mites get dispersed by the wind to nearby alternative hosts, where they can form overwintering aggregations (FAO 2017). Removal of alternate hosts like shaggy button weed (*Borreria hispida*), goat weed (*Scoparia dulcis*), chocolate weed (*Melochia corchorifolia*) and Fussiala (*Fussiala suffruticosa*) in and around plantations gives a good control of red spider mite (*Oligonychus coffeae*) in tea (TBI 2019).

Spider mites always cause sporadic problems in Midsouth cotton. Most important species of these mites on cotton are two spotted spider mite (*Tetranychus urticae*), desert spider mite (*T. desertorum*), strawberry spider mite (*T. turkestani*) and carmine spider mite (*T. cinnabarinus*). Spider mite outbreaks in cotton are related to the population levels on other host plants including weeds where they overwinter and develop during May–June. Infestations often begin in cotton adjacent to field borders or uncultivated areas. Thereafter, spider mites move from these alternate hosts to cotton by crawling over the soil or from plant to plant, carried by wind, human or equipment, or by animal movements. Palmer amaranth (*Amaranthus palmeri*) and pitted morning–glory (*Ipomoea lacunosa*) are reported as the major weeds in the field borders which serve as the sources of spider mite infestations in cotton fields in Arkansas (Steinkraus *et al.* 2003).

Coconut eriopyhid mite (*Aceria guerreronis*) is an invasive pest of coconut since its host range is very narrow, being coconut (*Cocos nucifera*) and palmyra palm (*Borassus flabellifer*) in India (Nair *et al.* 2005). The eriophyid mite (*Aceria solstitialis*) remains alive on yellow star thistle (*Centaurea solstitialis*), *Centaurea cyanus*, *Centaurea diffusa*, *Carthamus tinctorius*, and *Cynara scolymus* in Turkey (Vásquez *et al.* 2015).

Among the predatory plant mites (Cheyletidae, Stigmaeidae, Tydeidae, Bdellidae, Cunaxidae, Erythraeidae, Ameroseiidae, Ascidae and Phytoseiidae), no specificity has been observed though one species may occur only on a particular plant while another species may occur on a wide range of plants (Gupta 1985). Kreiter and Tixier (2002) explained the role of host plants in providing substrates for colonization, liquid and pollen foods, and pilosity and domatia either for pollen trapping or protection, which are important for phytoseiid mites (potential predators of the citrus rust mite and the broad mite in Guadeloupean citrus orchards). These mites live mostly on leaf undersurfaces having raised veins, dense hairs, tunnelled margins and cave–like structures in the vein axils (domatia).

Although Gupta (1985) made an enormous task in preparing a detailed list of plant–mite catalogue, still there is a need to have sufficient knowledge about true host ranges and mechanisms of host specificity in understanding mite–host interactions, potential mite–host coevolution, and species diversity (Skoracka *et al.* 2010).

Weed host–nematode relationship

Weeds have been recognized for their ability to serve as potential alternate hosts (Beasley 2013) as well as alternative hosts (Thomas *et al.* 2005) of plant–parasitic nematodes. Weed species enable plant–parasitic nematodes to survive in absence as well as presence of a crop, and thereby providing a nematode inoculum source for the subsequent crop season (Rich *et al.* 2008). The importance of a particular nematode as the damaging pest depends on its host range (Anwar *et al.* 2009, Dixit 2019), whereas the major role of weeds is to support the nematodes in their (nematodes) reproduction and survival under field condition. Such a relationship between weeds and nematodes may be a normal adaptation due to limited mobility of both the groups of organisms and obligate parasitism of phytophagous nematodes (Thomas *et al.* 2005). Most of the genera excepting the cyst nematodes (*Heterodera* spp. and *Globodera* spp.) do not survive for a long–term in absence of suitable host plants (Schmitt and Sipes 2000, Thomas *et al.* 2005). The role of weeds as alternate and alternative hosts depends largely on the feeding behaviour of nematode as determined by the level of host specialization needed for the parasite to successfully feed (Thomas *et al.* 2005, Anwar *et al.* 2009, Mitiku 2018). There are several other factors like type of plant and tissues invaded, soil types, nematode density, effective survival and dissemination mechanisms adopted by the nematode, *etc.* (Anwar *et al.* 2009, Dixit 2019). Based on the requirement of host specialization, different taxa of plant–parasitic nematodes are, however, broadly grouped into three feeding categories: sedentary endoparasites, migratory endoparasites, and ectoparasites (Ferris and Ferris 1998, Sijmons *et al.* 1994). Tiwari *et al.* (1994) recorded several plant parasitic nematode species with weed flora of Kymore Plateau and Satpula hills of Madhya Pradesh. Tiwari and Singh also (1995) found spiral nematode *Helicotylenchus* spp. as root parasite in 30 weed spices in Madhya Pradesh. *Helicotylenchus elegans* was recorded as a predominant species on more than 19 weeds whereas *T. dihystera* was observed common species in the state. Tiwari and Sushilkumar (1996) recorded root-rot nematode *Hirschmanniella oryzae* on the weed species *Cyperus rotundus* (pre-dominant), *C. difformis*, *C. iria* and *C. platystlis* in addition to root-knot nematode *Meloidogyne incognita* on *C. iria* from Madhya Pradesh and *C. compressus* from Chhattisgarh.

Sedentary endoparasites: Sedentary endoparasites require the highest level of host specialization at the time of feeding. Juveniles (pre–reproductive) females do not remain within the soil, and they rather enter into the plant roots and induce host transformations through some secretions, resulting in the formation of certain specialized feeding sites (giant cells, syncytia, nurse cells) which serve as the permanent sources of nutrients for growth and reproduction of nematode parasites and enable them to feed in a particular location throughout their life cycle for a long period of time (Thomas *et al.* 2005). Among the plant–parasitic nematodes, root–knot nematodes

(*Meloidogyne* spp.), cyst nematodes (*Heterodera* spp. and *Globodera* spp.), reniform nematode (*Rotylenchulus reniformis*), false root–knot nematodes (*Nacobbus* spp.) and citrus nematode (*Tylenchulus semipenetrans*) are the most important crop pests (Thomas *et al.* 2005, Anwar *et al.* 2009, Ntidi 2018). Their host ranges are more restricted than for other feeding behaviours (Thomas *et al.* 2005). Crops that are not affected by nematode secretions may be effective for crop rotation to suppress the nematode population. Simultaneously, weeds can serve as reservoirs for these nematodes in susceptible crops with increased proportions of early–season crop infection and more population of nematodes to affect subsequent crops (Schroeder *et al.* 1993, 1994, Bird and Hogger 1973, Davis and Webster 2005, Anwar *et al.* 2009, Singh *et al.* 2010). Weeds grown in the irrigation ditches or channels can help a lot in the maintenance and dissemination of false root–knot nematode (*Nacobbus aberrans*) into the non–infested fields through irrigation water (Inserra *et al.* 1985).

Most common species of root–knot nematodes in the tropics are *M. incognita* (southern root–knot) and *M. javanica* (Javanese root–knot) whereas other species occur less frequently (Schmitt and Sipes, 2000). These nematodes feed and mature inside the roots of plants. From the on–farm as well as pot experiments, Singh *et al.* (2010) identified slender amaranth (*Amaranthus viridis*), diamond–flower (*Oldenlandia corymbosa*), tropic ageratum (*Ageratum conyzoides*), sicklepod (*Senna obtusifolia*), wild bittermelon (*Momordica charantia*), purple bush–bean (*Macroptilium atropurpureum*), little ironweed (*Cyanthillium cinereum*), ivy gourd (*Coccinia grandis*) and cutleaf groundcherry (*Physalis angulata*) as the potential reservoir hosts commonly infected by root–knot nematodes (*Meloidogyne*). Singh *et al.* (2010) observed the presence of egg masses of root–knot nematode on these weed hosts which indicates their ability to sustain the nematode populations. *M. incognita* was reported to reproduce on the largest number of weeds with over 138 weedy plant hosts throughout the world, indicating weeds as the major reservoir of root–knot nematodes (Rich *et al.* 2008). Although witchweed (*Striga hermonthica*) is a parasitic weed of cereals, it also serves as a good alternate host of root–knot nematodes, which attack agroforestry species such as the Egyptian riverhemp (*Sesbania sesban*) and fish–poison–bean (*Tephrosia vogelii*) in Western Kenya (Desaeger *et al.* 2004).

Migratory endoparasites: Although migratory endoparasitic nematodes invade the roots of host plants, they generally do not induce specialized feeding sites. They typically use their stylets to pierce and feed upon cortical cells, which often subsequently die and collapse since these nematodes migrate through root tissue, causing an extensive damage (Thomas *et al.* 2005). The wounded roots of crops may also be infected by the fungal pathogens, leading to a complex of diseases (Abawi and Chen 1998, Rowe *et al.* 1985). Host pathogenicity in association with feeding behaviour of migratory endoparasites like lesion nematodes (*Pratylenchus* spp.), stem nematodes (*Ditylenchus* spp.), burrowing nematodes (*Radopholus* spp.), and rice root nematode (*Hirschmanniella oryzae*) tends to be less severe than for sedentary endoparasites, but greater than the damage caused due to most ectoparasites (Thomas *et al.* 2005). Here, crop rotation and host–plant resistance are less effective against certain migratory endoparasites which are less dependent on host specialization with respect to their feeding and reproduction (Thomas *et al.* 2005). Since weeds as alternative hosts may contribute substantially to the maintenance and population build–up of migratory endoparasites under fallow conditions, their deleterious effect on crop rotations and resistant crops is less likely than with sedentary endoparasites (Thomas *et al.* 2005).

In a study of Anwar *et al.* (2008), rice root nematode (*Hirschmanniella oryzae*) was reported to occur in roots of 11 rice cultivars and 10 weed species belonging to 7 families. Of the weed species, *Echinochloa colona*, *E. glabrescens* (Poaceae), *Chenopodium album* (Chenopodiaceae), *Cyperus difformis*, *Rumex dentatus* (Polygonaceae) and *Scripus maritimus* (Cyperaceae) were found to support the nematodes at levels similar to that recovered from roots of rice plants grown in and around the fields during and after the cropping season as well (Anwar *et al.* 2009). Some weed species like *Coronopus didymus* (Brassicaceae), *Marsilea minuta* (Marsileaceae), *Paspalum distichum* (Poaceae) and *Sphenoclea zeylanica* (Campanulaceae) were frequently infected by the nematode but at lower levels from those found in rice roots (Anwar *et al.* 2009).

The northern root–lesion nematode (*Pratylenchus penetrans*) has a wide host range including crops including cereals, cotton, pulses, pastures and oilseeds along with a number of weed genotypes. The nematode can penetrate and reproduce more easily in perennial weeds with soft–textured roots than in annual weeds with hard–textured roots. These act as reservoirs for the overwintering *P. penetrans*, posing substantial threat to any succeeding crop(s) susceptible to this nematode (Anwar *et al.* 2009). The winter–active annual groundsel (*Senecio vulgaris*) serves as an important winter reservoir for *P. penetrans* (Townshend and Davidson 1960). Furthermore, the life span of weeds plays a key role in keeping the nematode population alive throughout the year (Anwar *et al.* 2009). The noxious nut grass (*Cyperus* sp.) maintains harmful populations of several nematodes (Hogger and Bird 1976, Rhoades 1964).

Ectoparasites: Ectoparasitic nematodes live freely in the soil near the host, move closely or on the root surface, and feed intermittently on the epidermis and root hairs near the root tip. They only penetrate the plant roots with their stylets and feed on tissues from outside the plant. They have a wide host range and need a little or no host specialization for feeding (Thomas *et al.* 2005). Although some genera like ring nematodes (*Criconemella* spp.) may feed at the same location on a root for an extended period of time, most of them browse on epidermal and cortical tissues at different locations along roots (Thomas *et al.* 2005). Some examples of other ectoparasites are lance nematodes (*Hoplolaimus* spp.), spiral nematodes (*Helicotylenchus* spp.), sting nematodes (*Belonolaimus* spp.), stubby–root nematodes (*Trichodorus* spp.) and stunt nematodes (*Tylenchorhynchus* spp.). Crop damage occurs due to direct injury into the cells at the time of feeding, depending on the number of nematodes present, their size, rate of population growth, and specific host sensitivity (Thomas *et al.* 2005). Management of these nematodes is limited to non–specific strategies such as weed–free clean fallowing or using nematicides because of their presence in a wide host range during fallow period (Thomas *et al.* 2005).

However, weed hosts can be classified as good (susceptible), moderate, and weak or poor (resistant) host to nematodes, depending on their reproductive size (Rich *et al.* 2008, Anwar *et al.* 2009). The impact of each category varies with the interaction between the crop and the specific nematode (Anwar *et al.* 2008). Weed species resistant to nematodes have low potential to maintain a high level of nematode population, whereas susceptible weeds can maintain a high level of nematode population in the weed infested fields (Davis and Webster 2005, Anwar *et al.* 2009).

As the most economically important soybean pathogen in the United States, soybean cyst nematode (*Heterodera glycines*) has been reported to parasitize a wide range of host plants, covering about 100 legume genera of Fabaceae family and about 50 non–legume genera of 22 plant families (Johnson *et al.* 2008). Of these, the major ones are common winter annual weeds of soybean, and include purple deadnettle (*Lamium purpureum*) and henbit (*Lamium amplexicaule*) as strong hosts, field pennycress (*Thlaspi arvense*) as a moderate host, and shepherd's purse (*Capsella bursa–pastoris*) as a weak host (Johnson *et al.* 2008). There are some more instances. Wild marigold (*Tagetes minuta*) is generally considered as a poor host for a variety of nematode pests (Dixit 2018). Wandering Jew (*Commelina benghalensis*) and pigweeds (*Amaranthus* spp.) have been reported as good weed hosts for the root–knot nematode (*M. incognita*) based on their reproductive potential (Singh *et al.* 2010). Thus, there is an urgent need for a thorough study on the host–nematode relationships so as to design effective management strategies for weeds and nematodes both.

Weed host–rodent relationship

Weeds have been reported to form an important component in the diet of rodents (Fulk *et al.* 1981, Malhi and Parshad 1994), and also act as hiding niche (Jain *et al.* 1993). In India, about eighteen species of rodents are considered as pests in agriculture and allied sectors (Parshad, 1999). Of these, the lesser bandicoot rat (*Bandicota bengalensis*) is the most predominant and widespread pest of agriculture in wet and irrigated crop fields as well as grassland almost throughout the country excepting a few specified areas (Parshad 1999). Other species which are widespread in both irrigated and dry farming systems in the country are Indian gerbil (*Tatera indica*), soft–furred field rat (*Rattus meltada*) and house mouse (*Mus musculus*). Almost all field crops are affected by rodents from sowing to harvesting and even up to the storage areas (Parshad 1999). However, both the weeds and rodents are major concerns to rice farmers in the tropics (Htwe *et al.* 2019). Because, rodents selectively invade and cause more damage in weedy than in weed–free rice crop (Drost and Moody 1982). In temperate cereal systems, high protein seeds of grass weeds can be an important food source for rodents (Htwe *et al.* 2019). Weed infestations in and around rice crop fields provide important refuge areas for rodent pests (Htwe *et al.* 2019). The study of Htwe *et al.* (2019) under lowland irrigated rice agro–ecosystem in Myanmar revealed *B. bengalensis* as the dominant rodent species in transplanted rice during both wet and dry seasons. In dry season, *Cyperus difformis* was found dominant at the tillering stage, whereas *Echinochloa crus–galli* was the dominant weed species at the booting stage. *E. crusgalli* was the dominant weed throughout the wet season. Damage by rodents was higher in dry season as evidenced from larger economic benefits for best weed management and effective rodent control in the dry season than in the wet season (Htwe *et al*. 2019). Cutting weeds from the areas bordering rice crop and removing weeds from the rice field reduces potential nesting sites and shelters for rats and others (Islam 2001). But the presence of an alternative food source reduces the performance of other control techniques such as trapping and poison baiting (Parshad *et al*. 1991). Hence, concurrent control of weeds in and around rice fields combined with coordinated community trapping of rodents during the early tillering stage and ripening stage of rice are recommended management options (Htwe *et al*. 2019). In recent years, increasing trend of farm mechanization is expected to reduce the wastelands and wild vegetation on crop field boundaries which otherwise provide harbourage to rodents. A clean environment through harbourage reduction can discourage rodents from their establishment in an area (Parshad 1999).

Conclusion

Weeds are very much affiliated to different pest organisms like diseases, insects, mites, nematodes and rodents for their growth, multiplication, perpetuation, reproduction and/or survival. Individually, each one of these is responsible for a considerable loss by itself. But if weeds remain disregarded, it gives rise to the infestation of the other (s). Weeds play a key role by serving as the alternate and alternative hosts of various pest organisms. It is very much necessary to understand, circumvent and manage the weeds in time for an efficient management of other crop pests. Regular removal of weeds is a type of preventive control as it minimizes competition of nutrients, prevents hibernating pests, as well as, facilitates proper aeration and application of pesticides. The key behind the success of insect pests, diseases and other pests is significantly related to the weeds and their need–based management. Each of these problems and infestations need specific approach towards prevention and control. Eradicating and treating sources of inocula in the field are important preventive measures. Concerted efforts are very much needed to have an in–depth study over the relationship between weed hosts and other pests. This is imperative for updating the host range or host profile of different pest organisms, because the direct role as documented for *P. hysterophorus* as main host of Mexican beetle is not uncommon. An integrated approach would be more effective to obviate the weeds or wild plants for minimizing the carryover of crop pests on the cultivated hosts.

REFERENCES

Abawi GS and Chen J. 1998. Concomitant pathogen and pest interactions. pp. 135–158. In: *Plant and Nematode Interactions* (Eds. Barker KR, Pederson GA and Windham GL), Agronomy Monograph 36. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Adkins S, Webb SE, Baker CA and Kousik CS. 2008. Squash vein yellowing virus detection using nested polymerase chain reaction demonstrates that the cucurbit weed *Momordica charantia* is a reservoir host. *Plant Disease* **92**(7): 1119–1123 Available at. http://doi.org/10.1094/PDIS–92–7–1119.

Aguiar RWS, Alves GB, Queiroz AP, Nascimento IR and Lima MF. 2018. Evaluation of weeds as virus reservoirs in watermelon crops. *Planta Daninha* **36** Available at. http://doi.org/10.1590/S0100–83582018360100032.

Alatawi FJ. 2020. Field studies on occurrence, alternate hosts and mortality factors of date palm mite, *Oligonychus afrasiaticus* (McGregor) (Acari: Tetranychidae). *Journal of the Saudi Society of Agricultural Sciences* **19**: 146–150.

Ampong–Nyarko K and De Datta SK. 1991. *A Handbook for Weed Control in Rice*. International Rice Research Institute, Manila, Philippines. 69 p.

Anwar SA, McKenry MV and Yasin SI. 2008. Occurrence of rice–root nematode, *Hirschmanniella oryzae* among 11 rice and 10 weed selections. p. 198. In: *Proceedings of 5th International Congress of Nematology*, July 13–18, 2008, Brisbane, Australia.

Anwar SA, Zia A, Javed N and Shakeel Q. 2009. Weeds as reservoir of nematodes. *Pakistan Journal of Nematology* **27**(2): 145–153.

Beasley J. 2013. 4–H Ontario's Field Crops: *Weeds, Insects and Diseases–Reference Manual*. 4–H Ontario Provincial Office, Rockwood, ON N0B 2K0. 89 p.

Bélair G and Benoit DL. 1996. Host suitability of 32 common weeds to *Meloidogyne hapla* in organic soils of southwestern Quebec. *The Journal of Nematology* (Supplement) **28**: 643–647.

Bendixen LE. 1988. *Major Weed Hosts of Nematodes in Crop Production*. Special Circular No. 119, May, 1988. The Ohio State University, Ohio Agricultural Research and Development Center, Wooster, Ohio. 24 p.

Bernays EA and Chapman RE. 1994. Patterns of host–plant use. pp. 4–13. In: *Host–Plant Selection by Phytophagous Insects*. *Contemporary Topics in Entomology* **2**. Springer, Boston, MA Available at. http://doi.org/10.1007/978–0–585–30455–7_2).

Bhowmick MK, Duary B, Biswas PK and Bag MK. 2012. Weeds as alternate hosts of plant pathogens and their management. pp. 45. In: *Abstracts*. National Symposium on "Plant Microbe Interactions and Crop Health Management" & Twenty–fifth Annual General Meeting of Indian Phytopathological Society (Eastern Zone), October 6–7, 2012, Department of Plant Protection, Palli–Siksha Bhavana (Institute of Agriculture), Sriniketan, Birbhum, West Bengal, India.

Bhowmick MK, Duary B, Dhara MC, Biswas PK, Patra DK and Bhattacharyya P. 2016. Weeds as alternate hosts of plant pathogens and their chemical management. *Journal of Interacademicia* **20**(4): 569–584.

Bhowmick MK, Ghosh RK and Ghosh P. 2005. Management of weeds with new molecule XL 71 AG under non–crop situation. *Journal of Crop and Weed* **1**(1): 70–72.

Bhowmick MK. 2002. Weed as alternate host of crop pest and its control measure. *Advances in Plant Sciences* **15**(1): 141–143.

Bird GW and Hogger CH. 1973. Nutsedges as hosts of plant–parasitic nematodes in Georgia cotton fields. *Plant Disease Reporter* **57**: 402.

Brown J. 1997. Survival and dispersal of plant parasites: general concepts. pp. 195–206. In: *Plant Pathogens and Plant Diseases*. (Eds. Brown JF and Ogle HJ) Rockvale Publications, Armidale, NSW–Australia.

Capinera JL. 2005. Relationships between insect pests and weeds: an evolutionary perspective. *Weed Science* **53**: 892–901.

Chander S, Ortega–Beltran A, Bandyopadhyay R, Sheoran P, Oluwayemisi IG, Vasconcelos MW and Garcia–Oliveira AL. 2019. Prospects for durable resistance against an old soybean enemy: A four–decade journey from *Rpp1* (Resistance to *Phakopsora pachyrhizi*) to *Rpp7*. *Agronomy* **9**(7): 348.

Chandrasena GDSN, Jayawardane JDKM, Umange SD and Gunawardana ADBU. 2016. Host range of panicle rice mite *Steneotarsonemus spinki* Smiley (Acari: Tarsonemidae) in Sri Lanka. *Universal Journal of Agricultural Research* **4**(1): 21–24.

Chauhan R, Dahiya B and Khokhar KS. 1991. Weeding *Vicia sativa* L. to help check pod borer (*Helicoverpa armigera*) damage in chickpea (*Cicer arietinum* L.). *ACIAR Food Legume Newsletter* **15**(3).

Clementine D, Antoine S, Herve B and Kouahou FB. 2005. Alternative host plants of *Clavigralla tomentosicollis* Stal (Hemiptera: Coreidae), the pod sucking bug of cowpea in the Sahelian Zone of Burkina Faso. *Journal of Entomology* **2**(1): 9–16.

Darrasse A, Darsonval A, Boureau T, Brisset MN, Durand K and Jacques MA. 2010. Transmission of plant–pathogenic bacteria by nonhost seeds without induction of an associated defense reaction at emergence. *Applied and Environmental Microbiology* **76**(20): 6787–6796.

Das TK. 2015. *Weed Science: Basics and Applications*. Jain Brothers, Karol Bagh, New Delhi, India. 910 p.

Dasgupta MK. 1988. Plant disease control – Elimination of non–crop hosts. pp. 690–691. In: *Principles of Plant Pathology* (Ed. Dasgupta, MK). Allied Publishers Pvt. Ltd., New Delhi, India.

Davidson TR and Townshend JL. 1967. Some weed hosts of the southern root–knot nematode, *Meloidogyne incognita*. *Nematologica* **13**: 452–458.

Davis RF and Webster TM. 2005. Relative host status of selected weeds and crops for *Meloidogyne incognita* and *Rotylenchulus reniformis*. *The Journal of Cotton Science* **9**: 41–46.

de Oliveira EF, Santos PRR dos and Santos GR dos. 2018. Seeds of weeds as an alternative host of phytopathogens. *Arquivos Do Instituto Biológico* **85**: 1–7 Available at. http://doi.org/10.1590/1808–1657000972017.

Desaeger J, Rao MR and Bridge J. 2004. Nematodes and other soil borne pathogens in agroforestry. pp. 263–283. In: *Below–Ground Interactions in Tropical Agroecosystems: Concepts and Models with Multiple Plan Components* (Eds. Noordwijk M van, Cadisch G and Ong CK). CABI Publishing, Wallingford, UK.

Dixit G. 2019. Sustainable practices for the management of nematodes. *Acta Scientific Agriculture* **3**(7): 26–29.

Drost DC and Moody K. 1982. Rat damage in weed control experiments in rainfed transplanted rice. *Tropical Pest Management* **28**(3): 295–299.

Duary B, Mondal DC and Hossain A. 2005. Studies on biology and management of *Parthenium hysterophorus* in lateritic belt of West Bengal, India. pp. 251–252. In: *Proceedings*. Second International Conference on *Parthenium* Management, December 5–7, 2005, University of Agricultural Sciences, Bangalore, Karnataka, India.

Duary B, Teja KC and Bhowmick MK. 2014. Weed problem and management in vegetable crops. p. 331–341. In: *Innovative Horticulture: Concepts for Sustainable Development, Recent Trends* (Eds. Munsi PS, Ghosh SK, Bhowmick N and Deb P). New Delhi Publishers, India.

Evans G. 1971. Influence of weed hosts on the ecology of *Verticillium dahliae* in newly cultivated areas of the Namoi Valley, New South Wales. *Annals of Applied Biology* **67**(2): 169–175 Available at. http://doi.org/10.1111/j.1744–7348.1971.tb02917.x.

Eziashi EI, Omamor IB, Aisueni NO, Aisagbonhi CI, Airede CE, Ikuenobe CE, Ataga CD, Oruade–Dimaro EA, Odewale JO and Osagie IJ. 2013. Potential weed species as alternate hosts of insect vectors of the lethal yellowing disease (LYD) of coconut palms (*Cocos nucifera* L.) in Nigeria. *British Journal of Applied Science & Technology* **3**(1): 123–130.

FAO. 2017. *Integrated Pest Management of Major Pests and Diseases in Eastern Europe and the Caucasus*. Food and Agriculture Organization of the United Nations, Budapest. 98 p.

Ferris JM and Ferris VR. 1998. Biology of plant–parasitic nematodes. pp. 21–35. In: *Plant and Nematode Interactions*. (Eds. Barker KR, Pederson GA and Windham GL).Agronomy Monograph 36. Madison, WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Fulk GW, Lathiya SB and Khokhar AR. 1981. Rice–field rats of Lower Sind: abundance, reproduction and diet. *Journal of Zoology* **193**: 371–390.

Ghosh RK, Bhowmick MK and Ghosh P. 2002. Efficacy of glyphosate and 2,4–D combinations for weed management in non–crop areas. *Environment and Ecology* **20**(1): 143–146.

GoI. 2014. *Agro–Ecosystem Analysis (AESA) Based Integrated Pest Management in Wheat*. Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India (GoI), Directorate of Plant Protection Quarantine and Storage, Faridabad, Haryana and National Institute of Plant Health Management, Hyderabad, India. 83 p.

Gonzalez CF, Xu GW, Li HL and Cosper JW. 1991. *Leersia hexandra*, an alternative host for *Xanthomonas campestris* pv. *oryzae* in Texas. *Plant Disease* **75**(2): 159–162.

Gupta SK. 1985. *Handbook: Plant Mites of India*. Zoological Survey of India, Calcutta, West Bengal, India. 520 p.

Helbig JB and Carroll RB. 1984. Dicotyledonous weeds as a source of *Fusarium oxysporum* pathogenic on soybean. *Plant Disease* **68**(8): 694–696.

Hogger CH and Bird GW. 1976. Weed and indicator hosts of plant–parasitic nematode in Georgia cotton and soybean fields. *Plant Disease Reporter* **60**(3): 223–226.

Hopkins DL and Purcell AH. 2002. *Xylella fastidiosa: Cause of Pierce's disease of grapevine and other emergent diseases. Plant Disease* **86**(10): 1056–1066.

Htwe NM, Singleton GR and Johnson DE. 2019. Interactions between rodents and weeds in a lowland rice agro–ecosystem: the need for an integrated approach to management. *Integrative Zoology* **14**(4): 396–409.

Inserra RN, Griffin GD and Anderson JL. 1985. The false root knot nematode *Nacobbus aberrans*. Research Bulletin No. 510. Logan, UT: Utah Agricultural Experiment Station. 14 p.

Islam Z. 2001. Control of rice insect pests. 28 pp. In: *Crop Protection Compendium*, CAB international (UK), CD and On–line. Rice IPM (version 1), International Rice Research Institute (Philippines) and The University of Queensland (Australia).

Ito D, Miller Z, Menalled F, Moffet M and Burrows M. 2012. Relative susceptibility among alternative host species prevalent in the great plains to wheat streak mosaic virus. *Plant Disease* **96**(8): 1185–1192.

Jain AP, Tripathi RS and Rana BD. 1993. *Rodent Management: The State of Art*. Technical Bulletin No. 1. Project Coordinating Unit, All India Coordinated Research Project on Rodent Control, ICAR, Central Arid Zone Research Institute, Jodhpur, Rajasthan, India. 40 P.

Johnson DE, Riches CR, Kayeke J, Sarra S and Tuor FA. 1999. Wild rice in sub–Saharan Africa: Its incidence and scope for improved management. pp. 87–93. In: *Global Workshop on Red Rice Control* (Ed. Labrada R). FAO, Rome.

Johnson WG, Creech JE and Mock VA. 2008. Role of winter annual weeds as alternative hosts for soybean cyst nematode. *Crop Management* Available at. http://doi:10.1094/CM-2008–0701–01–RV.

Khan MQ and Murthy DV. 1956. *Dicanthium annulatum* Stapf., an important alternate host plant of jowar and sugarcane mites. *Indian Journal of Entomology* **18**: 190–199.

King KM, West JS, Brunner PC, Dyer PS and Fitt BDL. 2013. Evolutionary relationships between *Rhynchosporium lolii* sp. nov. and other *Rhynchosporium* species on grasses. *PLoS ONE* **8**(10): e72536 Available at. http://doi.org/10.1371/journal.pone.0072536.

Kreiter S and Tixier M–S. 2002. Some future prospects in agricultural acarology, with focus on phytoseiid mites–host plant relationships. pp. 283–302. In: *Acarid Phylogeny and Evolution: Adaptation in Mites and Ticks* (Eds. Bernini F, Nanelli R, Nuzacci G and de Lillo E). Proceedings of the 4th Symposium of the European Association of Acarologists, Siena, Italy, July 24–28, 2000, Klumer Acadenic Publisher, Netherlands.

Kyrkou I, Pusa T, Ellegaard–Jensen L, Sagot MF and Hansen LH. 2018. Pierce's disease of grapevines: A review of control strategies and an outline of an epidemiological model. *Frontiers in Microbiology* **9**(9): 2141, Available at. http://doi.org/10.3389/fmicb.2018.02141.

Laizer HC, Chacha MN and Ndakidemi PA. 2019. Farmers' knowledge, perceptions and practices in managing weeds and insect pests of common bean in Northern Tanzania. *Sustainability* **11**, 4076 doi:10.3390/su11154076.

Levins R and Miranda I. 2007. Mathematical models in crop protection. *Revista Protección Vegetal* **22**(1): 1–17.

Linde CC, Smith LM and Peakall R. 2016. Weeds, as ancillary hosts, pose disproportionate risk for virulent pathogen transfer to crops. *BMC Evolutionary Biology* **16**(1): 101.

Malhi CS and Parshad VR. 1994. Responses of *Bandicota bengalensis* to below ground baiting in orchard. *Mammalia* **58**(1): 73–84.

Mamun MSA and Ahmed M. 2011. Integrated pest management in tea: Prospects and future strategies in Bangladesh. *The Journal of Plant Protection Sciences* **3**(2): 1–13.

Marley PS. 1995. *Cynodon dactylon*: An alternative host for *Sporisorium sorghi*, the causal organism of sorghum covered smut. *Crop Protection* **14**(6): 491–493.

Marshall EJP, Brown VK, Boatman ND, Lutman PJW, Squire GR and Ward LK. 2003. The role of weeds in supporting biological diversity within crop fields. *Weed Research* **43**(2): 77–89.

McMaugh T. 2005. Guidelines for surveillance for plant pests in Asia and the Pacific. *ACIAR Monograph No. 119*, Australian Centre for International Agricultural Research. 192 p.

Mishra JS, Poonia SP, Choudhary JS, Kumar R, Monobrulla M.,Verma M, Malik RK and Bhatt BP. 2019. Rice mealybug (*Brevennia rehi*): a potential threat to rice in a long–term rice–based conservation agriculture system in the middle Indo–Gangetic Plain. *Current Science* **117**(4): 566–568.

Mishra JS. 2018. Weed management research in pulses and oilseeds in India. pp. 161–178. In: *Fifty Years of Weed Science Research in India* (Eds. Sushilkumar and Mishra JS). Indian Society of Weed Science, Jabalpur, India.

Mitiku M. 2018. Plant–parasitic nematodes and their management: A review. *Agricultural Research & Technology* **16**(2): 30–38.

Mondal S and Duary B. 2014. Ecological and socio–economic utilization of noxious weed *Parthenium hysterophorus* by exploring its beneficial aspects. pp. 375–384. In: *Innovative Horticulture: Concepts for Sustainable Development, Recent Trends* (Eds. Munsi PS, Ghosh SK, Bhowmick N and Deb P), New Delhi Publishers, India.

Mouhanna AM, Langen G and Schlösser E. 2008. Weeds as alternative hosts for BSBV, BNYVV, and the vector *Polymyxa betae* (German isolate). *Journal of Plant Diseases and Protection* **115**(5): 193–198.

Nair CPR, Rajan P and Mohan C. 2005. Coconut eriopyhid mite *Aceria guerreronis* Keifer – An overview. *Indian Journal of Plant Protection* **33**(1): 1–10.

Naveed M, Salam A and Saleem MA. 2007. Contribution of cultivated crops, vegetables, weeds and ornamental plants in harboring of *Bemisia tabaci* (Homoptera: Aleyrodidae) and associated parasitoids (Hymenoptera: Aphelinidae) in cotton agroecosystem in Pakistan. *Journal of Pest Science* **80**(4): 191–197.

Nelson EC and Ristaino JB. 2011. The Potato Late Blight pathogen in Ireland, 1846: Reconnecting Irish specimens with the Moore–Berkeley correspondence. *Archives of Natural History* **38**(2): 356–359.

Norris RF and Kogan M. 2005. Ecology of interactions between weeds and arthropods. *Annual Review of Entomology* **50**(1): 479–503.

Ntidi N. 2018. Impact of weeds and nematodes on crop production. *SA Grain* **20**(8): 92–93.

Nutter FW. 2007. The role of plant disease epidemiology in developing successful integrated disease management programs. pp. 45–79. In: *General Concepts in Integrated Pest and Disease Management* (Eds. Ciancio A and Mukerji KG). Springer, The Netherlands.

Ocimati W, Were E, Groot JCJ, Pablo T, Nakato GV and Blomme G. 2018. Risks posed by intercrops and weeds as alternative hosts to *Xanthomonas campestris* pv. *musacearum* in banana fields. *Frontiers in Plant Science* **9**, 1471 Available at. PMC6192450. http://doi.org/10.3389/fpls.2018.01471.

Padmanabhan SY. 1973. The great Bengal Famine. *Annual Review of Phytopathology* **11**: 11–24.

Papayiannis LC, Katis NI, Idris AM and Brown JK. 2011. Identification of weed hosts of tomato yellow leaf curl virus in *Cyprus*. *Plant Disease* **95**(2): 120–125.

Parshad VR, Ahmad N and Malhi CS. 1991. Control of *Rattus rattus* in poultry farms: Pen and field experiments of bait selection and control of *Rattus rattus* with trapping and poison baiting in poultry farm. *Indian Poultry Review* **22**: 37–40.

Parshad VR. 1999. Rodent control in India. *Integrated Pest Management Reviews* **4**: 97–126.

Penagos DI, Magallanes R, Valle J, Cisneros J, Martinez AM, Goulson D, Chapman JW, Caballero P, Cave RD and Williams T. 2003. Effect of weeds on insect pests of maize and their natural enemies in southern Mexico. *International Journal of Pest Management* **49**(2): 155–161.

Ramachandra Prasad TV and Sanjay MT. 2016. Weeds: Importance, characteristics and classification. pp. 21–43. In: *Weed Science and Management* (Eds. Yaduraju NT, Sharma AR and Das TK). Indian Society of Weed Science, and Indian Society of Agronomy, New Delhi, India.

Ramappa HK, Muniyappa V and Colvin J. 1998. The contribution of tomato and alternative host plants to tomato leaf curl virus inoculum pressure in different areas of south India. *Annals of Applied Biology* **133**(2): 187–198.

Rao AN, Singh RG, Mahajan G and Wani SP. 2018. Weed research issues, challenges, and opportunities in India. *Crop Protection* 134 Available at. http://doi.org/10.1016/j.cropro.2018.02.003.

Rao VS. 2000. *Principles of Weed Science*. Second Edition, CRC Press, 566 p.

Rathee M and Dalal P. 2018. Emerging insect pests in Indian agriculture. *Indian Journal of Entomology* **80**(2): 267–281.

Rathore SS, Shekhawat K, Premi OP and Kandpal BK. 2012. *Major Weeds of Rapeseed–Mustard in India* (Eds. Rathore SS and Chauhan JS). All India Coordinated Research Project on Rapeseed–Mustard, ICAR–Directorate of Rapeseed–Mustard Research, Sewar, Bharatpur, India. pp 36.

Ratnadass A, Fernandes P, Avelino J and Habib R. 2012. Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: A review. *Agronomy for Sustainable Development* **32**(1): 273–303 Available at. http://doi 10.1007/s13593–011–0022–4. Springer Verlag/EDP Sciences/INRA.

Records A, Lapitan N and Bertram R. 2020. Emerging plant diseases threaten global food security. pp. 3–11. In: *Emerging Plant Diseases and Global Food Security* (Eds. Ristaino JB and Records A). The American Phytopathological Society, St. Paul, MN 55121, USA Available at. http://doi.org/10.1094/9780890546383.001.

Rhoades HL. 1964. Nutsedge, an important host of plant nematode in Florida. *Plant Disease Reporter* **48**: 994–995.

Rich JR, Brito JA, Kaur R and Ferrell JA. 2008. Weed species as hosts of *Meloidogyne*: A review. *Nematropica* **39**: 157–185.

Rodenburg J and Johnson DE. 2009. Weed management in rice–based cropping systems in Africa. *Advances in Agronomy* **103**: 149–218.

Rouxel F, Lafon R, Blancard D and Messiaen C–M. 1991. *LesMaladies des Plantes Maraîchères*. INRA, Paris. 552 p.

Rowe RC, Riedel RM and Martin MJ. 1985. Synergistic interactions between *Verticillium dahliae* and *Pratylenchus penetram* in potato early dying disease. *Phytopathology* **75**: 412–418.

Saeed R, Razaq M and Hardy ICW. 2015. The importance of alternative host plants as reservoirs of the cotton leaf hopper, *Amrasca devastans*, and its natural enemies. *Journal of Pest Science* **88**(3): 517–531.

Schmitt DP and Sipes BS. 2000. Plant–parasitic nematodes and their management. pp. 145–149. In: *Plant Nutrient Management in Hawaii's Soils, Approaches for Tropical and Subtropical Agriculture* (Eds. Silva JA and Uchida R). College of Tropical Agriculture and Human Resources, University of Hawaii, Manoa, United States.

Schroeder J, Kenney MJ, Thomas SH and Murray L. 1994. Yellow nutsedge response to southern root–knot nematodes, chile peppers, and metolachlor. *Weed Science* **42**(4): 534–540.

Schroeder J, Thomas SH and Murray LW. 2005. Impacts of crop pests on weeds and weed–crop interactions. *Weed Science* **53**(6): 918–922.

Schroeder JS, Thomas H and Murray L. 1993. Yellow and purple nutsedge and chile peppers host southern root–knot nematode. *Weed Science* **41**(1): 150–156.

Sharma S, Kooner R and Arora R. 2017. Insect pests and crop losses. pp. 45–66. In: *Breeding Insect Resistant Crops for Sustainable Agriculture* (Eds. Arora R and Sandhu S). Springer Nature Singapore Pte Ltd.

Shrestha D, McAuslane HJ, Adkins ST, Smith HA, Dufault N and Webb SE. 2016. Transmission of squash vein yellowing virus to and from cucurbit weeds and effects on sweet potato whitefly (Hemiptera: Aleyrodidae) behavior. *Environmental Entomology* **45**(4): 967–973.

Sijmons PC, Atkinson HJ and Wyss U. 1994. Parasitic strategies of root nematodes and associated host cell responses. *Annual Review of Phytopathology* **32**(1): 235–259.

Sileshi G, Schroth G, Rao MR and Girma H. 2008. Weeds, diseases, insect pests, and tri–trophic interactions in tropical agroforestry. pp. 73–94. In: *Ecological Basis of Agroforestry* (Eds. Batish DR, Kohli RK, Jose S and Singh JP), CRC Press.

Singh R. and Singh G. 2016. Aphids and their biocontrol. pp. 63–108. In: *Ecofriendly Pest Management for Food Security* (Ed. Omkar). Academic Press.

Singh SK, Khurma UR and Lockhart PJ. 2010. Weed hosts of root–knot nematodes and their distribution in Fiji. *Weed Technology* **24**(4): 607–612.

Singh SS, Rai AB, Rai MK and Kamal S. 2009. Status, constraints and strategies of integrated pest management in vegetable crops. *Progressive Horticulture* **41**(1): 46–53.

Skoracka A, Smith L, Oldfield G, Cristofaro M and Amrine JW. 2010. Host–plant specificity and specialization in eriophyoid mites and their importance for the use of eriophyoid mites as biocontrol agents of weeds. *Experimental and Applied Acarology* **51**(1–3): 93–113.

Steinkraus D, Zawislak J, Lorenz G, Layton B and Leonard R. 2003. *Spider Mites on Cotton in the Midsouth*. University of Arkansas, Division of Agriculture, Fayetteville. 8 p.

Sushilkumar and Bhan VM. 1996. Development and damage potential of *Zygogrammma bicolorata*, introduced for *Parthenium hysterophorus* control on another weed *Xanthium strumarium*. *Journal of Applied Zoological Research* **6**(2): 120–121.

Sushilkumar and Bhan VM. 1998. Imported Mexican beetle *Zygogramma bicolorata* involved in sunflower feeding controversy emerged out as a safe bioagent against *Parthenium hysterophorus* in India. pp. 135. In: *Abstract Book.* 8th Biennial Conference of Indian Society of Weed Science, February 5–7, 1999. BHU, Varanasi, India.

Sushilkumar and Duary B. 2015. *Parthenium* problem and its management in India. *Indian Farming* **65**(7): 47–51.

Sushilkumar and Ray P. 2007. Biology of *Spodoptera litura* Fabricius (Lepidoptera: Noctuidae) on some of its major weed hosts. *Entomon* **32**(4): 287–290.

Sushilkumar and Varshney JG. 2010. *Parthenium* infestation and its estimated cost management in India. *Indian Journal of Weed Science* **42**(1&2): 73–77.

Sushilkumar Dalal B and Bhan VM. 1997. Comparative study of biochemical parameters of Mexican beetle *Zygogramma bicolorata* on various hosts. pp. 88–89. In: *Proceedings* Vol. **2**, (Eds. Mahadevappa M and Patil VC). First International Conference on *Parthenium hysterophorus* Management, October 6–8, 1997, Dharwad, India.

Sushilkumar, Dalal B and Bhan VM. 1995. Host preference on the basis of biochemical profile of the Mexican beetle *Z. bicolorata* Pallister (Coleoptera: Chrysomilidae). *Weed News* **2**(2): 6–8.

Sushilkumar. 2009. Biological control of *Parthenium hysterophorus* in India: status and prospects. *Indian Journal of Weed Science* **41**(1&2): 1–18.

Sushilkumar. 2014. Spread, menace and management of *Parthenium*. *Indian Journal of Weed Science* **46**(3): 205–219.

TBI. 2019. *Plant Protection Code*. Tea Board of India (TBI), Ministry of Commerce and Industry, Government of India, Kolkata, West Bengal, India. 58 p.

Tedford EC and Fortnum BA. 1988. Weed hosts of *Meloidogyne arenaria* and *M. incognita* common in tobacco fields in South Carolina. *Annals of Applied Nematology* (*The Journal of Nematology* Supplement **20**) **2**: 102–105.

Tiwari SP and Singh BP. 1995. Spiral nematode, *Helicotylenchus*, Steiner, 1945 associated with weed flora in five district of Madhya Pradesh. *Weed News* **2(**1&2): 41–44.

Tiwari SP, Sushilkumar and Bhan VM. 1994. Plant parasitic nematodes associated with weedflora of Kymore Plateau and Satpula Hills of M.P. *Weed News* **1 (**2): 14–18.

Tiwari SP and Sushilkumar. 1996. Root-rot nematode, *Hirschmanniella oryzae* (Sottwedel, 1889) Luc and Goodey, 1963 associated with Cyperus (L). species in some rice growing districts of Madhya Pradesh, India. *Weed News* **3**(1&2): 9–14.

Thomas SH, Schroeder J and Murray LW. 2005. The role of weeds in nematode management. *Weed Science* **53**(6): 923–928.

Townshend JL and Davidson TR. 1960. Some weed hosts of *Pratylenchus penetrans* in premier strawberry plantations. *Canadian Journal of Botany* **38**(3): 267–273.

Vásquez C, Colmenárez Y, Morales–Sánchez J, Valera N, Sandoval MF and Balza D. 2015. Current and potential use of phytophagous mites as biological control agent of weeds. Intech, Creative Commons Attribution License: 109–126 Available at. http://dx.doi.org/10.5772/59953.

Velásquez AC, Castroverde CDM and He SY. 2018. Plant–pathogen warfare under changing climate conditions. *Current Biology* **28**(10): R619–R634, Cell Press Available at. http://doi.org/10.1016/j.cub.2018.03.054.

Venkatesh R, Harrison SK and Riedel RM. 2000. Weed hosts of soybean cyst nematode (*Heterodera glycines*) in Ohio. *Weed Technology* **14**(1): 156–160.

Vicente JG and Holub EB. 2013. *Xanthomonas campestris* pv. *campestris* (cause of black rot of crucifers) in the genomic era is still a worldwide threat to *Brassica* crops. *Molecular Plant Pathology* **14**(1): 2–18.

Ward NA, Schneider RW and Robertson CL. 2012. Documentation of an extended latent infection period by *Phakopsora pachyrhizi*, the soybean rust pathogen. *Plant Health Progress* **13**(1): 22.

Webb SE, Adkins S and Reitz SR. 2012. Semi–persistent whitefly transmission of squash vein yellowing virus, causal agent of viral watermelon vine decline. *Plant Disease* **96**(6): 839–844 Available at. http://doi.org/10.1094/PDIS–09–11–0761.

White NH. 1970. Weeds as Reservoirs of Plant Diseases. University of Sydney, New South Wales: 4(a)5–4(a)6.

Wisler GC and Norris RF. 2005. Interactions between weeds and cultivated plants as related to management of plant pathogens. *Weed Science* **53**(6): 914–917.

Yaduraju NT and Mishra JS. 2018. Integrated weed management for doubling farmers' income. *Indian Farming* **68**(11): 9–12.

Yaduraju NT, Sharma AR and Rao AN. 2015. Weeds in Indian agriculture: Problems and prospects to become self–sufficient. *Indian Farming* **65**(7): 2–6.

Yandoc–Ables CB, Rosskopf EN and Charudattan R. 2006. *Plant Pathogens at Work: Progress and Possibilities for Weed Biocontrol. Part 1: Classical vs. Bioherbicidal Approach* Available at. http://www.apsnet.org/publications /apsnetfeatures/Pages/WeedBiocontrolPart1.aspx.

Indian Journal of Weed Science **53**(1): 30–35, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Sesbania, Azolla and herbicide use for weed management and optimizing yield in direct-seeded rice

Suryendra Singh*, S. Elamathi[1], Gautam Ghosh and N.S. Abeysingha[2]

Department of Agronomy, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS), Prayagraj, Uttar Pradesh 211007, India

[1]Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641003, India

[2]Rajarata University of Sri Lanka, Puliyankulama, Anuradhapura, Sri Lanka

**Email: suryendra_aligarh@yahoo.com*

Article information

DOI: 10.5958/0974-8164.2021.00003.4

Type of article: Research article

Received : 30 September 2020
Revised : 19 February 2021
Accepted : 22 February 2021

Key words
Azolla
Direct-seeded rice
Grain yield
Sesbania
Weed smothering efficiency

ABSTRACT

The experiment was conducted at Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (U.P.) during *Kharif* seasons of 2009 and 2010 to assess the performance of direct-seeded rice as influenced by *Sesbania*/ *Azolla* with nitrogen levels and herbicide use for managing weeds and optimizing the yield of direct-seeded rice (DSR). Weed density and dry weight were consistently lower with *Azolla* culture than with *Sesbania* during initial crop growth stages, however, they were similar at 90 days after sowing (DAS). Among weed management practices, pretilachlor (with safener) at 0.3 kg /ha at 2 DAS as pre-emergence application followed by (*fb*) hand weeding (HW) at 45 DAS was effective in controlling weeds and increasing the grain yield of DSR, which resulted in higher net returns and benefit cost ratio than HW twice at 20 and 45 DAS. The higher yields were recorded under *Sesbania* and *Azolla* than DSR (sole) crop. *Sesbania Azolla* + 100% recommended dose of nitrogen with pretilachlor (with safener) 0.3 kg /ha at 2 DAS as pre-emergence application *fb* HW at 45 DAS recorded lower weeds density, dry weight and higher economic returns in direct-seeded rice.

INTRODUCTION

Water crises and shortage of labour at critical times as well as hike in wage rates (Mishra *et al.* 2019), threatens the sustainability of transplanted rice in India. Direct-seeded rice (DSR) system has various advantages over transplanted rice in terms of less water (35-57%) and labour (up to 67%) requirement (Choudhary 2018, Arya and Syriac 2018). However, performance of DSR depends on effective weed control (Brar and Bhullar 2012), because there is no seedling size advantage as in transplanted rice and weed seedlings and crop plants emerge concurrently as well as no standing water to conquest weed emergence and growth at crop emergence. Weeds in DSR can cause a huge yield loss (up to 95%) in India (Choudhary 2018). Manual weeding is becoming less common because of not availability of labor at critical time and increased labour costs (Choudhary 2018, Arya and Syriac 2018, Mishra *et al.* 2019). Herbicides are replacing manual weeding as they are easy to use, economical and practicable; however, there are also worries about the sole use of herbicides, such as evolution of herbicide resistance in weeds, shifts in weed populations, and concerns about the environment (Arya and Syriac 2018).

Raising *Sesbania* or *Azolla* conjointly with DSR, and incorporating them at 35-40 days of growth has revealed increase in rice yield and profitability with assured adding of organic matter and weed suppression (Singh Kumarjit *et al.* 2005, Ravisankar *et al.* 2008, Anitha and Mathew 2010, Subramanian *et al.* 2011). Though, the potential for exploiting *Sesbania*/ *Azolla* to smother or suppress weeds and the efficacy of herbicide are needed to formulate integrated weed management strategies in DSR. Therefore, this study was conducted to compare the effects of *Sesbania*, *Azolla* and herbicide use in DSR (drum seeded unpuddled) for managing weeds and optimizing the yield.

MATERIALS AND METHODS

The experiment was conducted during rainy (*Kharif*) seasons of 2009 and 2010 at the Crop Research Farm of Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj

(U.P.) India. The annual average rainfall and temperature of the region range from 1000 to 1200 mm and from 5^0C to 45^0C, respectively. The soil was sandy loam in texture with pH 8.4; organic carbon 0.54%; available N 208.3, P 15.9 and K 186.6 kg/ha.

The experiment was laid out in a split-plot design and replicated thrice. The main plots treatments included combinations of rice plating systems and nitrogen levels while, weed management practices were taken as the sub-plots treatments. The rice planting systems included were: transplanted rice (TPR), DSR (sole), DSR + *Sesbania* (brown manuring) and DSR + *Azolla*. The nitrogen levels were 100% recommended dose of nitrogen (RDN) and 75% RDN. The weed management practices in the sub-plots treatments were: no weeding, pretilachlor (with safener) 0.3 kg/ha at 2 DAS as pre-emergence application followed by (*fb*) hand weeding (HW) at 45 DAS and HW twice at 20 and 45 DAS. The preparation of field was done according to the planting systems/treatments during both the years. After preparation of the field, direct-seeding of rice (50 kg seed/ha) was done using a drum seeder in rows 20 cm apart. The plots were kept in saturated condition at the time of sowing and for next ten days in case of DSR while, in transplanted rice, a thin film of water was maintained at the time of transplanting. Later irrigation was applied periodically.

The N was applied 150 kg/ha in three splits, ½ as basal and the remainder in two equal splits; one half at tillering (42 DAS) and the remaining at panicle initiation stage (65 DAS) as top dressing. Both P and K 60 kg/ha and zinc 25 kg/ha as $ZnSO_4$ were broadcasted and mixed in all plots uniformly before rice sowing/transplanting. In treatments, DSR + *Sesbania* + 100% RDN and DSR + *Sesbania* + 75% RDN, *Sesbania* seed 25 kg/ha was uniformly broadcasted after rice seeding and was controlled by spraying 2, 4-D 500 g/ha at 37 days after sowing (DAS). In treatments DSR + *Azolla* + 100% RDN and DSR + *Azolla* + 75% RDN, the *Azolla* at 200 kg/ha was uniformly broadcasted after a week of rice sowing. In the sub-plots treatment, pretilachlor (with safener) was applied as pre-emergence using a knap-sack sprayer fitted with a flat-fan nozzle in a spray volume of 600 L/ha. Weed density and dry weight data were collected at 30, 60, and 90 DAS. Weed count, for estimating weed density, was recorded with the help of a quadrate (0.5 x 0.5 m) placed randomly at two spots in each plot. Weeds were cut at ground level, washed with tap water, dried at 70 ºC for 48 hours, and then weighed and this data was subjected to square-root $\sqrt{x+0.5}$ transformation to normalize its distribution prior to statistical analysis. Weed smothering efficiency was worked out as per the standard formula (Mani *et al.* 1973) at 30 DAS. Grain and straw yields were taken from a 4.2 m^2 area in the center of each plot and expressed in t/ha at 14% moisture. The data was analyzed statistically and least significant difference (LSD) was used to compare the treatment means at 5% probability level (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Weed flora

The common weeds infested the experimental field included grasses *Digitaria sanguinalis* (8.39%), *Echinochloa crus-galli* (12.69%), *Echinochloa colona* (16.57%), *Panicum repens* (5.94%) and broad-leaved weeds *Commelina benghalensis* 11.99%), *Digera arvensis* (13.04%), *Convolvulus arvensis* (3.29%) and *Cyperus rotundus* (8.42%), *Cyperus esculentus* (5.57%) and *Fimbristylis miliacea* (14.10%) among the sedges.

Weeds density and dry weight

Sesbania and *Azolla* significantly (p=0.05) reduced grass and broad-leaved weeds as well as total weeds density and dry weight (**Table 1** and **2**). DSR with *Sesbania* or *Azolla* recorded significantly lower density of grass and broad-leaved weeds compared to DSR (sole) in 2009 and 2010 at 30, 60 and 90 DAS. Among the weed management practices, significantly highest grass and broad-leaved weeds count was recorded in weedy check plots, whereas, the lowest weed density was recorded in pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS except at 30 DAS as weeding was done on 10 days before the count of weeds in HW twice treatment (**Table 1**).

The total weed density decreased up to 90 DAS in DSR in sequence with *Sesbania* or *Azolla* and both recorded significantly lower density and dry weight than DSR (sole) in 2009 and 2010 at 30, 60 and 90 DAS. DSR (sole) recorded higher total weed density and dry weight than with *Sesbania* or *Azolla* (**Table 2**). The densities of grass and broad-leaved weeds as well as total weed dry weight were consistently lower with *Azolla* (**Table 1** and **2**), being similar to *Sesbania*. This is consistent with the findings of Ravisankar *et al.* (2008), except that at later stage (90 DAS) the dry weight of weeds with *Sesbania* and *Azolla* did not differ in present study. In comparison to DSR (sole), *Sesbania* or *Azolla* alone caused a considerable reduction in total weeds density and dry weight at 60 DAS. At 60 DAS, *Azolla* with 100% RDN reduced the total weed density to the extent of

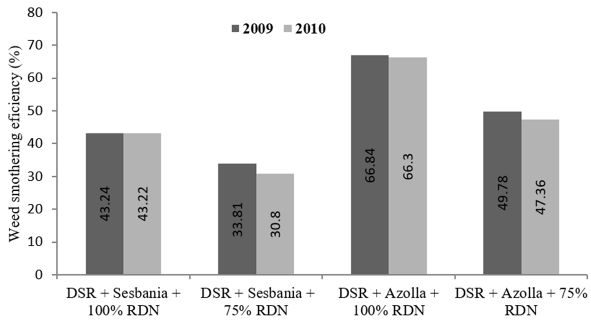


Figure 1. Weed smothering efficiency as influenced by dual culture in direct-seeded rice

81% (**Table 2**), which could be due to the covered surface of rice field, reduces photosynthetic activity of weeds by intercepting light (Anitha *et al*. 2012). In this study, *Azolla* proved to be as effective as *Sesbania* in weed-suppressing ability. *Azolla* this way also did not require additional irrigation and labour for incorporation and also recorded higher weed smothering efficiency (**Figure 1**).

The no-weeding treatment recorded significantly (p=0.05) maximum total weeds density and dry weight (**Table 2**). Total weeds density was lower with pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS, which reduced the total weeds density by 86%in 2010 at 60 DAS. Hand weeding twice at 20 and 45 DAS gave around 81% reduction in weeds density at 60 DAS during both the years compared to no weeding. The weeds dry weight also followed the same trend, however; HW twice was not equally effective in reducing total weeds dry weight. Pretilachlor (with safener) is known to control of grasses followed by broad-leaved weeds and sedges (Suganthi *et al*. 2005, Ravisankar *et al*. 2008).

Effect on rice yield

The DSR in sequence with *Sesbania* and *Azolla* being at par recorded significantly higher yields than DSR (sole) (**Table 3**). DSR with *Sesbania* and 100% RDN recorded 20.9% and 15.3% higher yield in 2009 and 2010, respectively than DSR (sole). Contrary to the earlier study that intercropping of *Sesbania* with rice can cause rice yield loss (Mathew and Alexander 1995), our study revealed that there was a beneficial effect mainly due to weed suppression. It supports findings of Singh *et al.* (2007). (Gupta *et al.* 2006)

Table 1. Effect of planting systems of rice with nitrogen levels and weed management practices on density of grass and broad-leaved weeds in direct-seeded rice

Treatment	Grass weeds (no./m²)						Broad-leaved weeds (no./m²)					
	30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Planting systems with nitrogen levels												
M_1N_1-TPR + 100% RDN	4.22 (18.3)	3.96 (16.0)	3.71 (19.1)	3.32 (15.8)	3.52 (17.9)	3.19 (15.0)	3.46 (12.8)	3.21 (11.3)	3.03 (14.2)	2.82 (12.1)	2.84 (12.9)	2.52 (10.2)
M_1N_2-TPR + 75% RDN	4.75 (23.5)	4.44 (20.4)	4.23 (23.4)	3.79 (19.7)	3.97 (21.5)	3.61 (17.9)	3.81 (15.2)	3.59 (13.7)	3.89 (21.4)	3.44 (17.3)	3.62 (20.0)	3.17 (15.9)
M_2N_1-DSR (sole) + 100% RDN	9.15 (92.5)	8.45 (78.3)	9.47 (120.7)	8.62 (99.7)	9.20 (116.0)	8.48 (99.1)	8.66 (77.1)	7.60 (60.7)	8.59 (89.4)	7.61 (70.9)	8.32 (84.8)	7.62 (73.0)
M_2N_2-DSR (sole) + 75% RDN	8.70 (83.5)	8.10 (72.7)	9.15 (112.7)	8.24 (91.7)	8.92 (109.7)	8.24 (93.9)	8.09 (68.2)	7.34 (56.8)	7.77 (73.4)	6.93 (58.5)	7.52 (69.8)	6.88 (60.1)
M_3N_1-DSR +*Sesbania* + 100% RDN	7.70 (63.2)	7.06 (53.9)	6.82 (54.0)	6.14 (43.8)	6.50 (49.3)	5.98 (41.8)	7.18 (53.7)	6.58 (45.5)	6.15 (41.0)	5.42 (32.0)	5.93 (38.7)	5.40 (32.8)
M_3N_2-DSR + *Sesbania* + 75% RDN	6.84 (58.7)	6.81 (50.1)	6.54 (50.5)	5.92 (41.1)	6.20 (45.7)	5.74 (39.1)	6.57 (45.7)	6.12 (40.4)	5.61 (35.3)	4.92 (27.3)	5.33 (32.4)	4.84 (27.4)
M_4N_1-DSR + *Azolla* + 100% RDN	6.84 (51.2)	6.36 (44.7)	5.94 (44.0)	5.33 (35.7)	5.60 (39.8)	5.16 (33.8)	5.31 (31.9)	5.05 (28.7)	4.65 (26.4)	4.10 (20.7)	4.33 (24.1)	3.92 (20.1)
M_4N_2-DSR + *Azolla* + 75% RDN	7.13 (54.9)	6.66 (48.5)	6.24 (47.1)	5.65 (38.5)	5.93 (42.9)	5.43 (36.2)	5.88 (36.9)	5.41 (32.1)	5.03 (29.5)	4.42 (23.0)	4.59 (26.0)	4.20 (22.2)
LSD (p=0.05)	0.33	0.27	0.31	0.29	0.34	0.29	0.77	0.72	0.76	0.67	0.68	0.58
Weed management												
Pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS	6.69 (46.0)	5.98 (36.4)	3.92 (16.5)	3.43 (12.7)	3.59 (13.8)	3.29 (11.5)	5.79 (36.6)	5.02 (26.9)	3.45 (13.9)	2.92 (9.6)	3.10 (11.5)	2.61 (7.9)
HW twice at 20 and 45 DAS	4.70 (22.7)	4.40 (19.9)	4.28 (19.3)	3.89 (16.1)	4.05 (17.5)	3.68 (14.5)	4.56 (23.6)	4.02 (17.9)	4.12 (18.7)	3.71 (15.3)	3.83 (16.5)	3.46 (13.7)
No weeding	9.57 (98.4)	9.05 (87.9)	11.34 (141.0)	10.30 (115.9)	11.05 (134.7)	10.22 (115.3)	8.01 (67.9)	7.76 (63.6)	9.19 (91.4)	8.24 (73.3)	9.00 (87.7)	8.39 (76.6)
LSD (p=0.05)	0.32	0.18	0.25	0.22	0.22	0.19	0.28	0.18	0.42	0.36	0.42	0.38

M_1= Transplanted rice; M_2= DSR (sole); M_3= DSR + *Sesbania*; M_4= DSR + *Azolla*; N_1= 100% RDN; N_1= 75% RDN; TPR: Transplanted rice, RDN: Recommended dose of nitrogen, DSR: Direct-seeded rice, DAS: Days after sowing, *fb*: followed by, HW: Hand weeding, no.: numbers, Data were subjected to square root ($\sqrt{x+0.5}$); the figures in the parentheses are original values

Table 2. Effect of planting systems of rice with nitrogen levels and weed management practices on total weeds density and dry weight of weeds in direct-seeded rice

Treatment	Total weed density (no./m^2)						Weeds dry weight (g/m^2)					
	30 DAS		60 DAS		90 DAS		30 DAS		60 DAS		90 DAS	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Planting systems with nitrogen levels												
M_1N_1-TPR+100% RDN	7.58 (61.2)	6.99 (52.3)	6.94 (64.7)	6.19 (52.9)	6.56 (59.7)	5.92 (49.9)	2.84 (10.9)	2.67 (9.5)	3.83 (16.7)	3.58 (14.6)	5.80 (37.0)	5.43 (32.8)
M_1N_2-TPR+75% RDN	8.27 (72.1)	7.66 (62.3)	7.81 (78.9)	6.94 (64.4)	7.34 (72.8)	6.67 (61.3)	3.28 (14.3)	3.10 (12.7)	4.48 (23.5)	4.21 (20.9)	6.17 (41.3)	5.90 (38.1)
M_2N_1-DSR (sole)+100% RDN	15.43 (250.8)	13.84 (205.1)	15.46 (299.5)	13.93 (244.1)	14.99 (286.0)	13.85 (246.0)	8.21 (81.4)	7.66 (72.1)	9.40 (109.7)	9.05 (101.8)	12.35 (195.0)	11.89 (183.0)
M_2N_2-DSR (sole)+75% RDN	15.20 (244.9)	13.40 (193.0)	14.67 (270.9)	13.16 (218.3)	14.25 (259.8)	13.15 (223.1)	7.07 (60.4)	6.52 (51.2)	8.91 (99.7)	8.58 (92.4)	12.01 (186.8)	11.57 (175.4)
M_3N_1-DSR+ *Sesbania*+100% RDN	13.18 (182.0)	11.98 (153.2)	11.56 (151.4)	10.32 (121.1)	11.03 (139.7)	10.05 (116.2)	5.99 (46.2)	5.63 (40.9)	5.92 (36.8)	5.69 (33.8)	7.94 (69.8)	7.60 (64.5)
M_3N_2-DSR+ *Sesbania*+75% RDN	12.57 (166.5)	11.43 (140.5)	10.94 (138.2)	9.78 (110.5)	10.44 (127.0)	9.52 (106.1)	5.49 (40.0)	5.15 (35.4)	5.31 (29.2)	5.12 (27.1)	7.44 (60.5)	7.12 (55.9)
M_4N_1-DSR+ *Azolla*+100% RDN	11.36 (138.5)	10.37 (118.1)	9.85 (116.9)	8.80 (93.4)	9.34 (106.9)	8.50 (88.3)	4.42 (27.0)	4.18 (24.3)	4.37 (20.5)	4.19 (18.8)	6.81 (52.1)	6.53 (48.3)
M_4N_2-DSR+ *Azolla*+75% RDN	11.92 (150.4)	10.95 (129.7)	10.39 (127.1)	9.26 (101.0)	9.84 (115.4)	8.95 (96.0)	4.74 (30.3)	4.48 (27.0)	4.87 (25.3)	4.66 (23.0)	7.09 (56.0)	6.76 (51.8)
LSD (p=0.05)	0.71	0.62	0.52	0.47	0.46	0.39	0.75	0.63	0.71	0.71	0.60	0.61
Weed management												
Pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS	11.53 (140.5)	9.79 (99.2)	6.88 (50.7)	5.98 (38.5)	6.35 (43.5)	5.69 (34.9)	4.91 (26.6)	4.70 (24.2)	3.84 (15.6)	3.72 (14.7)	5.56 (31.9)	5.13 (27.1)
HW twice at 20 and 45 DAS	8.64 (78.8)	7.76 (63.3)	7.78 (64.4)	7.03 (52.8)	7.34 (57.8)	6.68 (48.3)	2.03 (5.0)	1.82 (3.8)	4.94 (25.6)	4.66 (22.8)	6.24 (40.6)	5.98 (37.4)
No weeding	15.64 (255.7)	14.92 (232.9)	18.20 (352.8)	16.39 (285.9)	17.73 (336.3)	16.35 (286.8)	8.82 (84.9)	8.25 (74.3)	8.88 (94.3)	8.52 (87.2)	12.80 (189.4)	12.44 (179.2)
LSD (p=0.05)	0.49	0.22	0.32	0.30	0.34	0.29	0.56	0.53	0.45	0.43	0.43	0.43

M_1= Transplanted rice; M_2= DSR (sole); M_3= DSR + *Sesbania*; M_4= DSR + *Azolla*; N_1= 100% RDN; N_1= 75% RDN; TPR: Transplanted rice, RDN: Recommended dose of nitrogen, DSR: Direct-seeded rice, DAS: Days after sowing, *fb*: followed by, HW: Hand weeding, no.: numbers, Data were subjected to square root ($\sqrt{x + 0.5}$); the figures in the parentheses are original values

Table 3. Effect of planting systems of rice with nitrogen levels and weed management practices on grain and straw yields (t/ha) as well as economic returns of direct-seeded rice

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Cost of cultivation (x10^3 `/ha)		Gross income (x10^3 `/ha)		Net returns (x10^3 `/ha)		B:C ratio	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Planting systems with nitrogen levels												
M_1N_1-TPR + 100% RDN	3.88	4.27	6.95	7.26	39.7	39.7	68.3	74.3	28.6	34.6	1.72	1.87
M_1N_2-TPR + 75% RDN	3.73	4.11	6.83	7.02	39.2	39.2	65.9	71.5	26.7	32.3	1.68	1.82
M_2N_1-DSR (sole) + 100%RDN	3.15	3.72	6.29	6.73	31.9	31.9	56.7	65.6	24.8	33.6	1.77	2.05
M_2N_2-DSR (ole) + 75% RDN	2.99	3.52	5.98	6.45	31.4	31.4	53.8	62.3	22.4	30.8	1.71	1.98
M_3N_1-DSR + *Sesbania* + 100% RDN	3.81	4.29	6.80	7.00	33.0	33.0	66.9	74.0	33.8	41.0	2.02	2.24
M_3N_2-DSR + *Sesbania* + 75% RDN	3.66	4.05	6.61	6.81	32.5	32.5	64.5	70.3	32.0	37.7	1.98	2.16
M_4N_1-DSR + *Azolla* + 100% RDN	3.76	4.18	6.79	6.85	32.9	32.9	66.3	72.2	33.4	39.3	2.01	2.19
M_4N_2-DSR + *Azolla* + 75% RDN	3.64	3.98	6.66	6.74	32.4	32.4	64.3	69.2	31.9	36.8	1.98	2.13
LSD (p=0.05)	0.21	0.39	0.40	0.83	-	-	-	-	-	-	-	-
Weed management												
Pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS	4.43	5.20	7.79	8.25	38.2	38.2	77.6	89.3	39.3	51.1	2.02	2.33
HW twice at 20 and 45 DAS	4.24	4.70	7.55	7.83	41.3	41.3	74.6	81.4	33.2	40.1	1.80	1.96
No weeding	2.06	2.15	4.50	4.50	34.1	34.1	37.9	39.1	38.1	49.6	1.11	1.14
LSD (p=0.05)	0.19	0.15	0.20	0.44	-	-	-	-	-	-	-	-

M_1= Transplanted rice; M_2= DSR (sole); M_3= DSR + *Sesbania*; M_4= DSR + *Azolla*; N_1= 100% RDN; N_1= 75% RDN; TPR: Transplanted rice, RDN: Recommended dose of nitrogen, DSR: Direct-seeded rice, DAS: Days after sowing, *fb*: followed by, HW: Hand weeding; selling price of rice = 14000/t, selling price of strow = 2000/t

Table 4. Grain yield, gross realization, cost of cultivation, net realization and benefit cost ratio of direct-seeded rice as per the treatment combinations

Treatment	Grain yield (t/ha)		Gross realization ($x10^3$`/ ha)		Cost of cultivation ($x10^3$`/ ha)		Net realization ($x10^3$`/ ha)		B:C ratio	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
$M_1N_1W_1$	2.52	2.85	45.3	50.4	39.7	39.7	5.6	10.7	1.14	1.27
$M_1N_1W_2$	4.64	5.31	81.1	91.5	43.7	43.7	37.3	47.7	1.85	2.09
$M_1N_1W_3$	4.49	4.65	78.4	81.1	46.9	46.9	31.5	34.2	1.67	1.72
$M_1N_2W_1$	2.35	2.65	42.7	47.0	39.2	39.2	3.5	7.8	1.08	1.20
$M_1N_2W_2$	4.47	5.16	78.4	89.0	43.2	43.2	35.1	45.7	1.81	2.05
$M_1N_2W_3$	4.38	4.51	76.7	78.6	46.4	46.4	30.3	32.2	1.65	1.69
$M_2N_1W_1$	1.57	1.80	30.4	33.1	31.9	31.9	1.43	1.2	0.95	1.03
$M_2N_1W_2$	4.05	4.92	71.6	85.8	36.0	36.0	35.6	49.8	1.99	2.38
$M_2N_1W_3$	3.83	4.44	68.2	77.8	39.1	39.1	29.0	38.7	1.74	1.98
$M_2N_2W_1$	1.39	1.72	27.4	31.5	31.4	31.4	-4.0	0.07	0.87	1.00
$M_2N_2W_2$	3.93	4.60	69.5	80.6	35.5	35.5	34.0	45.0	1.95	2.26
$M_2N_2W_3$	3.65	4.23	64.6	74.5	38.6	38.6	26.0	35.9	1.67	1.92
$M_3N_1W_1$	2.33	2.26	41.6	41.1	33.0	33.0	8.6	8.1	1.26	1.24
$M_3N_1W_2$	4.62	5.54	80.9	94.2	37.1	37.1	43.7	57.0	2.17	2.53
$M_3N_1W_3$	4.47	5.06	78.2	86.8	40.2	40.2	38.0	46.6	1.94	2.15
$M_3N_2W_1$	2.08	1.94	38.2	36.3	32.5	32.5	5.6	3.7	1.17	1.11
$M_3N_2W_2$	4.54	5.36	79.1	91.0	36.6	36.6	42.4	54.4	2.15	2.48
$M_3N_2W_3$	4.37	4.84	76.4	83.6	39.7	39.7	36.6	43.9	1.92	2.10
$M_4N_1W_1$	2.25	2.02	40.7	37.1	32.9	32.9	7.8	4.1	1.23	1.12
$M_4N_1W_2$	4.61	5.45	80.5	92.8	37.0	37.0	43.5	55.8	2.17	2.50
$M_4N_1W_3$	4.42	5.07	77.6	86.8	40.1	40.1	37.4	46.7	1.93	2.16
$M_4N_2W_1$	2.02	1.94	37.1	36.1	32.4	32.4	4.7	3.6	1.14	1.11
$M_4N_2W_2$	4.55	5.24	79.4	89.7	36.5	36.5	42.9	53.2	2.17	2.45
$M_4N_2W_3$	4.36	4.76	76.4	81.9	39.6	39.63	36.8	42.2	1.92	2.06
LSD (p=0.05)	NS	0.43	-	-	-	-	-	-	-	-

M_1= Transplanted rice; M_2= DSR (sole); M_3= DSR + *Sesbania*; M_4= DSR + *Azolla*; N_1= 100% RDN; N_1= 75% RDN; W_1= No weeding; W_2= pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS; W_3= HW twice at 20 and 45 DAS, Selling price of paddy = 1400/ quintal, Selling price of straw = 200/ quintal

reported that co-culture of *Sesbania* in rice and its subsequent knock down by 2,4-D-ester reduced the weed population by nearly half without any adverse effect on rice yield. When *Sesbania* seed is not readily available, farmers can opt for growing *Azolla* with direct-seeded rice up to 37 DAS. The dual culture of *Azolla* provides an alternative to *Sesbania* with respect to environmental fate of herbicides use. DSR intercropped with *Sesbania rostrata* or *Azolla microphylla* combined with physical incorporation at 37 DAS, suppressed weeds effectively and resulted in comparable yields with transplanted rice.

The rice grain yield with the pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS treatment was significantly higher in 2009 and 2010 (4.5 to 10.6%) than with the HW twice at 20 and 45 DAS. The efficacy of pretilachlor (with safener) in combination with HW in controlling weeds in wet-seeded rice was reported by (Ravisankar *et al.* 2008). The interaction was significant only in 2010. Such yield advantages might be due to weed free environment from beginning and supply of nutrients in soil after decomposition of these dual crops which resulted in increased test weight and yield (Majhi *et al.* 2009)

Economics

Economic analysis showed that *Sesbania* and *Azolla* were equally good in realizing higher economic returns (**Table 3**), in spite of variation in the cost of *Sesbania* (INR1125/ha) and *Azolla* (INR1000/ha), whereas, it was lower in DSR (sole) crop. Amongst weed management practices, the net returns with pretilachlor (with safener) 0.3 kg/ha at 2 DAS *fb* HW at 45 DAS were higher than with the HW twice at 20 and 45 DAS because of the lower cost of the herbicide-based weed control method. Among the interaction effect, the highest net realization (INR43674 and 56982/ha) and B:C ratios (2.17 and 2.53) were recorded in DSR + *Sesbania* + 100% RDN coupled with pretilachlor (with safener) 0.3 kg/ ha at 2 DAS as pre-emergence application *fb* HW at 45 DAS in 2009 and 2010 respectively (**Table 4**).

Thus, it was concluded that, DSR with *Sesbania* or *Azolla* + 100% RDN with pretilachlor (with safener) 0.3 kg/ha at 2 DAS as pre-emergence application *fb* HW at 45 DAS recorded lower weeds density, dry weight and profitable grain yield and it might be recommended to the farmers for getting optimum yield with higher farm income.

REFERENCES

Anitha S and Mathew J. 2010. Direct and residual effect of concurrent growing of *dhaincha* (*Sesbania aculeate*) in wet-seeded rice (*Oryza sativa*) on the productivity of rice – rice cropping system. *Indian Journal of Agricultural Sciences* **80**(6): 34–37.

Anitha S, Mathew J, Abraham CT. 2012. Concurrent growing of green manure with wet seeded rice for cost-effective weed management. *Indian Journal of Agricultural Sciences* **44**(1): 487–492.

Arya SR and Syriac Elizabeth K. 2018. Bioefficacy of flucetosulfuron in wet-seeded rice. *Indian Journal of Weed Science* **50**(2): 103–107.

Brar HS and Bhullar MS. 2012. Dry-seeded rice productivity in relation to sowing time, variety and weed control. *Indian Journal of Weed Science* **44**(3): 193–195.

Choudhary VK.and Dixit Anil. 2018. Herbicide weed management effect on weed dynamics, crop growth and yield in direct-seeded rice. *Indian Journal of Weed Science* **50**(1): 6–12.

Gomez KA, Gomez A. 1984. *Statistical Procedures for Agricultural Research* (Second Edition). Wiley India (P) Ltd., New Delhi. 139p.

Gupta R, Jat ML, Singh Samar, Singh VP, Sharma RK. 2006. Resource conservation technologies for rice production. *Indian Farming* **56**(7): 42–45.

Majhi Shushama, Thakur R, Upasani RR, Singh MK and Pal SK. 2009. Growth and productivity of direct seeded upland rainfed rice as influenced by integrated weed management *Indian Journal of Weed Science* **41**(3&4): 160–162.

Mani VS, Pandita ML, Gautam KC and Das B. 1973. Weed killing chemicals in potato cultivation. *Indian Farming* **23**: 7–13.

Mathew G, Alexander D. 1995. Influence of intercropped green manure crops on weed pressure and grain yield of semi-dry rice. *Madras Agricultural Journal* **82**: 66–67.

Mishra JS, Kumar Rakesh, Saurabh Kirti and Bhatt BP. 2019. *Conservation Agriculture for Climate Resilient Farming & Doubling Farmers' Income*. ICAR Research Complex for Eastern Region, Patna, 246p.

Ravisankar N, Chandrasekaran B, Raja R, Din M and Ghoshal Chaudhuri S. 2008. Influence of integrated weed-management practices on productivity and profitability of wet-seeded rice. *Indian Journal of Agronomy* **53**(1): 57–61.

Singh Kumarjit RK, Athokpam Herojit Singh and Changte Zoliana. 2005. Integrated management of *Azolla*, vermicompost and urea on yield of and nutrient uptake by rice and soil fertility. *Journal of the Indian Society of Soil Science* **53**(1): 107–110.

Singh Samar, Ladha JK, Gupta RK, Bhushan Lav, Rao AN, Sivaprasad B, Singh PP. 2007. Evaluation of mulching, intercropping with *Sesbania* and herbicide use for weed management in dry seeded rice. *Crop Protection* **26**: 518–524.

Subramanian E, James Martin G, Rajakumar D, and Durai Singh R. 2011. Weed and nitrogen management through inorganic and companion crops for drum-seeded wet rice. *International Rice Research Notes* **36**: 1–4.

Suganthi M, Kandasamy OS, Subbian P and Jayakumar R. 2005. Rlative efficacy of pretilachlor 50 EC for weed control in lowland transplanted rice-rice cropping system. *Indian Journal of Weed Science* **37**(1-2): 105–106.

Indian Journal of Weed Science **53**(1): 36–40, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Indian Journal of Weed Science

Weed dynamics, crop growth and yield as affected by different weed management practices and plant growth-promoting rhizobacteria in direct-seeded upland rice

Jimni Phukan* and Jayanta Deka

College of Agriculture, Assam Agricultural University, Jorhat, Assam 785013, India

**Email: jimniphukan2016@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00004.6

Type of article: Research article

Received : 25 June 2020
Revised : 30 November 2020
Accepted : 2 December 2020

Key words

Direct-seeded upland rice

Plant Growth-promoting Rhizobacteria

Pretilachlor

Pseudomonas fluorescens

Weed dynamics

ABSTRACT

Effect of different weed management practices and plant growth-promoting rhizobacteria (PGPR) were evaluated in Jorhat (Assam) on weed dynamics, crop growth and yield in direct-seeded upland rice during 2018 and 2019. Results revealed that density and dry weight of weeds were the lowest with *Pseudomonas fluorescens* among PGPR treatments. The growth and yield attributing characters were significantly improved due to *P. fluorescens* contributing to the highest grain and straw yield of rice. Single application of pretilachlor pre-emergence 0.75 kg/ha or application of pretilachlor pre-emergence 0.75 kg/ha followed by one hand weeding at 30 DAS resulted in least density and dry weight of weeds at initial stages of crop growth. The lowest values were recorded in three hand weedings done at 15, 30 and 45 DAS. Better growth and yield attributing characters of rice with three hand weedings at 15, 30 and 45 DAS resulted in the highest grain and straw yields. Combination of *P. fluorescens* with either three hand weedings at 15, 30 and 45 DAS or pretilachlor pre-emergence 0.75 kg/ha followed by one hand weeding at 30 DAS was found to be superior with grain and straw yields along with similar trend in gross and net returns. However, the benefit: cost ratio was the highest in the combination of *P. fluorescens* with pretilachlor pre-emergence at 0.75 kg/ha followed by one hand weeding at 30 DAS.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important staple food crops in the world and it occupies a pivotal position in the food security system in India. Direct-seeded rice (DSR) serves several advantages *i.e.* saves labour, helps faster, easier and timely planting, less drudgery, early crop maturity by 7-10 days, less water requirement, high tolerance to water deficit, often high yield, low production cost, more profit and less methane emission (Balasubramanian and Hill 2002). Weed management is the major challenge towards the success of this crop as weeds are comparatively denser in this system than in transplanted situation, because of simultaneous emergence of rice and weeds due to the absence of standing water at the early stage of rice growth (Chauhan 2012) and they compete with crop for nutrients, light, space and moisture. The extent of yield reduction of rice due to weeds has been estimated up to 95% in India (Naresh *et al.* 2011). Weed control constitutes one of the major input costs of crop production. Manual control of weeds is considered to be the best but it is labour intensive, tedious and back breaking.

It is suggested to use pre-emergence herbicides in DSR to prevent the simultaneous emergence of the weeds with rice and to provide competitive advantage to the crop under relatively weed free condition. Integrated weed management, combining herbicide and other means is essential for effective weed management as one single application of a pre-emergence herbicide cannot facilitate a competition-free environment during critical growth period of upland direct seeded rice. Plant growth promoting rhizobacteria (PGPR) is the bacterium that improves plant growth by inoculating seeds, roots or soil through various mechanisms. An improved growth and vigour of the crop might indirectly help in suppressing the associated weeds. Keeping in view the above issues, this study was conducted with the objectives of studying the performance of plant growth-promoting rhizobacteria and weed management practices on crop growth and yield of rice.

MATERIALS AND METHODS

A field study was conducted during autumn rice season from March to July *(ahu)*, 2018 and 2019 at Assam Agricultural University, Jorhat (Assam). The soil of the experimental site was sandy loam in texture, acidic in reaction (pH: 5.5), medium in organic carbon (0.54%), low in available N (191 kg/ha), available P (22.28 kg/ha) and available K (107.05 kg/ha). Seeds of rice variety '*Inglongkiri*' (100-110 days duration) 75 kg/ha were sown in rows 20 cm apart in individual plots of 4 x 3 m size during both the years. Crop was applied with 40:20:20 of N:P:K kg/ha. Nitrogen was applied in 3 split doses *i.e.*, ½ of N was applied in final ploughing, ¼ at active tillering stage and remaining ¼ at panicle initiation stage. All the phosphatic and potassic fertilizers were applied during final land preparation. The experiment was laid out in factorial randomized block design with three replications. The treatments consisted of three PGPR inoculations, *viz*.; *Bacillus cereus*, *Pseudomonas fluorescens* and no inoculation and four weed management practices, *viz*.; pretilachlor pre-emergence at 0.75 kg/ha, pretilachlor pre-emergence at 0.75 kg/ha followed by one hand weeding at 30 DAS, three hand weedings at 15, 30 and 45 DAS and weedy check. In case of PGPR inoculation, the surface sterile rice seed were inoculated by immersion in the appropriate PGPR suspension (at 10^7 cfu/ml)and air dried before sowing.

Weed samples were collected with the help of a quadrate of 50 x 50 cm from two places in each plot to determine the density and dry weight of different weeds. Weed dry weight was recorded after drying the weed samples at 70°C for 48 h. Weed control efficiency (WCE) was calculated based on the data recorded at 15, 30, 45, 60 DAS and at harvest as per standard formula. Weed density and dry weight were square root transformed before analysis.

Plant population at 15 DAS, plant height (cm), tillers/m and total dry matter (g/m^2) at 45 DAS were recorded. Panicle length (cm), panicles/m^2, number of grains per panicle were recorded just before harvesting. The grain and straw yield were recorded after harvest and sun dried for 3 days. Harvest index was calculated using standard formula.

All the data wherever needed were statistically analysed for factorial randomized block design. Least significant differences (LSD) at 5 per cent probability level were calculated only when the F value was found to be significant.

RESULTS AND DISCUSSION

Weed flora

The relative density in weedy check were *Eleusine indica* (14.03 and 22.43%), *Digitaria setigera* (25.18 and 32.04%), *Cynodon dactylon* (13.24 and 12.82%), *Cyperus difformis* (8.31 and 6.41%), *Cyperus rotundus* (6.23 and 6.41%), *Ageratum houstonianum* (4.65 and 3.21%), *Commelina diffusa* (6.87 and 5.77%), *Oldenlandia corymbosa* (3.58 and 1.28%), *Spermacoce articularis* (7.58 and 3.21%), *Cleome rutidosperma* (3.65 and 3.21%), *Mimosa pudica* (3.58 and 3.21%) and *Acmella ciliata* (3.1 and 0%) at 60 DAS in 2018 and 2019, respectively. The most dominant weed species was *D. setigera* in both the years. It might be due to favourably high rainfall and high temperature in the different crop growth stages and also presence of vegetative propagules in soil, and rich seed bank of weeds in soil that could help in early establishment and abundance of these weed species.

Weed density, dry weight and weed control efficiency

At 15 and 30 DAS inoculation with *P. fluorescens* resulted in significantly lower weed density and dry weight as compared to other PGPR treatments (**Table 1** and **2**). Schroth and Hancock (1982) suggested that rhizobacteria do not necessarily eradicate the weeds, but significantly suppress early growth of weeds and allow the development of crop plants to effectively compete with weakened weed seedlings. The maximum weed density and dry weight at all the growth stages, was recorded in weedy check in both the years. Application of pretilachlor was more effective at initial crop growth stage which might be due to the activity of the herbicide up to 30 days after application. Similar findings were reported by Mahanta *et al.* (2019). Significantly, the lower weed density and dry weight was observed with hand weeding at all crop growth stages other than 45 DAS where it was at par with pretilachlor 0.75 kg/ha followed by one hand weeding at 30 DAS (**Table 1** and **2**). This might be due to timely eradication of weeds by intercultural tools, which uprooted and killed the weeds.

Among the PGPR inoculations, highest WCE was found in *P. fluorescens* followed by *Bacillus cereus* in both the years (**Table 3**). In the initial stages, the WCE was higher due to greater suppression of weed density at the initial stages of crop growth as compared to later stages (Kremer and Kennedy 1996).

Application of pretilachlor at 0.75 kg/ha and pretilachlor at 0.75 kg/ha followed by one hand weeding at 30 DAS resulted in higher WCE due to lower weed density at 15 DAS in both the years. Similar findings were found by Saha (2005). At 30, 45, 60 DAS and harvest, three hand weedings and pretilachlor at 0.75 kg/ha + one hand weeding at 30 DAS resulted in higher WCE due to effective and sustained weed control by these treatments.

Crop growth parameters

There was no significant difference in plant population at 15 DAS amongst the PGPR inoculation and weed management practices and their interaction.

Significantly higher plant height, number of tillers/m and dry matter accumulation (g/m^2) in both the years were recorded in *P. fluorescens* which could be due to production of plant growth hormones like

Table 1. Effect of PGPR and weed management on weed density at different days after sowing (DAS) and harvest in 2018 and 2019

Treatment	Weed density (no./m^2)									
	15 DAS		30 DAS		45 DAS		60 DAS		At harvest	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
PGPR										
Bacillus cereus	5.7(34.0)	5.8(34.8)	8.3(69.2)	8.3(69.3)	7.8(68.7)	7.7(68.7)	9.4(93.8)	9.3(93.5)	11.0(123.5)	10.9(123.3)
Pseudomonas fluorescens	5.3(29.3)	5.4(29.9)	7.6(58.5)	7.5(58.5)	7.7(66.8)	7.6(66.7)	9.0(87.2)	9.0(87.5)	10.9(121.9)	10.9(122.2)
No inoculation	6.5(43.6)	6.6(44.7)	8.7(75.7)	8.6(75.6)	8.2(73.8)	8.1(73.7)	9.6(98.6)	9.6(98.9)	11.3(130.1)	11.3(130.3)
LSD (p=0.05)	0.41	0.39	0.35	0.36	NS	NS	NS	NS	NS	NS
Weed management										
Pretilachlor 0.75 kg/ha	4.7(21.8)	4.8(22.7)	8.1(66.1)	8.1(65.8)	9.9(98.3)	9.9(98.0)	10.9(119.4)	10.9(119.2)	12.5(156.7)	12.5(156.9)
Pretilachlor 0.75 kg/ha + 1 HW at 30 DAS	4.7(22.3)	4.8(23.0)	8.0(64.1)	8.0(63.7)	5.0(24.8)	4.9(24.4)	7.7(59.1)	7.7(59.1)	9.9(98.2)	9.9(97.7)
Three HW at 15, 30 and 45 DAS	7.0(48.8)	7.0(49.3)	6.8(45.8)	6.7(45.8)	5.3(27.8)	5.2(27.3)	6.2(38.9)	6.2(38.9)	8.8(76.7)	8.7(76.1)
Weedy check	7.0(49.7)	7.2(51.0)	9.8(95.2)	9.8(96.0)	11.3(128.2)	11.3(129.0)	12.5(155.3)	12.5(156.1)	13.0(169.1)	11.1(170.4)
LSD (p=0.05)	0.47	0.45	0.41	0.42	0.72	0.73	0.67	0.67	0.51	0.52
Interaction (P × W)										
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

LSD-least significant difference at 5% level of significance, NS- Non-significant, DAS- Days after sowing, original values in parentheses were subject to square root transformation $\sqrt{x+0.5}$

Table 2. Effect of PGPR and weed management on weed dry matter accumulation at different days after sowing (DAS) and harvest in 2018 and 2019

Treatment	Weed dry weight (g/m^2)									
	15 DAS		30 DAS		45 DAS		60 DAS		At harvest	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
PGPR										
Bacillus cereus	2.4(5.8)	2.4(5.8)	4.7(22.4)	4.7(22.5)	5.2(32.1)	5.1(32.1)	6.4(48.9)	6.3(48.7)	9.6(96.3)	9.5(96.3)
Pseudomonas fluorescens	2.2(4.9)	2.1(4.3)	4.4(19.7)	4.4(19.7)	5.2(31.4)	5.1(31.8)	6.3(47.4)	6.3(47.5)	9.5(95.1)	9.4(95.3)
No inoculation	2.7(7.2)	2.7(7.2)	5.1(26.5)	5.1(26.6)	5.2(33.3)	5.2(33.6)	6.6(51.1)	6.5(51.0)	9.8(101.0)	9.6(100.8)
LSD (p=0.05)	0.18	0.22	0.29	0.29	NS	NS	NS	NS	NS	NS
Weed management										
Pretilachlor 0.75 kg/ha	1.9(3.2)	1.9(3.2)	5.0(24.6)	5.0(24.7)	7.2(51.0)	7.1(50.8)	7.8(61.0)	7.8(60.9)	10.8(115.7)	10.7(115.6)
Pretilachlor 0.75 kg/ha + one HW at 30 DAS	1.9(3.3)	1.9(3.2)	4.9(23.2)	4.8(23.1)	2.8(7.3)	2.7(7.3)	4.1(16.5)	4.1(16.3)	8.5(72.7)	8.5(72.5)
Three HW at 15, 30 and 45 DAS	3.0(8.6)	2.8(7.8)	3.5(12.2)	3.5(12.2)	2.8(7.6)	2.8(7.7)	3.2(9.5)	3.1(9.3)	6.3(39.2)	6.2(39.2)
Weedy check	3.0(8.7)	3.0(8.8)	5.6(31.4)	5.6(31.7)	8.0(63.1)	8.0(64.1)	10.5(109.4)	10.4(109.8)	12.7(162.1)	12.7(162.5)
LSD (p=0.05)	0.21	0.25	0.34	0.34	0.26	0.29	0.29	0.27	0.30	0.29
Interaction (P × W)										
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

LSD-least significant difference at 5% level of significance, NS- Non-significant, DAS- Days after sowing, original values in parentheses were subject to square root transformation $\sqrt{x+0.5}$

Table 3. Effect of PGPR and weed management on weed control efficiency at different days after sowing (DAS) and harvest in 2018 and 2019

Treatment	Weed control efficiency (%)									
	15 DAS		30 DAS		45 DAS		60 DAS		At harvest	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
PGPR										
Bacillus cereus	21.98	22.17	8.48	8.27	6.99	6.68	4.82	5.40	5.06	5.37
Pseudomonas fluorescens	32.70	33.14	22.69	22.60	9.48	9.50	11.57	11.54	6.27	6.26
No inoculation	-	-	-	-	-	-	-	-	-	-
Weed management										
Pretilachlor 0.75 kg/ha	56.15	55.55	30.57	31.48	23.31	24.03	23.11	23.63	7.36	7.95
Pretilachlor 0.75 kg/ha + one HW at 30 DAS	55.04	54.90	32.67	33.68	80.67	81.03	61.95	62.14	41.92	42.70
Three HW at 15, 30 and 45 DAS	1.79	3.27	51.92	52.31	78.33	78.81	74.96	75.08	54.66	55.34
Weedy check	-	-	-	-	-	-	-	-	-	-

auxin by the bacteria. Similar findings were also obtained by Kaushal *et al*. (2013). Among the weed management practices, growth parameters like plant height, number of tillers per/m^2 and dry matter accumulation (g/m^2) were higher with the treatment of three hand weeding but it was at par with pretilachlor 0.75 kg/ha + hand weeding at 30 DAS in both the years (**Table 4**).

Yield attributing characters

The yield attributes of rice were significantly influenced due to PGPR inoculation. Panicle length, number of panicles/m^2 and number of grains/panicles were significantly increased by *P. fluorescens* in both the years (**Table 5**). Elekhtyar (2015) reported the ability of PGPR to increase nitrogen uptake efficiency, capable of solving phosphorus problem and increased auxin production.

Among all the weed management practices, the highest panicle length, number of panicles/m^2 and number of grains/panicles were recorded in three hand weedings at 15, 30 and 45 DAS in both the years (**Table 5**). This was closely followed by pretilachlor 0.75 kg/ha + hand weeding at 30 DAS. The higher yield attributes under these treatments might be due to reduced weed density, weed dry weight and higher weed control efficiency leading to effective control of the weeds at critical crop growth period and a better establishment of crop. However, the weed management practices could not affect significantly the test weight of grains.

Grain and straw yield

Grain and straw yields of rice increased significantly due to *P. fluorescens* inoculation in both the years (**Table 5**). Jambhulkar and Sharma (2013) reported that PGPR increased the availability of nitrogen and phosphorous and also amounts of cytokinin, gibberelin, auxin leading to better grain and straw yield. Among the weed management practices, significantly higher grain and straw yield were recorded under three hand weedings at 15, 30 and 45 DAS, which was closely followed by pretilachlor at 0.75 kg/ha + hand weeding at 30 DAS. Better management of weeds at critical stages of crop

Table 4. Effect of PGPR and weed management on crop growth parameters in 2018 and 2019

Treatment	Plant population/m at 15 DAS		Plant height (cm) at 45 DAS		No. of tillers/m at 45 DAS		Dry matter accumulation (g/m^2) at 45 DAS	
	2018	2019	2018	2019	2018	2019	2018	2019
PGPR								
Bacillus cereus	14.8	15.6	44.2	45.29	44.50	46.33	49.71	51.58
Pseudomonas fluorescens	14.8	15.8	47.2	48.52	50.67	52.42	54.85	55.88
No inoculation	14.7	15.3	41.2	42.36	42.25	43.83	46.61	48.53
LSD (p=0.05)	NS	NS	2.90	2.95	6.11	6.07	4.26	4.18
Weed management								
Pretilachlor 0.75 kg/ha	14.6	15.1	40.3	41.62	41.78	43.22	48.23	49.96
Pretilachlor 0.75 kg/ha + one HW at 30 DAS	14.7	15.7	48.8	50.08	53.22	55.11	53.28	55.14
Three HW at 15, 30 and 45 DAS	15.3	16.1	51.8	53.08	60.00	62.00	57.68	59.33
Weedy check	14.6	15.2	35.8	36.78	28.22	29.78	41.70	43.54
LSD (p=0.05)	NS	NS	3.35	3.41	7.06	7.01	4.92	4.83
Interaction (P × W)								
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

LSD-least significant difference at 5% level of significance, NS- Non-significant, DAS- Days after sowing

Table 5. Effect of PGPR and weed management on yield attributing parameters, yield and harvest index in 2018 and 2019

Treatment	Panicle length (cm)		No. of panicles/ m^2		No. of grains/ panicle		Test weight (g)		Grain yield (t/ha)		Straw yield (t/ha)		Harvest index (%)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
PGPR														
Bacillus cereus	10.23	17.32	179.17	181.58	97.5	120.92	17.53	17.80	1.39	1.60	1.82	2.06	43.3	43.7
Pseudomonas fluorescens	10.86	18.99	193.08	196.67	106.83	137.50	17.60	17.92	1.66	1.85	2.14	2.37	43.7	43.8
No inoculation	9.63	16.77	169.42	174.33	94.58	117.00	17.23	17.51	1.15	1.35	1.55	1.79	42.6	43.4
LSD (p=0.05)	0.65	1.37	13.27	12.72	8.25	15.95	NS	NS	0.13	0.12	0.16	0.16	-	
Weed management														
Pretilachlor 0.75 kg/ha	9.93	15.78	150.78	153.67	91.67	124.33	17.43	17.74	1.07	1.29	1.65	1.88	39.3	40.7
Pretilachlor 0.75 kg/ha + one HW at 30 DAS	10.69	20.92	215.78	219.89	109.67	143.11	17.47	17.76	1.88	2.08	2.19	2.42	46.2	46.2
Three HW at 15, 30 and 45 DAS	11.71	22.79	232.33	236.33	131.00	161.78	17.70	17.97	2.05	2.26	2.38	2.62	46.3	46.3
Weedy check	8.62	11.28	123.33	126.89	66.22	71.33	17.22	17.50	0.60	0.76	1.14	1.35	34.6	36.1
LSD (p=0.05)	0.75	1.58	15.32	14.69	9.52	18.42	NS	NS	0.15	0.14	0.18	0.19	-	-
Interaction (P × W)														
LSD p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	0.26	0.25	0.32	0.33	-	-

LSD-least significant difference at 5% level of significance**,** NS- Non-significant

Table 6. Economic analysis of different treatment combinations in 2018 and 2019

Treatment	Cost of cultivation (x10^3 `/ha)		Gross returns (x10^3 `/ha)		Net returns (x10^3 `/ha)		B:C ratio	
	2018	2019	2018	2019	2018	2019	2018	2019
Bacillus cereus with pretilachlor 0.75 kg/ha	25.65	25.65	25.82	31.12	0.17	5.47	1.01	1.21
Bacillus cereus with pretilachlor 0.75 kg/ha + one HW at 30 DAS	26.50	26.50	43.89	49.09	17.39	22.59	1.66	1.85
Bacillus cereus with three hand weedings (HW) at 15, 30 and 45 DAS	28.90	28.90	50.98	55.87	22.08	26.97	1.76	1.93
Bacillus cereus with weedy check	24.65	24.65	15.28	19.75	-9.37	-4.90	0.62	0.80
Pseudomonas fluorescens with pretilachlor 0.75 kg/ha	25.65	25.65	31.45	36.55	5.80	10.90	1.23	1.43
Pseudomonas fluorescens with pretilachlor 0.75 kg/ha + one HW at 30 DAS	26.50	26.50	52.53	58.30	26.03	31.80	1.98	2.20
Pseudomonas fluorescens with three HW at 15, 30 and 45 DAS	28.90	28.90	56.74	61.74	27.84	32.84	1.96	2.13
Pseudomonas fluorescens with weedy check	24.65	24.65	21.16	24.19	-3.49	-0.46	0.86	0.98
No inoculation with pretilachlor 0.75 kg/ha	25.15	25.15	24.70	29.63	-0.44	4.48	0.98	1.17
No inoculation with pretilachlor 0.75 kg/ha + one HW at 30 DAS	26.00	26.00	37.79	42.54	11.79	16.54	1.45	1.64
No inoculation with Three HW at 15, 30 and 45 DAS	28.40	28.40	37.78	42.88	9.38	14.48	1.33	1.51
No inoculation with weedy check	24.15	24.15	13.06	17.42	-11.09	-6.72	0.54	0.72

growth under these two treatments could have minimized the competition between crop and weeds leading to higher crop uptake of nutrients resulting in better crop growth and yield attributing characters, thus contributing to higher grain yield.

The PGPR and weed management treatments interacted significantly with regards to grain and straw yield. The highest values were given by the combination of *P. fluorescens* and three hand weedings at 15, 30 and 45 DAS which were at par with the combination of *P. fluorescens* and pretilachlor 0.75 kg/ha + hand weeding at 30 DAS. Better weed suppression, plant growth and yield attributing characters under these treatment combinations could finally increase the yields.

P. fluorescens resulted the highest harvest index (43.7 and 43.8) followed by *B. cereus* (43.3 and 43.7) and no inoculation (42.6 and 43.4) in 2018 and 2019, respectively (**Table 5**). Higher dry matter accumulation and its efficient mobilization into grains due to *P. fluorescens* might have resulted higher harvest index. Regarding weed management practices, three hand weedings at 15, 30 and 45 DAS resulted highest harvest index (46.3) closely followed by pretilachlor 0.75 kg/ha + hand weeding at 30 DAS (46.2) in both the years.

Cost of cultivation

Inoculation of *P. fluorescens* along with three hand weedings at 15, 30 and 45 DAS resulted in highest gross returns and net returns but the B: C ratio was lower than *P. fluorescens* along with pretilachlor at 0.75 kg/ha + hand weeding at 30 DAS as the cost of cultivation was higher in the previous treatment due to costly labour requirement to carry out the hand weedings (**Table 6**).

It could be concluded from the study that treatment of rice seeds with *P. fluorescens* and weed management by three hand weedings at 15, 30 and 45 DAS or pretilachlor pre-emergence at 0.75 kg/ha followed by one hand weeding at 30 DAS performed the best in terms of weed suppression, grain yield and economics.

REFERENCES

Balasubramanian V and Hill JE. 2002. Direct seeding of rice in Asia: emerging issues and strategic research needs for the 21st century. *Direct seeding: Research strategies and opportunities* 15–39.

Chauhan BS. 2012. Weed ecology and weed management strategies for dry-seeded rice in Asia. *Weed Technology* **26**(1): 1–13.

Elekhtyar NM. 2015. Efficiency of pseudomonas fluorescens as plant growth-promoting rhizobacteria (PGPR) for the enhancement of seedling vigor, nitrogen uptake, yield and its attributes of rice (*Oryza sativa* L.). *International Journal of Scientific Research in Agricultural Sciences* **2**: 057–067.

Jambhulkar PP and Sharma P. 2013. Promotion of rice seedling growth characteristics by development and use of bioformulation of *Pseudomonas fluorescens*. *Indian Journal of Agricultural Sciences* **83**(2): 136–142.

Kaushal S, Karnwal A and Rai Y. 2013. Potential plant growth-promoting activity of rhizobacteria *Pseudomonas* sp. in *Oryza sativa*. *Journal of Natural Products and Plant Resources* **3**(4): 38–50.

Kremer RJ and Kennedy AC. 1996. Rhizobacteria as Biocontrol Agents of Weeds. *Weed Technology* **10**: 601–609.

Mahanta K, Bora N, Deka J and Barua IC. 2019. Herbicide residues in rice–based cropping systems in Assam. pp. 305–324. In *Herbicide Residue Research in India*. (Eds. Sondhia Shobha, Choudhury Partha P and Sharma AR). Springer: Environmental Chemistry for a Sustainable World book series (ECSW, volume 12).

Naresh RK, Gupta RK, Singh RV, Singh D, Singh B, Singh VK, Jain N and Bhatia A. 2011. Direct seeded rice: potential, performance and problems- A review. *Current Advances in Agricultural Sciences* **3**(2): 105–110.

Saha S. 2005. Evaluation of some new herbicide formulations alone or in combination with hand weeding in direct sown rainfed lowland rice. *Indian Journal of Weed Science* **37**(1&2): 103–104.

Schroth MN and Hancock JG. 1982. Disease-suppressive soil and root-colonizing bacteria. *Science* **216**: 1376–1381.

Indian Journal of Weed Science **53**(1): 41–48, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Herbicide combinations for management of resistance in *Phalaris minor*

Jeetendra Kumar Soni*, Amarjeet, S.S. Punia and V.K. Choudhary[1]

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

[1]ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482004, India

**ICAR RC NEH Region, Mizoram Centre, Kolasib, Mizoram 796081, India*

**Email: jeetendra.soni@icar.gov.in*

Article information

DOI: 10.5958/0974-8164.2021.00005.8

Type of article: Research article

Received : 30 August 2020
Revised : 25 January 2021
Accepted : 28 January 2021

Key words

Resistance

Phalaris minor

Herbicides

Grain yield

Regression

Correlation

ABSTRACT

Littleseed canarygrass (*Phalaris minor* Retz.) is a problematic weed of wheat under irrigated rice-wheat cropping system of Indo-Gangetic plains (IGP) of India. Due to its morphological similarity with wheat, herbicides are the best-suited method for its control. However, continuous use of same herbicide along with monocropping leads to development of multiple-herbicide resistance. To tackle this problem, an experiment was conducted at CCS Haryana Agricultural University, Hisar during 2016-17 and 2019-20 to find out the suitable herbicide combinations for management of resistance *Phalaris minor*, its regression and correlation studies with wheat. The finding revealed that increase in weed density and dry weight displayed a strong negative linear relationship with grain yield. Linear regression equation represented that increase in every one unit of density and dry weight of *P. minor* led to reduction in wheat yield by 0.027 and 0.0102 times, respectively. Among the herbicidal treatments, sequential application of pendimethalin + pyroxasulfone (tank-mix, TM) *fb* mesosulfuron + iodosulfuron (ready-mix, RM) (1500 + 102 g/ha) pre-emergence, (PE) *fb* 14.4 g/ha post-emergence, (PoE) or pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 g/ha PoE led to significantly control of *P. minor*, broad-leaved weeds (BLWs) and total weeds. This resulted in better crop growth, higher yield attributes, 37.6-51.9% higher grain yield and 80-81% higher net return as compared to unweeded control. However, PE or PoE herbicide applied alone recorded poor efficacy towards *P. minor* and other weeds and resulted in poor yield. Correlation studies indicated strong positive association of grain yield with visual weed control, crop dry weight and its height and negative association with weed density and dry weight. Therefore, for effective management of resistant *P. minor* along with other weed flora, herbicide combination with its sequential application is of prime importance for optimum yield in wheat.

INTRODUCTION

The resistance of weeds towards herbicides is increasing day by day and upto year 2020 nearly 512 unique cases (species × site of action) of herbicide resistance have been recorded. Total 262 weed species (152 dicots and 110 monocots) having resistance to 23 of the 26 known herbicide sites of action was observed (Heap 2020). In India, the problem of herbicide resistance in weeds is increasing drastically. This is primarily due to the indiscriminate use of herbicides coupled with monocropping of rice-wheat system, that develops the selection pressure and ultimately resulting in resistant weed population. Littleseed canarygrass (*Phalaris minor* Retz.) is a mimic weed of wheat, predominant in the irrigated rice-wheat cropping system and severely infests wheat fields in the north-western Indo-Gangetic plains of India including Haryana (Kaur *et al.* 2016). If left uncontrolled, it may lead to 15-40% or more yield loss along with lowering the quality (Chhokar *et al*. 2008). To control this weed, application of herbicide is most appropriate tool. However, repeated application of same herbicide resulted in the development of herbicide resistance in *P. minor*. Herbicide resistance in this weed started from isoproturon to clodinafop, fenoxaprop and sulfosulfuron. Also, some of the biotypes developed resistance to some new herbicides, *viz*., pinoxaden and mesosulfuron + iodosulfuron. As of now, multiple herbicide resistance has evolved in *P. minor* (Dhawan *et al*. 2012, Rasool *et al*. 2017). It is estimated that *P. minor* invades about 50% (15 million ha) of the cultivated wheat area in India, out of that multiple herbicide-resistant *P. minor* affected area is about 3.0 m ha (Chhokar *et al.* 2019).

Phalaris minor has superior growth traits and competitive advantage over wheat. Cultivation of semi-dwarf wheat varieties require frequent irrigation along with high fertilizer doses, modifies the agro-ecological conditions, provides conducive micro-climate for growth and development of *P. minor* that helps to compete vigorously with wheat (Singh *et al.* 1995). The heavy infestation of *P. minor* (2000-3000 plants/m^2) results in complete crop failure (Malik and Singh 1995). Targeting the resistant *P. minor* along with other weed flora within a field by using different herbicides with different modes of action, herbicide combinations and/or their compatible mixture is the best possible option. They offer broad-spectrum action, enhanced herbicide efficacy through synergistic or additive effect, requirement in lesser quantity, arrest weed shifts, prevent herbicide resistance in weeds and reduced the selection pressure (Powles and Shaner 2001). The herbicide-resistant weeds in wheat were found susceptible to pre-emergence herbicides such as pendimethalin, metribuzin and pyroxasulfone (Dhawan *et al.* 2012). The use of pre-emergence herbicides offers an alternate mode of action to most of post-emergence herbicides, reduce selection pressure on subsequent post-emergence herbicide applications and remove much of the early season weed competitive pressure on the crop (Singh 2015). However, only pre-emergence herbicide application is not enough to control all weeds and its cohorts. Therefore, pre-emergence herbicides require a mixing partner for improved and broad-spectrum control of weeds. The practice of herbicide mixtures is now endorsed worldwide as a part of a proactive herbicide-resistant weed management program. One way to improve crop safety is to reduce the rate of the herbicides in combination with reduced dose of other herbicides, which will also broaden the spectrum of weed control and delay the evolution of resistance. Therefore, keeping this in view, the present study has been planned to manage herbicide resistance in *P. minor* Retz. through sequential application of pre- and post-emergence herbicides in wheat.

MATERIALS AND METHODS

A field experiment was conducted at Agronomy Research Farm, CCS Haryana Agricultural University, Hisar (Haryana) (29°8’56.62"N latitude and 75°41’4.24"E longitude) in winter season 2016-17 and 2019-20 with a history of poor control of *P. minor* with clodinafop (Abdullrasheed, 2019). Seasonal weather was quite different during both cropping seasons (**Figure 1**).

The wheat *cv* ‘*HD 2967*’ was sown on 20th November and 4th December using seed rate of 100 kg/ha in solid rows 20 cm apart; and harvested on 16th April and 27th April during 2016-17 and 2019-20, respectively. Sixteen treatments: pendimethalin (1500 g/ha) pre-emergence (PE), metribuzin (210 g/ha) PE, pendimethalin + metribuzin [tank mix (TM)] (1500 + 175 g/ha) PE, pendimethalin + metribuzin (TM) *fb* pinoxaden (1000 +175 g/ha) PE *fb* 60 g/ha post-emergence (PoE), pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron [ready mix (RM)] (1000 + 175 g/ha) PE *fb* 14.4 g/ha PoE, pendimethalin + pyroxasulfone (TM) (1500 + 102

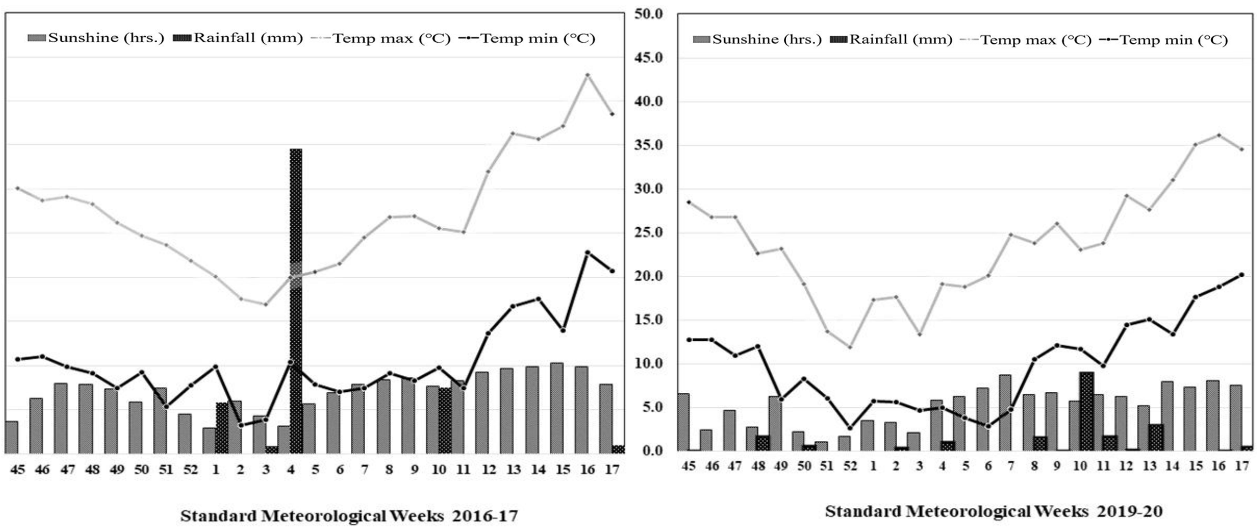


Figure 1. Weekly mean weather during crop season (2016-17 and 2019-20)

g/ha) PE, pendimethalin + pyroxasulfone (TM) *fb* pinoxaden (1500 + 102 g/ha) PE *fb* 60 g/ha PoE, pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ha) PE *fb* 14.4 g/ha PoE, pendimethalin + metribuzin (TM) *fb* pinoxaden (1500 + 175 g/ha) before sowing *fb* 60 g/ha PoE, sulfosulfuron *fb* pinoxaden [25 g/ha before irrigation (BI) *fb* 60 g/ha PoE], pinoxaden (60 g/ha) PoE, pinoxaden + metribuzin (TM) (50+120 g/ha) PoE, pinoxaden + metribuzin (TM) (50 + 150 g/ha) PoE, mesosulfuron + iodosulfuron (RM) (14.4 g/ha) PoE, weed-free check, unweeded control, were evaluated in a randomized block design with three replication having plot size 6 × 6 m. Herbicides were applied as per treatment using knapsack sprayer fitted with a flat fan nozzle using spray fluid at 500 l/ha immediately after sowing and 35 days after sowing. Hand weeding was done in weed-free treatment whenever it is required in crop season and no weed management was done in unweeded control. All other management practices were done as per recommendation given by CCS Haryana Agricultural University, Hisar. Crop growth and weed parameters were recorded at 60 DAS; yield attributes and yield were recorded at harvest, while economics was calculated based on prevailing market price. Statistically analysed by using OPSTAT software (Sheoran *et al.* 1998) with the following link http://14.139.232.166/opstat/default.asp. The response of different treatments was similar during both the years and followed the homogeneity test; data was pooled for statistical analysis. Wherever the treatment differences were found significant (F test), least significant difference (LSD) was tested at 5% level of significance.

RESULTS AND DISCUSSION

Weed studies

The experimental field was dominated by *P. minor* under grassy and *Melilotus indica, Rumex dentatus*, *Chenopodium album* under broad-leaved weeds (BLWs) in both the year. The relative composition of *P. minor* and BLWs at 60 DAS was 49.4 and 49.5%, respectively (pooled data of two years).

Wheat grain yield followed the strong negative linear relationship with weed density and dry weight (**Figure 2**). Coefficient of determination (R^2) was 0.78 and 0.77 for *P. minor* density and dry weight, respectively that indicate 78 and 77% variation in wheat yield was due to *P. minor* density and dry weight, respectively. Whereas, one unit increase in *P. minor* density and its dry weight led to reduction in yield by 0.027 and 0.0102 times, respectively (**Figure 2a** and **2b)**. Under BLWs, 77 and 73% variation in wheat yield was predicted due to BLWs density and dry weight, respectively. A unit increase in BLWs density and dry weight may lead to reduction in wheat yield by 0.0227 and 0.0043 times, respectively (**Figure 2c** and **2d)**. Whereas, total weed density and dry weight resulted in 91 and 86% variation in wheat yield, respectively. The unit increase in total weed density and dry weight may lead to reduction in wheat yield by 0.05 and 0.0145 times, respectively (**Figure 2e** and **2f)**.

This could be due to heavy weed infestation that robbed the crop's of common essential resources from early-stage onwards. Hence, crop was deprived of resources and could not grow to its full potential that ultimately reduced grain yield (Choudhary 2019).

The weed control treatment studies at 60 DAS showed that significantly minimum density and dry weight of all types of weeds were recorded in weed-free check and maximum in unweeded control (**Table 1**). Among the herbicide treated plot, significantly higher reduction in total weed density, dry weight, *P. minor* density and dry weight, and BLWs density and dry weight was observed in sequentially applied pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ha) PE *fb* 14.4 g/ha PoE followed by pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 g/ha PoE. However, *P. minor* density and dry weight was also found least in pendimethalin + pyroxasulfone (TM) *fb* pinoxaden (1500 + 102 g/ha) PE *fb* 60 g/ha PoE. Whereas, significantly higher density and dry weight of all types of weed was observed under PE metribuzin followed by PE pendimethalin. Visual control of weed (*P. minor* and BLWs) was recorded at 60 DAS on 0-100 scale (**Table 1**). Unweeded control was taken as reference (zero per cent control), while weed-free provided complete control. Under *P. minor,* application of PE pendimethalin + metribuzin resulted in 75% control (pooled of two years) and its sequential application *fb* PoE pinoxaden or mesosulfuron + iodosulfuron resulted in 93 and 98% control level of *P. minor*, respectively. Similarly, PE pendimethalin + pyroxasulfone caused 88% control and its sequential application *fb* PoE pinoxaden or mesosulfuron + iodosulfuron resulted in similar level of control (≈100%). Whereas PE metribuzin (52%) and pendimethalin (60%) showed poor efficacy compared to other herbicide treatments.

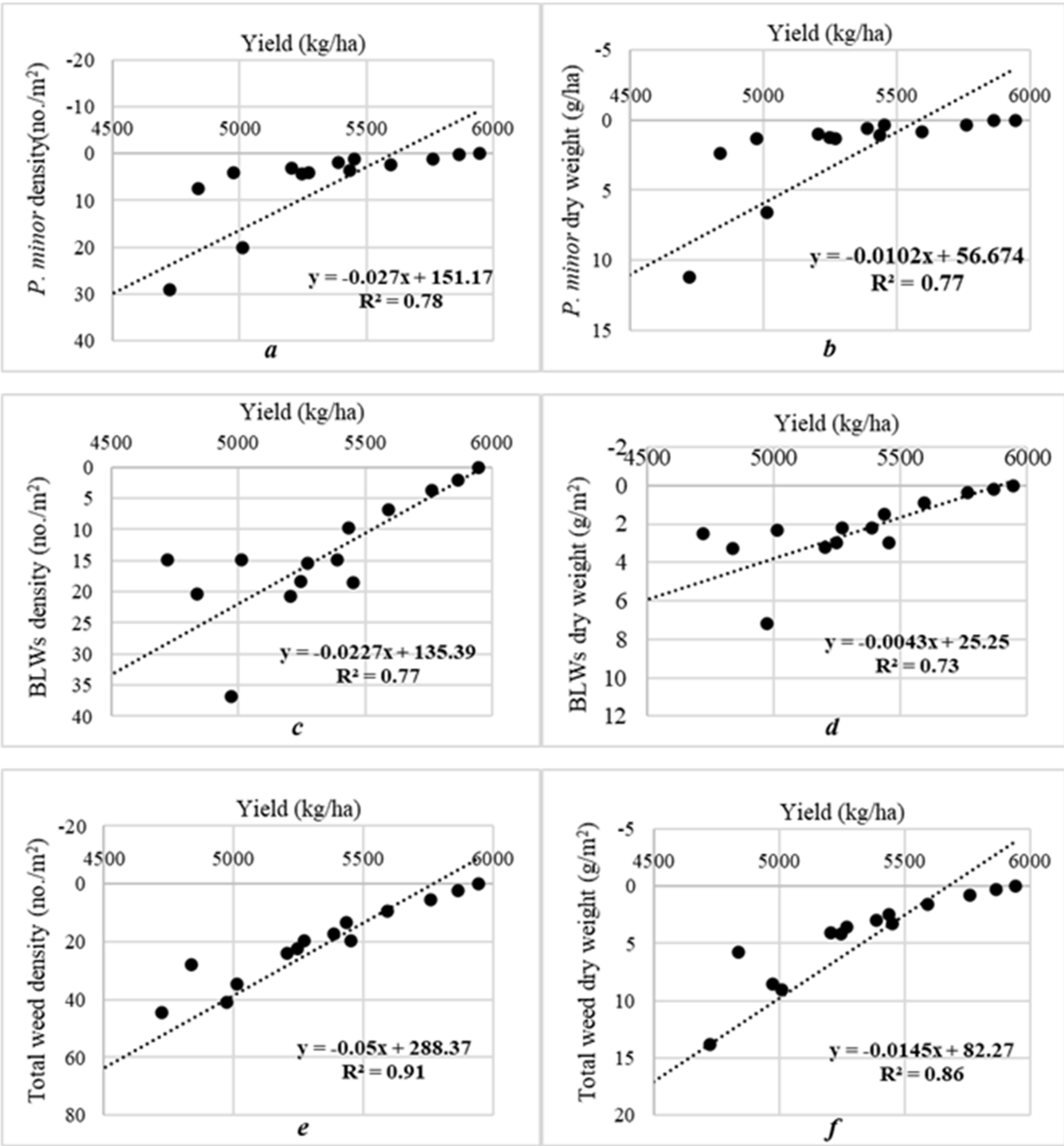


Figure 2. Relationship between wheat grain yield and weed density and dry weight (pooled data of two years) a: *P. minor* density, b: *P. minor* dry weight, c: BLWs density, d: BLWs dry weight, e: Total weed density and f: Total weed dry weight

Under BLWs, application of PE pendimethalin + metribuzin (TM) provided nearly similar control level as its sequential application with PoE pinoxaden. Similarly, PE pendimethalin + pyroxasulfone (TM) showed comparable efficacy as its sequential application with PoE pinoxaden. Whereas, PE pendimethalin + metribuzin *fb* PoE mesosulfuron + iodosulfuron and PE pendimethalin + pyroxasulfone *fb* PoE mesosulfuron + iodosulfuron caused similar efficacy towards BLWs (≈100%). While PE metribuzin (57%) shows poor control of BLWs in comparison with other herbicide treatments. This might be due to broad-spectrum control of *P. minor* and BLWs by sequential application of pre-emergence tank-mixed herbicide followed by post-emergence herbicide. Pinoxaden provides 90-100% control of *P. minor* and its resistant population (Singh *et al*. 2010, Soni *et al*. 2020) and pyroxasulfone best suited against grassy weed including resistant grassy weeds, however both these herbicides were non-effective against BLWs (Punia *et al*. 2020). Punia *et al*. (2018) reported that pre-emergence pendimethalin or metribuzin provided <35% control of *P. minor*, while, pendimethalin + metribuzin provided sufficient control of *P. minor* and other BLWs. However, it did not control weeds of second and further flushes of weeds.

Crop growth, yield attributes and grain yield

Among the crop growth parameters (60 DAS), dry weight per plant was recorded highest in weed-free check (3.3 g) that was statistically at par with sequentially applied pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) or pinoxaden. Leaf area index (LAI) was significantly higher in weed-free check (3.39) at par with pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM), and mesosulfuron + iodosulfuron (RM) alone. Similarly, yield attributes (at harvest) like grains per spike was significantly higher in weed-free check (56 no.) at par with sequentially applied pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) or pinoxaden and pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM). While across the treatments spike length remains non-significant (**Table 2**).

Weed growing throughout the crop duration significantly reduced the wheat grain yield to the extent of 34.6 and 29.9% in 2016-17 and 2019-20, respectively compared to weed-free check. All the weed control treatments produced significantly higher grain yield as compared to unweeded control. Significantly higher grain yield was recorded in weed-free check with 6.32 t/ha and 5.57 t/ha in 2016-17 and 2019-20, respectively and it was statistically at par with pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ha) PE *fb* 14.4 g/ha; pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 g/ha PoE, and mesosulfuron + iodosulfuron (RM) (14.4 g/ha) PoE in both year. While significantly lower grain yield was obtained in unweeded check with 34.6% in 2016-17 and 32.4% in 2019-20 lower grain yield as compared to weed-free check (**Figure 3**). This could be due to effective reduction in weed density and dry weight by sequential application of herbicide that controlled most of weed cohorts and helped crop to get sufficient nutrients, moisture, light and optimum space. This ultimately helped in more photosynthesis, produced more dry weight, productive tillers, higher yield attributes and hence increased grain yield. However, relatively less grains yield was recorded with alone application of either pre- or post-emergence herbicides. This could be due to resistant *P. minor* and other weeds which were not efficiently controlled by alone pre- or post-emergence

Table 1. Weeds density (no./m²), dry matter (g/m²) and visual control at 60 DAS as influenced by different weed control treatments (pooled data of two years)

Treatment	Total weed		*P. minor*		BLWs		Visual control	
	Density	Dry weight	Density	Dry weight	Density	Dry weight	*P. minor*	BLWs
Pendimethalin (1500 g/ha) PE	6.7(44.3)	3.9(13.8)	5.5(29.0)	3.5(11.2)	4.0(14.8)	1.9(2.5)	60	83
Metribuzin (210 g/ha) PE	8.5(71.0)	4.5(19.1)	6.4(40.3)	3.9(13.9)	5.6(30.7)	2.5(5.2)	52	57
Pendimethalin + metribuzin (TM) (1500 + 175 g/ha) PE	6.0(34.8)	3.2(9.0)	4.6(20.0)	2.8(6.6)	3.9(14.8)	1.8(2.3)	75	88
Pendimethalin + metribuzin (TM) *fb* pinoxaden (1000 +175 g/ha) PE *fb* 60 PoE	4.8(22.5)	2.3(4.2)	2.3(4.3)	1.5(1.2)	4.4(18.3)	2.0(3.0)	93	80
Pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 PoE	2.5(5.3)	1.3(0.8)	1.4(1.2)	1.1(0.3)	2.1(3.7)	1.2(0.4)	98	97
Pendimethalin + pyroxasulfone (TM) (1500 + 102 g/ha) PE	5.4(27.8)	2.6(5.8)	2.9(7.5)	1.8(2.4)	4.6(20.3)	2.1(3.3)	88	55
Pendimethalin + pyroxasulfone (TM) *fb* pinoxaden (1500 + 102 g/ha) *fb* 60 PE *fb* PoE	4.5(19.7)	2.1(3.3)	1.4(1.2)	1.1(0.3)	4.4(18.5)	2.0(3.0)	99	67
Pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ha) *fb* 14.4 PE *fb* PoE	1.7(2.2)	1.1(0.3)	1.1(0.2)	1.0(0.0)	1.6(2.0)	1.1(0.2)	99	98
Pendimethalin + metribuzin (TM) *fb* pinoxaden (1500 + 175 g/ha) *fb* 60 g/ha before sowing *fb* PoE	5.0(23.9)	2.3(4.1)	2.0(3.2)	1.4(1.0)	4.6(20.8)	2.0(3.2)	92	85
Sulfosulfuron *fb* pinoxaden (25 *fb* 60 g/ha) BI *fb* PoE	4.3(17.3)	2.0(3.0)	1.7(2.0)	1.3(0.6)	4.0(14.8)	1.8(2.2)	80	89
Pinoxaden (60 g/ha) PoE	6.5(40.8)	3.1(8.5)	2.2(4.0)	1.5(1.3)	6.1(36.8)	2.9(7.2)	72	15
Pinoxaden + metribuzin (TM) (50+120 g/ha) PoE	4.5(19.7)	2.1(3.6)	2.3(4.2)	1.5(1.3)	4.0(15.5)	1.8(2.2)	83	70
Pinoxaden + metribuzin (TM) (50+150 g/ha) PoE	3.7(13.3)	1.9(2.5)	2.1(3.5)	1.4(1.1)	3.3(9.8)	1.6(1.5)	86	87
Mesosulfuron + iodosulfuron (RM) (14.4 g/ha) PoE	3.1(9.2)	1.6(1.6)	1.8(2.3)	1.3(0.8)	2.7(6.8)	1.4(0.9)	86	96
Weed-free check	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	100	100
Unweeded control	10.3(105.7)	5.6(30.5)	7.3(52.2)	4.6(20.4)	7.3(52.3)	3.3(9.9)	0	0
LSD (p=0.05)	0.5	0.2	0.5	0.3	0.5	0.2	-	-

Data given in parentheses are original values, and outside are square-root transformed value herbicides, therefore weeds grow continue with crop and competing with limited available resources resulting in suppressed crop growth and finally lower grains yield. The beneficial effect of herbicide mixture and its sequential application for management of resistant *P. minor* and higher grain yield comparable to weed-free was reported by Yadav *et al.* (2016) and Kaur *et al.* (2019).

Economics

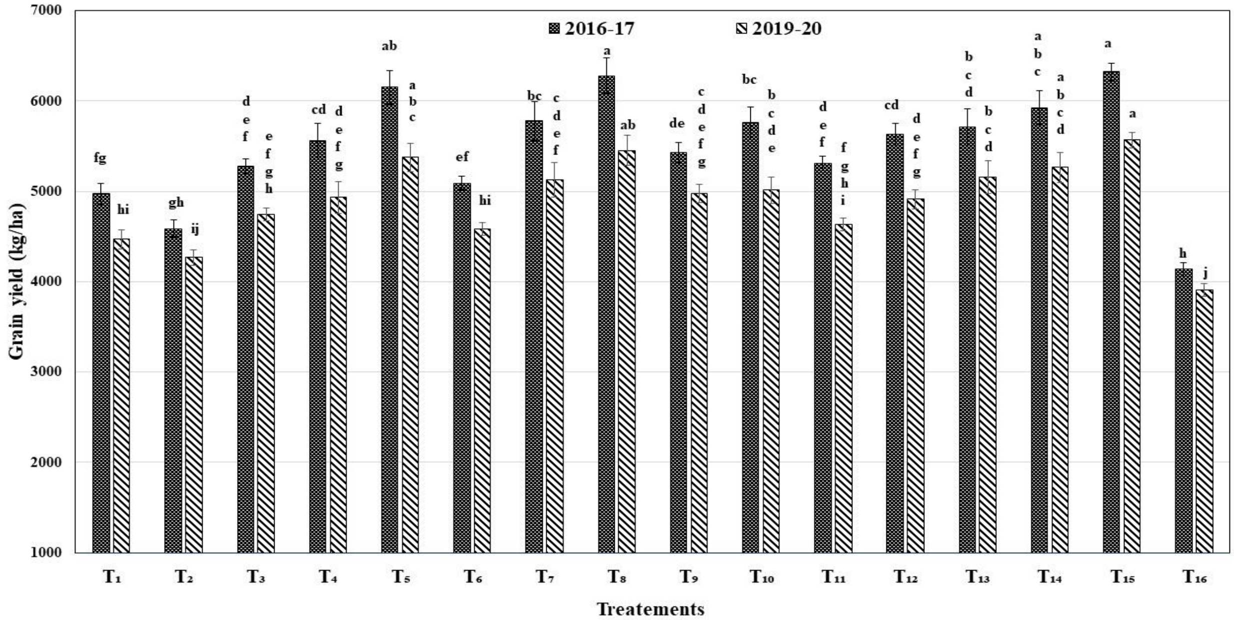
Economics of different treatments was recorded in the form of net return and BC ratio. The highest net return (71,213 ₹/ha) was observed in pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ha) PE *fb* 14.4 g/ha PoE followed by pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 g/ ha PoE. Whereas, highest BC ratio (2.31) was recorded in sole applied mesosulfuron + iodosulfuron (RM) (14.4 g/ha) PoE followed by sequentially applied pendimethalin + metribuzin (TM) or pendimethalin + pyroxasulfone (TM) *fb* PoE mesosulfuron + iodosulfuron. Whereas, least net return (39,297 ₹/ha) and BC ratio (1.76) was recorded in unweeded control (**Table 2**). This was due to higher yield in sequentially applied herbicides with comparatively lower cost of cultivation as compared to weed-free treatment.

Correlation studies

Plant dry weight, visual control of *P. minor* and BLWs had significant positive correlation with grain yield while density and dry weight of total weed, *P. minor* and BLWs were negatively correlated with grain yield during both the years (**Table 3**). Plant height had non-significant positive correlation with grain yield, visual control of *P. minor* and BLWs, respectively. It has non-significant negative correlated with density and dry weight of total weed and *P. minor,* respectively during both the years. Weed density and dry weight were negatively correlated with its visual control through different weed control treatments and crop growth parameters and vice-versa. In most of the cases, the correlations were highly significant (at 1% probability level). Among the parameters studied, the highest degree of positive association was observed between weed density and dry weight of *P. minor* followed by total weed, and BLWs (r=0.990 to 0.997**). Whereas, the highest negative association was recorded between visual control of *P. minor* with total weed dry weight (r=-0.967**) followed by visual control of BLWs with its dry weight (r= -0.958**). Wheat grain yield had positive relationship with visual control of *P. minor* (r= 0.875**), visual control of BLWs (r= 0.767**), plant dry weight (r= 0.794**) and plant height (0.261^{NS}). Negative correlation coefficient was

Table 2. Plant dry weight (g), leaf area index (LAI) at 60 DAS; grains per spike (no.), spike length (cm) at harvest stage, and economics of different weed control treatments (pooled data of two years)

Treatment	Plant dry weight	LAI	Grains per spike	Spike length	Net return (₹/ha)	B:C ratio
Pendimethalin (1500 g/ha) PE	2.8	2.98	46	10.3	51,258	1.95
Metribuzin (210 g/ha) PE	2.7	2.89	44	10.1	46,697	1.88
Pendimethalin + metribuzin (TM) (1500 + 175 g/ha) PE	3.0	3.05	47	10.4	57,206	2.05
Pendimethalin + metribuzin (TM) *fb* pinoxaden (1000 +175 g/ha) PE *fb* 60 PoE	3.0	3.13	51	10.7	60,216	2.07
Pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 PoE	2.8	3.26	53	10.8	70,730	2.27
Pendimethalin + pyroxasulfone (TM) (1500 + 102 g/ha) PE	2.9	3.02	49	10.7	51,200	1.92
Pendimethalin + pyroxasulfone (TM) *fb* pinoxaden (1500 + 102 g/ha) *fb* 60 PE *fb* PoE	3.1	3.12	52	10.8	62,447	2.08
Pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ha) *fb* 14.4 PE *fb* PoE	3.2	3.35	55	11.1	71,213	2.24
Pendimethalin + metribuzin (TM) *fb* pinoxaden (1500 + 175 g/ha) *fb* 60 g/ha before sowing *fb* PoE	2.8	3.07	49	10.5	58,371	2.03
Sulfosulfuron *fb* pinoxaden (25 *fb* 60 g/ha) BI *fb* PoE	2.9	3.17	50	10.8	63,470	2.15
Pinoxaden (60 g/ha) PoE	2.8	2.99	46	10.6	56,021	2.04
Pinoxaden + metribuzin (TM) (50+120 g/ha) PoE	2.9	3.13	48	10.8	63,369	2.17
Pinoxaden + metribuzin (TM) (50+150 g/ha) PoE	3.0	3.13	50	10.8	66,625	2.23
Mesosulfuron + iodosulfuron (RM) (14.4 g/ha) PoE	3.0	3.22	50	10.8	70,202	2.31
Weed-free check	3.3	3.39	56	11.1	55,739	1.75
Unweeded control	2.6	2.76	42	9.8	39,297	1.76
LSD (p=0.05)	0.3	0.22	4	0.9	-	-



T_1:pendimethalin (1500 g/ha) PE, T_2: metribuzin (210 g/ha) PE, T_3: pendimethalin + metribuzin (TM) (1500 + 175 g/ha) PE, T_4: pendimethalin + metribuzin (TM) *fb* pinoxaden (1000 +175 g/ha) PE *fb* 60 g/ha PoE, T_5: pendimethalin + metribuzin (TM) *fb* mesosulfuron + iodosulfuron (RM) (1000 + 175 g/ha) PE *fb* 14.4 g/ha PoE, T_6: pendimethalin + pyroxasulfone (TM) (1500 + 102 g/ha) PE, T_7: pendimethalin + pyroxasulfone (TM) *fb* pinoxaden (1500 + 102 g/ha) PE *fb* 60 g/ha PoE, T_8: pendimethalin + pyroxasulfone (TM) *fb* mesosulfuron + iodosulfuron (RM) (1500 + 102 g/ha)PE *fb* 14.4 g/ha PoE, T_9: pendimethalin + metribuzin (TM) *fb* pinoxaden (1500 + 175 g/ha) before sowing *fb* 60 g/ha PoE, T_{10}: sulfosulfuron *fb* pinoxaden (25 g/ha BI *fb* 60 g/ha PoE), T_{11}: pinoxaden (60 g/ha) PoE, T_{12}: pinoxaden + metribuzin (TM) (50 + 120 g/ha) PoE, T_{13}: pinoxaden + metribuzin (TM) (50 + 150 g/ha) PoE, T_{14}: mesosulfuron + iodosulfuron (RM) (14.4 g/ha) PoE, T_{15}: weed-free check and T_{16}: unweeded control

Figure 3. Wheat grain yield influenced by different weed control treatments (error bars indicate ±S.E. of mean of 3 replicates)

Table 3. Correlation coefficient (*r*) between weeds, different crop growth and yield of wheat (pooled data of two years)

Parameter	Yield	Total weed density	Total weed dry weight	*P. minor* density	*P. minor* dry weight	BLWs density	BLWs dry weight	Visual control *P. minor*	Visual control BLWs	Plant height	Plant dry weight
Yield	1										
Total weed density	-0.953**	1									
Total weed dry weight	-0.930**	0.990**	1								
P. minor density	-0.881**	0.935**	0.969**	1							
P. minor dry weight	-0.875**	0.936**	0.973**	0.997**	1						
BLWs density	-0.879**	0.906**	0.845**	0.698**	0.702**	1					
BLWs dry weight	-0.856**	0.900**	0.844**	0.691**	0.699**	0.995**	1				
Visual control *P. minor*	0.875**	-0.951**	-0.967**	-0.924**	-0.938**	-0.816**	-0.823**	1			
Visual control BLWs	0.767**	-0.804**	-0.747**	-0.574*	-0.586*	-0.940**	-0.958**	0.735**	1		
Plant height	0.261NS	-0.337NS	-0.279NS	-0.132NS	-0.160NS	-0.519*	-0.502*	0.370NS	0.437NS	1	
Plant dry weight	0.794**	-0.759**	-0.724**	-0.660**	-0.659**	-0.745**	-0.718**	0.721**	0.624**	0.561*	1

**Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed); NS non-significant

found between grain yield with total weed density (r= -0.953**), total weed dry weight (r= -0.930**), *P. minor* density (r= -0.881**), *P. minor* dry weight (r= -0.875**), BLWs density (r= -0.879**) and BLWs dry weight (-0.856**). The correlation study with grain yield of wheat was found significantly positively with WCE, crop growth parameters and negatively with the weed density and dry weight (Singh *et al.* 2007; Kaur and Singh 2019).

Conclusion

Phalaris minor is a potential threat for the sustainability of wheat in irrigated rice-wheat cropping system. Development of herbicide resistance in *P. minor* lead to poor herbicidal efficacy that resulted in higher *P. minor* density and finally lesser grain yield. The finding of the present study indicate that the coefficient of determination value was much higher in *P. minor* and become a major factor for yield reduction with higher negative correlation than other types of weeds. Among the treatment effect, solely applied either pre- or post-emergence herbicide remains ineffective for control of resistant *P. minor* or other weeds cohorts resulted in poor crop growth, yield attributes and grain yield. Therefore, herbicide combination with its sequential application with pre-emergence tank-mixed pendimethalin + pyroxasulfone (or) pendimethalin + metribuzin followed by post-emergence application of mesosulfuron + iodosulfuron provide effective control of resistance *P. minor* with broad-spectrum weed control resulted in better crop performance, higher yield and net returns.

REFERENCES

Abdullrasheed. 2019. Herbicide Resistance Management of *Phalaris minor* through Sequential Applications of Pre- and Post-emergence Herbicides in Wheat" (*Triticum aestivum* L.). M.Sc thesis CCSHAU, Hisar.

Chhokar RS, Sharma RK and Verma RPS. 2008. Pinoxaden for controlling grass weeds in wheat and barley. *Indian Journal of Weed Science* **40**(1&2): 41–46.

Chhokar RS, Sharma RK, Gill SC and Singh RK. 2019. Broad spectrum weed control in wheat with pyroxsulam and its tank mix combination with sulfosulfuron. *Journal of Research* **11**(1): 23–36.

Choudhary VK. 2019. Assessment of soil fertility using *Ageratum conyzoides* in mid-hills of Arunachal Pradesh. *Indian Journal of Weed Science* **51**(1): 62–66.

Dhawan RS, Singh N and Singh S. 2012. Littleseed canarygrass resistance to sulfonyl-urea herbicides and its possible management with pendimethalin. *Indian Journal of Weed Science* **44**(4): 218–224.

Heap I. 2020. The International Herbicide-Resistant Weed Database. http://www.weedscience.org/Home.aspx.

Kaur A and Singh S. 2019. Performance of different herbicides on wheat grain yield and correlation between growth and yield attributes of wheat and weeds. *Indian Journal of Weed Science* **51**(2): 129–132.

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

Kaur N, Kaur T, Kaur Sand Bhullar MS. 2016. Development of cross resistance in isoproturon resistant *Phalaris minor* Retz. in Punjab. *Agricultural Research Journal* **53**(1): 69–72.

Malik RK and Singh S. 1995. Littleseed canarygrass (*Phalaris minor* Retz.) resistant to isoproturon in India. *Weed Technology* **9**: 419–425.

Powles S and Shaner DL. 2001. *Herbicide Resistance and World Grains*. Boca Raton, FL, USA, CRC Press.

Punia SS, Singh SK and Singh S. 2018. Management of cross resistance in *Phalaris minor* against recommended herbicides in wheat, p 54. In: *Proceedings, ISWS Golden Jubilee International Conference on "Weeds and Society: Challenges and Opportunities*", ICAR- Directorate of Weed Research. Jabalpur, India during 21-24 November 2018.

Punia SS, Soni J, Manjeet, Singh SK and Kamboj P. 2020. Management of herbicide resistant *Phalaris minor* in wheat. *Indian Journal of Weed Science* **52**(3): 237–240.

Rasool R, Bhullar MS and Gill GS. 2017. Growth stage of *Phalaris minor* Retz. and wheat determines weed control and crop tolerance of four post-emergence herbicides. *Spanish Journal of Agricultural Research* **15**(1)1001: 1–8.

Sheoran OP, Tonk DS, Kaushik LS, Hasija RC and Pannu RS. 1998. Statistical software package for agricultural research workers. pp. 139–143. In: *Recent Advances in Information Theory, Statistics and Computer Applications* (Eds. Hooda DS and Hasija RC), Department of Mathematics Statistics, CCS HAU, Hisar.

Singh S, Kirkwood RC and Marshall G. 1995. Resistant *Phalaris minor* mimics wheat in detoxifying isoproturon. *Resistant Pest Management Newsletter* **7**: 16–18.

Singh S, Yadav A, Punia SS, Malik RS. and Balyan RS. 2010. Interaction of stage of application and herbicides on some *Phalaris minor* populations. *Indian Journal of Weed Science* **42**: 144–154.

Singh S. 2007. Role of management practices on control of isoproturon-resistant littleseed canarygrass (*Phalaris minor*) in India. *Weed Technology* **21**: 339–346.

Singh, S. 2015. Management of multiple herbicide resistance in *Phalaris minor* in India, p 21. In: *Proceedings, Volume II (oral papers). 25th Asian-Pacific Weed Science Society Conference*. Hyderabad, Indian Society of Weed Science, Jabalpur.

Soni JK, Choudhary VK, Singh PK and Hota S. 2020. Weed management in conservation agriculture, its issues and adoption: a review. *Journal of Crop and Weed* **16**(1): 09–19.

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

Indian Journal of Weed Science **53**(1): 49–53, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Effect of post-emergence herbicides in chickpea

Indu Bala Sethi*, Harphool Singh, Suresh Kumar, Mahesh Jajoria, Lokesh Kumar Jat, Niranjan Kumar Braod, Suresh Muralia and Hans Ram Mali[1]

Agricultural Research Station, Navgaon (Alwar), S.K.N. Agriculture University, Jobner, Jaipur, Rajasthan 303329, India

[1]Krishi Vigyan Kendra, Navgaon, Alwar, Rajasthan 301025, India

**Email: indubalasethia2012@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00006.X

Type of article: Research article

Received : 21 October 2020

Revised : 16 February 2021

Accepted : 19 February 2021

Key words

Chickpea

Herbicides

Weed management

ABSTRACT

A field experiment was conducted during two consecutive (*Rabi*) winter seasons (2018-19 and 2019-20) at Agricultural Research Station, Navgaon (Alwar), S.K.N. Agriculture University, Jobner, Jaipur (Rajasthan), India, to study the effect of weed management practices in chickpea. The experiment was laid out in a randomized block design with eight treatments and replicated thrice. The crop was sown as per the package of practices recommended for zone IIIB of Rajasthan. Treatments included application of pendimethalin 30% EC 1.0 kg/ha as pre-emergence, and quizalofop-p-ethyl 10% SL at 50g/ha, fenoxaprop p-butyl 10% EC at 100 g/ha, imazethapyr 10% EC at 75 g/ha, imazethapyr (35%) + imazamox (35%) at 100 g/ha, imazethapyr (2%) + pendimethalin (30%) at 2.5 litre/ha as post-emergence along with weedy and weed free checks. Among the different herbicidal treatments, imazethapyr (35%) + imazamox (35%) at 100 g/ha recorded significantly higher seed yield 2.22 t/ha in 2018-19 and 2.28 t/ha in 2019-20 with higher weed control efficiency and the lowest weed index. However, it remained at par with imazethapyr 10% EC 75 g/ha and, imazethapyr (2%) + pendimethalin (30%) at 1.0 kg/ha.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is one of the most important *Rabi* pulse crops of India and occupies first position among the pulses. It was grown in an area of 8.4 million ha and producing 10.13 million tonnes with productivity of 1.07 t/ha during 2019-20 in India (Anonymous 2019). In Rajasthan, chickpea is successfully cultivated in arid and semi-arid districts and occupied second rank in respect of area (1.26 mha) with low productivity (725 kg/ha) (Anonymous 2018). Poor weed management is one of the most important yield limiting factors in chickpea. Being slow in its early growth and short statured plant, chickpea is highly susceptible to weed competition and weeds causes up to 75% yield loss (Chaudhary *et al.* 2005). Excessive weed competition may adversely affect seed size which is an important quality parameter in chickpea. Initial 60 days is the period considered as too critical for weed crop competition in chickpea (Singh and Singh 2000). Manual weed control is labour intensive and therefore limits the production area (Dubey 2014). Suitable herbicide (s) for effective control of mixed weed flora in chickpea is required application of pendimethalin at 1.0 kg/ha (Singh and Jain 2017) and oxyfluorfen (80 g/ha) as pre-emergence (Patel *et al.* 2006) provided effective control of annual broad-leaved and grassy weeds in chickpea field at early stages. However, later flushes of weeds can only be control by application of imazethapyr as post-emergence (Rathod *et al.* 2017). The use of post-emergence herbicides for season-long weed control is thus, preferred over pre-plant incorporation (fluchloralin and trifluralin) and pre-mergence (pendimethalin) herbicides. Keeping in view above facts, the present study was undertaken to evaluate the performance of post-emergence herbicides in chickpea.

MATERIALS AND METHODS

The field experiment was conducted during *Rabi* season in year 2018-19 and 2019-20 at Agricultural Research Station, Navgaon (Alwar), S.K.N Agriculture University, Jobner, Jaipur (Rajasthan), India, to study the effect of different herbicides in chickpea**.** The soil of experimental field was sandy loam in texture, low in organic carbon and available nitrogen, and medium in phosphorus and potassium with alkaline in pH. The experiment was laid out in a randomized block design with eight treatments including pendimethalin 30% EC 1.0 kg/ha as pre-emergence, and quizalofop-p-ethyl 10% SL50 g/ha, fenoxaprop-p-butyl 10% EC 100 g/ha, imazethapyr 10% EC 75 g/ha, imazethapyr (35%) + imazamox (35%)100g/ha, imazethapyr (2%) + pendimethalin (30%) at 1.0 kg/ha as post-emergencealong with weedy and weed free checks with three replications. Chickpea, *cv. RSG-974* was sown at the end of the October. The fertilizer dose 20:40:00 kg/ha of N, P and K was applied as basal and thoroughly mixed with the soil. The seeds were inoculated with selected *Rhizobium* culture and sown at 80 kg/ha in furrows by keeping 30 x 15 cm spacing at a depth of 5 cm. Foliar herbicides spray was done with knap-sack sprayer using flat-fan nozzle in 600 L of water/ha.

Weed density (no./m^2) was recorded species-wise just before the execution of first-hand weeding or before the application of post-emergence herbicides during both the years by using a quadrate of 0.5 x 0.5 m (0.25 m^2) size. Weed count was expressed as number per meter square. Weed dry matter of all the weed species (grasses, broad-leaved weeds and sedges) was recorded just before the execution of first-hand weeding and before application of post-emergence herbicides within an area of quadrate (0.25 m^2) by cutting them close to ground surface, separating species-wise and sun-drying for first 4-5 days and thereafter by keeping into an oven at 70$\pm$1^{O}C temperature till a constant weight was obtained. The dry weight of weeds was expressed as g/m^2.

RESULTS AND DISCUSSION

Weed flora

The weed flora in the experimental field consisted of grasses like *Cynodon dactylon, Asphodelus tenuifolius, Phalaris minor, Spergula arvensis;* sedges like *Cyperus rotundus* and broad-leaved weeds like *Chenopodium murale, Chenopodium album, Melilotus indica, Anagallis arvensis, Pluchea lanceolata, Convolvulus arvensis, Phyllanthus niruri, Cirsium arvense, Launaea asplenifolia, Coronopus didymus, Rumex dentatus etc*. The weed flora was more pronounced during second year of investigation due to enough soil moisture.

The lowest total weed density (no./m^2) was recorded with imazethapyr 10% EC at 75 g/ha as PoE (148) closely followed by imazethapyr (2%) + pendimethalin (30%) at 1.0 kg/ha (147), imazethapyr (35%) + imazamox (35%) at 100 g/ha PoE (156) and pendimethalin 30% EC at 1.0 kg/ha as PE (163) during 2018-19 (**Table 1**). The corresponding values were 144, 145, 162 and 163, respectively during 2019-20. After application of imazethapyr (35%) + imazamox (35%) 100 g/ha PoE significantly lower weed density (5.67 in 2018-19 and 4.67 in 2019-20) was recorded.

Among herbicidal treatments, weed dry weight (g/m^2) was significantly lower in imazethapyr (2%) + pendimethalin (30%) at 1.0 kg/ha (65.4) closely

Table 1. Effect of weed management practices on weed density and dry matter in standing chickpea crop

Treatment	Weed density (no./m^2)						Weed dry matter (g/m^2)					
	Before spray			After spray			Before spray			After spray		
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
Pendimethalin 1.0 kg/ha as PE	12.87 (165.3)	12.74 (162.0)	12.81 (163.7)	9.82 (96.0)	9.43 (88.7)	9.63 (92.3)	8.64 (74.4)	8.52 (72.4)	8.58 (73.4)	7.86 (61.5)	7.74 (59.6)	7.80 (60.6)
Quizalofop-p-ethyl 50 g/ha as PoE	13.30 (176.7)	13.18 (173.3)	13.24 (175.0)	9.42 (88.3)	9.13 (83.0)	9.28 (85.7)	8.77 (76.6)	8.61 (73.9)	8.69 (75.2)	7.56 (57.1)	7.38 (54.4)	7.47 (55.7)
Fenoxaprop-p-butyl 100 g/ha as PoE	13.49 (181.7)	13.25 (175.3)	13.37 (178.5)	8.90 (78.7)	8.71 (75.3)	8.80 (77.0)	9.08 (82.1)	8.95 (79.8)	9.02 (81.0)	6.99 (48.7)	6.78 (45.8)	6.88 (47.2)
Imazethapyr 75 g/ha as PoE	12.13 (148.0)	11.97 (144.3)	12.05 (146.2)	4.60 (20.7)	4.33 (18.3)	4.47 (19.5)	8.33 (69.3)	8.06 (64.8)	8.20 (67.1)	3.37 (11.2)	3.13 (9.6)	3.25 (10.4)
Imazethapyr + imazamox 100 g/ha PoE	12.46 (156.3)	12.74 (163.0)	12.60 (159.7)	2.47 (5.7)	2.26 (4.7)	2.36 (5.7)	8.53 (72.4)	8.28 (68.4)	8.41 (70.4)	1.98 (3.5)	1.85 (3.0)	1.92 (3.2)
Imazethapyr + pendimethalin 1.0 kg/ha	12.14 (147.0)	12.04 (144.7)	12.09 (145.8)	3.89 (14.7)	3.53 (12.0)	3.71 (13.3)	8.09 (65.4)	7.74 (59.8)	7.92 (62.7)	2.88 (7.9)	2.62 (6.4)	2.75 (7.2)
Weed free	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)
Weedy check	14.06 (197.3)	13.70 (187.3)	13.88 (192.3)	13.79 (189.7)	13.42 (179.7)	13.60 (184.7)	9.82 (96.2)	9.47 (89.5)	9.65 (92.9)	9.57 (91.2)	9.24 (85.0)	9.40 (88.1)
LSD (p=0.05)	1.06	1.07	1.03	0.36	0.43	0.28	0.80	0.69	0.61	0.58	0.74	0.52

Original values given in parentheses was subjected to square root $(\sqrt{x+1})$ transformation before analysis followed by imazethapyr 10% EC at 75 g/ha as PoE (69.3), imazethapyr (35%) + imazamox (35%) at 100 g/ha PoE (72.4), pendimethalin 30% EC at 1.0 kg/ha as PE (74.5) and quizalofop-p-ethyl 10% SL at 50 g/ha as PoE (76.6).

The highest weed control efficiency (97%) was attained with the application of post-emergence herbicide imazethapyr (35%) + imazamox (35%) at 100 g/ha closely followed by imazethapyr (2%) + pendimethalin (30%) at 1.0 kg/ha and imazethapyr 10% EC 75 g/ha at harvest stage (**Table 2**). However, the lowest weed control efficiency was recorded in post-emergence application fenoxaprop-p-butyl 10% EC at 100 g/ha. Broad-spectrum nature of pendimethalin which killed weed by inhibiting cell division and elongation thereafter coincides with imazethapyr which acted as inhibitor of three branched-chain amino-acids and thus, resulted in lesser weed counts and ultimately produced lower weed dry weight. Imazethapyr emerged as promising one in averting both density and dry matter accumulation in weeds (Das 2015). Similar results were also reported by Kalyani (2011) and (Yadav *et al.* 2018)

Weed index indicates the loss of yield caused by weeds under particular treatment as compared to weed free plot (**Table 2**). Efficacy of different treatments under weed management varied due to their mode and extent of weed control. However, minimum losses in yield *i.e.* weed index was associated with post-emergence herbicides *i.e.* imazethapyr (35%) + imazamox (35%) at 100 g/ha (2.65 and 0.58 during first year and second year, respectively) followed by imazethapyr (2%) + pendimethalin (30%) at 1.0 kg/ha and imazethapyr 10% EC 75 g/ha compared to weed free plot. The loss of yield as measured in terms of weed index was recorded maximum under weedy check due to heavy infestation of weeds, while application of pendimethalin, quizalofop-p-ethyl and fenoxaprop-p-butyl also recorded reduction in yield due to lesser efficacy against weed control as compared to other post-emergence herbicides. These results were parallel with the findings of Singh *et al.* (2014), Chandrakar *et al.* (2015), and Yadav *et al.* (2018)

Growth, yield and yield attributes

Plant height indicates the important growth variation caused by weeds under particular treatment as compared to weed free plot (**Table 2**). At 30, 60, 90, 120 DAS and at harvest, the maximum plant height was recorded in weed free, but it was at par with imazethapyr 10% EC 75 g/ha as PoE, imazethapyr (35%) + imazamox (35%) at 100g/ha PoE and imazethapyr (2%) + pendimethalin (30%) 1.0 kg/ha (**Table 2)**. Minimum plant height was recorded under unweeded control. These findings were in agreement with those of Singh *et al.* (2003), Kachhadia *et al.* (2009), Poonia *et al.* (2013) and Rupareliya *et al.* (2017).

Imazethapyr (35%) + imazamox (35%) at 100 g/ha PoE produced maximum number of pods per plant which were significantly higher than other weed management practices. However, seeds per pod of chickpea were not significantly affected by different weed management practices (**Table 4)**. Significantly higher seed yield of 2.22, 2.18 and 2.11 t/ha in 2018-19 and 2.28, 2.23 and 2.19 kg/ha, respectively in 2019-20 (**Table 3**). Significantly the highest harvest index was recorded with pendimethalin 30% EC 1.0 kg/ha as PE treatment (25.3%) during 2018-19 and quizalofop-p-ethyl 10% SL 50 g/ha as PoE treatment (25.2%) during 2019-20. Similar trend was also found with respect to the stover yield. Correlation between seed yield and weed density (**Figure 1**) were fond perfectly negative (r=0.977). It might be due to lesser infestation of weeds that encourage proper translocation of photosynthesis from source to sink. Such condition may increase the seed production

Table 2. Effect of weed management practices on weed index, weed control efficiency and plant height in standing chickpea crop

Treatment	Weed index		Weed control efficiency				Plant height at harvest		
			Before spray		After spray				
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	Pooled
Pendimethalin 1.0 kg/haas PE	20.98	20.07	16.21	13.52	49.39	50.65	34.0	34.8	34.4
Quizalofop-p-ethyl 50 g/ha as PoE	18.93	19.30	10.47	7.47	53.43	53.80	35.0	35.3	35.1
Fenoxaprop-p-butyl 100 g/ha as PoE	17.07	16.38	7.94	6.40	58.52	58.07	35.5	35.8	35.7
Imazethapyr 75 g/ha as PoE	7.50	4.52	25.00	22.95	89.10	89.80	36.0	36.1	36.0
Imazethapyr + imazamox 100 g/ha PoE	2.65	0.58	20.78	12.99	97.01	97.40	37.3	37.7	37.5
Imazethapyr + pendimethalin 1.0 kg/ha	4.81	2.75	25.51	22.77	92.27	93.32	37.1	37.4	37.2
Weed free	0.00	0.00	100.00	100.00	100.00	100.00	40.5	40.8	40.7
Weedy check	39.63	35.46	0.00	0.00	0.00	0.00	32.0	32.5	32.3
LSD (p=0.05)							2.25	4.16	2.46

Table 3. Effects of weed management practices on growth, yield attributes and yield in standing chickpea crop

Treatment	Pods/plant (no.)			Seeds/pod (no.)			100 Seed wt.(g)			Seed yield (t/ha)			Stover yield (t/ha)			Harvest index (%)		
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
Pendimethalin 1.0 kg/ha as PE	29.7	30.3	30.0	1.50	1.60	1.55	12.2	11.4	11.8	1.81	1.83	1.82	5.41	5.44	5.43	25.1	25.2	25.2
Quizalofop-p-ethyl 50 g/ha as PoE	30.7	31.0	30.8	1.42	1.50	1.46	12.8	12.0	12.4	1.85	1.84	1.85	5.48	5.43	5.45	25.3	24.9	25.1
Fenoxaprop-p-butyl 100 g/ha as PoE	31.3	31.7	31.5	1.50	1.50	1.50	12.0	12.1	12.0	1.90	1.92	1.91	5.68	5.75	5.71	25.0	25.1	25.0
Imazethapyr 75 g/ha as PoE	30.3	30.7	30.5	1.58	1.60	1.59	13.3	13.4	13.3	2.11	2.19	2.15	6.57	6.59	6.58	24.4	25.0	24.7
Imazethapyr + imazamox 100 g/ha PoE	35.0	35.3	35.2	1.50	1.60	1.55	12.8	12.1	12.5	2.22	2.28	2.25	6.80	6.84	6.82	24.6	25.1	24.8
Imazethapyr + pendimethalin 1.0 kg/ha	33.0	33.7	33.3	1.50	1.60	1.55	13.2	12.4	12.8	2.18	2.23	2.20	6.75	6.81	6.78	24.4	24.7	24.5
Weed free	34.0	34.3	34.2	1.58	1.67	1.63	12.7	12.0	12.3	2.29	2.27	2.28	6.97	6.91	6.94	24.7	24.5	24.6
Weedy check	27.3	27.7	27.5	1.42	1.48	1.45	10.7	10.9	10.8	1.38	1.49	1.43	4.21	4.53	4.37	24.6	24.9	24.7
LSD (p=0.05)	2.72	2.55	1.55	NS	NS	NS	0.87	0.99	0.71	0.36	0.50	0.24	0.48	0.56	0.51	3.48	5.52	3.14

Table 4. Effect of weed management practices on economics

Treatment	Cost of cultivation (x10^3 `/ha)		Gross returns (x10^3 `/ha)			Net returns (x10^3 `/ha)			BC ratio		
	2018-19	2019-20	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
Pendimethalin 1.0 kg/ha as PE	32.73	32.95	83.46	89.41	86.44	50.73	56.47	53.60	2.55	2.71	2.63
Quizalofop-p-ethyl 50 g/ha as PoE	32.36	32.58	85.62	89.60	87.61	53.26	57.01	55.14	2.65	2.75	2.70
Fenoxaprop-p-butyl 100 g/ha as PoE	32.64	32.86	87.59	93.69	90.64	54.95	60.83	57.89	2.68	2.85	2.77
Imazethapyr 75 g/ha as PoE	32.67	32.89	97.69	106.94	102.32	65.02	74.05	69.54	2.99	3.25	3.12
Imazethapyr + imazamox 100 g/ha PoE	34.00	34.22	102.82	111.41	107.11	68.82	77.20	73.01	3.02	3.26	3.14
Imazethapyr + pendimethalin 1.0 kg/ha	36.90	37.12	100.53	108.91	104.72	63.63	71.80	67.71	2.72	2.93	2.83
Weed free	36.95	37.46	105.60	110.62	108.11	68.65	73.16	70.90	2.86	2.95	2.91
Weedy check	31.84	32.06	63.76	72.49	68.12	31.92	40.43	36.18	2.00	2.26	2.13
LSD (p=0.05)	0.00	0.00	16.46	24.32	11.76	16.46	24.32	11.76	0.50	0.70	0.35

ratio in total produce. The results generated gains support from the other report by Dubey *et al.* (2018).

Economics

The lowest cost of cultivation was in weedy check treatment (₹ 31838/ha during 2018-19 and ₹ 32058/ha during 2019-20) due to no use of any herbicide or other means, whereas, it was more in weed free treatment. Weed free treatment recorded higher gross returns (₹ 105597/ha) during 2018-19 and imazethapyr (35%) + imazamox (35%) at 100 g/ha PoE (₹ 111411/ha) during 2019-20 as compared to other treatments. Imazethapyr (35%) + imazamox (35%) at 100 g/ha PoE resulted in higher net returns (₹ 68822/ha during 2018-19 and ₹ 77196/ha during 2019-20) compared to other treatments. The highest B:C was recorded with imazethapyr (35%) + imazamox (35%) 100 g/ha PoE treatment (3.02 during 2018-19 and 3.26 during 2019-20) compared to rest of the treatments (**Table 4)**. Therefore, from the study it was found that the application imazethapyr (35%) + imazamox (35%) at 100 g/ha proved superior in chickpea in the agro climatic zone IIIB of Rajasthan.

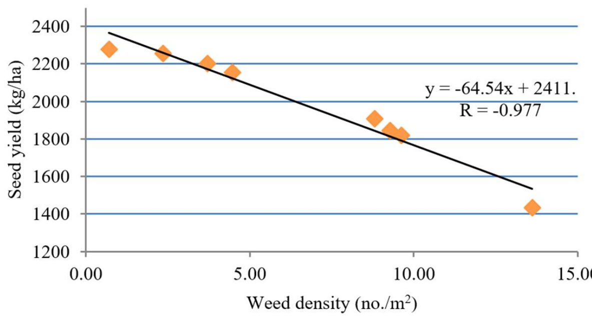


Figure 1. Correlation between seed density and seed yield of chickpea crop

REFERENCES

Ahmed A, Thakral SK, Yadav A and Balyan RS. 2010. Grain yield of wheat as affected by different tillage practices varieties and weed control methods. p. 19. In: *National Symposium on Integrated Weed Management in the Era of Climate Change*, held at NAAS, New Delhi on 21-22 August.

Anonymous 2018. *Agricultural Statistics at a Glance 2018*. Directorate of Economics and Statistics, Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Govt. of India, New Delhi.

Anonymous. 2019. *3rd Advanced Estimates*. Ministry of Agriculture and Farmers Welfare, Govt. of India.

Chandrakar S, Sharma A and Thakur DK. 2015. Effect of chickpea (*Cicer arietinum* L.) varieties and weed management practices on quality parameters, nutrient content and uptake by crop and weed. *International Journal of Agricultural Sciences* **11**: 217–220.

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

Das TK. 2015. *Weed Science: Basic and Applications*. Jain Brothers, New Delhi, India.

Dubey RP. 2014. Integrated weed management- an approach. pp. 19-21. In: *Training Manual Advance Training in Weed Management*, held at DWSR, Jabalpur, India on 14-23 January.

Dubey SK, Kumar A, Singh D, Pratap T and Chaurasiya A. 2018. Effect of different weed control measures on performance of chickpea under irrigated condition. *International Journal of Current Microbiology and Applied Science* **7**: 3103–3111.

Kachhadia SP, Savaliya JJ, Bhalu VB, Pansuriya AG and Savalia SG. 2009. Evaluation of new herbicides for weed management in chickpea (Cicer arietinum L.). *Legume Research* **32**(4): 293–297.

Kalyani D. 2011. *Integrated Weed Management in Chickpea (Cicer arietinum L.)*. M.Sc. submitted to ANGRAU, Rajendranagar, Hyderabad.

Mani VS, Malla MC, Gautam KC and Bhagwant's. 1973. Weed killing chemicals in potato cultivars. *Indian Farming* **32**: 17–18.

Patel BD, Patel VJ, Patel JB and Patel RB. 2006. Effect of fertilizers and weed management practices on weed control in chickpea (*Cicer arietinum* L.) under middle Gujrat conditions. *Indian Journal of Crop Science*s **1**: 180–183.

Poonia TC and Pithia MS. 2013. Pre- and post-emergence herbicides for weed management in chickpea. *Indian Journal of Weed Science* **45**(3): 223–225.

Rathod PS, Patil DH and Dodamani BM 2017. Evaluation of time and dose of imazethapyr in controlling weeds of chickpea (*Cicer arietinum* L.). *Legume Research* **40**: 906–910.

Rupareliya VV, Chovatia PK, Vekariya SJ and Javiya PP. 2017. Effects of different pre- and post emergences herbicide on growth, yield attributes, yield and quality of chickpea (*Cicer arietinum* L.). *International Journal of Science, Environment and Technology* **6**(4): 2587–2593

Ryan MR, Smith RG and Mortensen DA. 2009. Weed: crop competition relationships differ between organic and conventional cropping systems. *Weed Research* **49**: 572–580.

Singh A and Jain N. 2017. Integrated weed management in chickpea. *Indian Journal of Weed Science* **49**: 93–94.

Singh RP, Verma SK, Singh RK and Idnani LK. 2014. Influence of sowing dates and weed management on weed growth and nutrients depletion by weeds and uptake by chickpea (*Cicer arietinum*) under rainfed condition. *Indian Journal of Agricultural Sciences* **84**: 468–472.

Singh RV, Sharma AK and Tomar RK 2003. Weed control in chickpea (*Cicer arietinum* L.) under late-sown condition. *Indian Journal of Agronomy* **48**(2):114–116.

Singh S and Singh AN. 2000. Crop-weed competition in chickpea: Challenges and strategies for the New Millenium. p. 199. In: *National Symposium on Agronomy*. 15-18 November 2000. GAU Campus, Junagarh.

Verma SK. 2014. Enhancing sustainability in wheat production though irrigation regimes and weed management practices in eastern Uttar Pradesh. *The Ecoscane* **6**: 115–119.

Yadav VL, Shukla UN, Raiger PR and Mandiwal M. 2018. Efficacy of pre- and post-emergence herbicides on weed control in chickpea (*Cicer arietinum* L.) *Indian Journal of Agricultural Research* **53**(1): 112–115.

Indian Journal of Weed Science **53**(1): 54–58, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Bio-efficacy of weed management practices in rainfed potato

S.K. Yadav*, T.K. Bag[1], A.K. Srivastava[2] and V.P. Yadav[3]

ICAR- Central Potato Research Station, Shillong, Meghalaya 793 009, India

**ICAR-Indian Institute of Sugarcane Research, Lucknow, Uttar Pradesh 226002, India*

[1]ICAR-Indian Agricultural Research Institute, New Delhi 110012, India

[2]ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh 208024, India

[3]Chandra Shekhar Azad University of Agriculture & Technolog Kanpur, Uttar Pradesh 208002, India

**Email: sanjaybhu05@rediffmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00007.1

Type of article: Research article

Received : 19 August 2020
Revised : 8 February 2021
Accepted : 10 February 2021

Key words
Herbicide
Metribuzin
Potato
Tuber crop

ABSTRACT

A field experiment was conducted during 2013-14, 2014-15 and 2015-16 at ICAR-Central Potato Research Station, Shillong to evaluate the bio-efficacy of weed management practices in rainfed potato under North-Eastern hill region of India. Maximum potato tubers yield (21.3 t/ha) was recorded under weed free treatment followed by metribuzin application 0.75 kg/ha as a pre-emergence (PE). Reduction in crop yield due to presence of weeds was 54.0 per cent. Maximum uptake of nutrients, *viz.* nitrogen (113.2 kg/ha), phosphorus (14.5 kg/ha) and potassium (89.4 kg/ha) were recorded by the potato under weed free *fb* application of metribuzin 0.75 kg/ha as a PE. The highest net returns (₹ 176100/ha) and B:C ratio (2.3) were recorded under the metribuzin application 0.75 kg/ha. Thus, application of metribuzin 0.75 kg/ha as PE was found more effective in potato under the rainfed ecosystem of North-Eastern hill region of India.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important cash crop in the North-Eastern hill region of India. The per capita consumption of potato in the Meghalaya is three times higher than the national average but the average productivity of potato in this region is almost half of the country. There are several constraints in potato production in this land lock region, of which weeds are the severe biotic constraint and cause more reduction in productivity of potato. Weeds pose a serious problem in potato crop in the North-Eastern hill region of India due to high rainfall during crop growth season accompanied by slow emergence of potato crop during initial stage, which become favourable for profuse growth and development of weeds in the field. Weed emergence is directly related to the intensity of rainfall to wet the soil horizons. Weeds compete with potato crop for nutrient, solar radiation, moisture and also act as host plants and source of diseases (Singh 2016) and insects (Capinera 2005). Mechanical weeding is tedious during rainy season and prone to spread of virus disease from infested plant to healthy plant (Yadav and Srivatava 2014). Yield losses in potato tubers due to weed infestation have been found 34.4 to 86.0% (Monteiro *et al.* 2011 and Yadav *et al.* 2014). Depletion of soil fertility due to presence of weeds in the potato fields is another indirect major losses caused by the weeds besides the direct monetary loss of poor yield of potato crop. Extent of depletion of soil nutrients has not been worked out in this land lock region which needs to become essential to maintain fertility of soil for higher productivity of potato. Keeping this in view, an experiment was conducted to evaluate the bio-efficacy of weed management practices on productivity of potato under rainfed condition of North-Eastern hill region of India.

MATERIALS AND METHODS

A field experiment was conducted under AICRP on potato during 2013-14, 2014-15 and 2015-16 at ICAR-Central Potato Research Station, Shillong, Meghalaya. The geographical coordinates of fixed experimental field are 25°54’ N latitude and 91°84’ E longitude and an altitude of 1739 m above mean sea level. The trial was laid out in randomized block design, replicated fourth, with 7 treatments, *viz.* weedy check (no weed control measure were followed); weed free (weekly or as per require manual weeding to make plot weed free), hand weeding at 30 days and weed free up to maturity;

hand weeding at 40 days and weed free up to maturity; hand weeding at 50 days and weed free up to maturity; metribuzin 0.75 kg/ha as pre-emergence (PE) and metribuzin 0.75 kg/ha as post-emergence (PoE) at 10% of plant-emergence.

The soil was sandy loam in the texture having acidic reaction (pH 5.12), moderately fertile, being high in organic carbon (1.84) and medium in available nitrogen (293.9 kg/ha) while low in available phosphorus (11.5 kg/ha) and high in available potassium (290.3 kg/ha). Maximum temperature varied between 20 and 26°C during crop seasons. Similarly, minimum temperature varied between 7 and 18°C. In weed free check treatment, weeding was done weekly by manual labour as and when the weeds emerged in the field. The crop was planted during the month of March with the onset of rainfall. The recommended dose of fertilizer was applied in this experiment for this region 140: 120: 60 kg/ha N, P_2O_5 and K_2O, respectively. Half dose of nitrogen and full dose of P and K were applied at the time of planting, while remaining dose of nitrogen was given at the time of earthing up. The most popular variety of potato of this region *i.e.* *'Kufri Jyoti'* was taken for this experiment. The other recommended package of practices for potato was followed as per recommendation of this crop in the North-Eastern hill region of India like two spray of mancozeb and one spray of curzate (cymoxanil 8% + mancozeb 64%) were used for controlling the most devastating disease of potato *i.e.* late blight. The crop was harvested at around 120 days after planting in the last week of July.

The herbicides were applied using knap-sack sprayer fitted with flat-fan nozzle and using 800 litres of water/ha. Density of weeds (g/m^2) was taken using quadrates at 30, 40, 50, 60, 90 and 120 (at harvest) days after planting in each plot after removing the weeds from the base. Weed dry matter was determined after drying the weeds samples at 80°C for 48 hours by maintaining constant moisture content in the weed samples. The weed counts were subjected to square root transformation ($\sqrt{x+0.5}$) to normalize the distribution. Weed index and weed control efficiency was calculated as per the standard method (Yadav *et al.* 2015) at the harvest of the crop. The calculated values of the treatments and error variance ratio were compared with Fisher and Yates F Table at 5 per cent level of significance. The differences between significant treatments means were tested against CD at 5 percent probability.

RESULTS AND DISCUSSION

Weed species

The prominent weed species found in potato field were grouped in two categories like broad-leaves and narrow-leaves weeds. The major broad-leaves weeds were *Hydrocotyle javanica*, *Plantago major, Potentilla kleiniana, Oxalis corniculata, Senecio densiforus, Oxalis griffithii, Polygonum alatum, Solanum khasiana,* as broad-leaved weeds while *Spergula arvensis, Cyperus cyperoides, Arundinella nepalensis, Arundinella khasiana, Digitaria adscendens, Imperata cylindrica, Commellina diffusa, Arthraxon* sp. *Brachiaria reptans, Capillipedium assimile, Paspalum orbiculare* and other *Cyperus* sp, were narrow-leaves weeds found in potato field.

Weed density

The data on weed density at different stages presented in **Table 1** shown that the no. of total weed density per unit area increased gradually with duration of crop in each treatment. However, the maximum total density (587/m^2) of weeds per unit area were recorded at harvest (120 DAP) in weedy check as compared to other treatments. While minimum density of weed per unit area was noticed in weed free treatment followed by metribuzin (at 0.75 kg/ha) either as PE or at 10% of plant-emergence. Initially very low density of weeds was recorded in metribuzin than manual weeding. However, total weed density was found comparatively lower in metribuzin applied treatment than manual weeding.

Table 1. Effect of weed management practices on density of weed in potato (mean over three years)

Treatment	Total weed density (no./m^2)					
	30 DAP	40 DAP	50 DAP	60 DAP	90 DAP	120 DAP
Hand weeding at 30 days and weed free up to maturity	276.5	0.0	0.0	0.0	0.0	0.0
Hand weeding at 40 days and weed free up to maturity	270.3	291.3	0.0	0.0	0.0	0.0
Hand weeding at 50 days and weed free up to maturity	269.7	293.0	313.3	0.0	0.0	0.0
Metribuzin 0.75 kg/ha as PE	14.0	18.8	20.7	23.0	33.0	36.3
Metribuzin 0.75 kg /ha as PoE at 10% of plant-emergence	14.7	20.7	20.2	24.7	35.0	37.3
Weedy check	274.9	299.7	351.0	365.7	483.7	587.0
Weed free	0.0	0.0	0.0	0.0	0.0	0.0
LSD (p=0.05)	2.66	4.80	35.6	1.68	2.52	1.97

Weed biomass

Maximum dry weight (143.3 g/m^2) of weed biomass per unit area at harvest was recorded in weedy check as compared to other treatments. While minimum dry weight of weed biomass per unit area was recorded in weed free treatment followed by metribuzin (at 0.75 kg/ha) either as PE or at 10% of plant-emergence (**Table 2**). Initially very low dry matter of weed was recorded in metribuzin than manual weeding. However, weed biomass was found comparatively lower in metribuzin applied treatment than manual weeding. Hand weeding after 30 DAP was found more effective to reduce dry weight of weed biomass as compared to 40 and 50 DAP and weed free treatment. This might be due to that the weed control during initial period is more effective than making weed free at later stages. Similar result was also reported by Yadav *et al.* (2016).

Tuber yield

The lowest tuber yield (9.8 t/ha) of potato was recorded under weedy check (**Table 3**). The variations among yield at different treatments were recorded in the range of 9.8 to 21.3 t/ha. Similarly, the highest yield of potato (21.3 t/ha) was recorded under weed free treatment followed by metribuzin at 0.75 kg/ha as a PE application (20.0 t/ha). However, both the treatments were at par to each other but significantly superior to other treatments except application metribuzin 0.75 kg/ha as PoE at 10% of plant-emergence. Bio-efficacy of metribuzin was found more effective as compared to the other treatment except weed free treatment due to controlling the weeds during initial stage to maturity of crop. This result was also with conformity of Mishra *et al.* (2002) and Mukherjee *et al.* (2012).

Weed index and weed control efficiency

Weed index is the reduction in crop yield due to presence of weeds in comparison with weed-free check, which is an ideal parameter to judge the bio-efficacy of a particular herbicide or weed management practices in the associated crop (Yadav *et al*. 2016). The weed index among different treatments was found to be in the range of 0-54%. The maximum reduction in crop yield due to presence of weeds by 54% was found under weedy check plot followed by manual hand weeding at 50 days and weed free upto maturity compared to weed free treatment **(Table 3).** Application of metribuzin 0.75 kg/ha either PE or PoE at 10% of plant-emergence followed by manual hand weeding was found more effective to control the weeds in the potato crop. Similar result was also reported by Yadav *et al.* (2013).

The highest weed control efficiency (WCE) was recorded under weed free treatment followed by application of metribuzin 0.75 kg/ha as PE or PoE at 10% of plant-emergence (Singh *et al.* 2007). Hand weeding at 30 DAP and weed free upto maturity

Table 2. Impact of weed management practices on dry matter yield of weed biomass (mean over three years)

Treatment	Dry matter of weed biomass (g/m^2)					
	30 DAP	40 DAP	50 DAP	60 DAP	90 DAP	120 DAP
Hand weeding at 30 days and weed free up to maturity	7.84	0.00	0.00	0.00	0.00	0.00
Hand weeding at 40 days and weed free up to maturity	7.62	18.9	0.00	0.00	0.00	0.00
Hand weeding at 50 days and weed free up to maturity	7.27	18.4	38.5	0.00	0.00	0.00
Metribuzin 0.75 kg/ha as PE	2.30	6.30	12.3	24.5	50.2	65.2
Metribuzin 0.75 kg /ha as PoE at 10% of plant-emergence	2.50	6.40	14.0	25.1	56.2	68.5
Weedy check	7.79	18.5	38.5	56.8	115.5	143.3
Weed free	0.00	0.00	0.00	0.00	0.00	0.00
LSD (p=0.05)	0.43	1.23	2.13	3.69	2.25	7.46

Table 3. Impact of weed management practices on yield of potato and bio-efficacy parameters of weeds

Treatment	Yield (t/ha)			Pooled over 3 years		
	2013-14	2014-15	2015-16	Yield (t/ha)	Weed index (%)	Weed control efficiency (%)
Hand weeding at 30 days and weed free up to maturity	19.1	16.4	17.5	17.7	16.9	100.0
Hand weeding at 40 days and weed free up to maturity	18.2	15.2	15.8	16.4	23.0	100.0
Hand weeding at 50 days and weed free up to maturity	17.5	14.8	15.7	16.0	24.9	100.0
Metribuzin 0.75 kg/ha as PE	19.9	19.3	20.9	20.0	6.1	60.6
Metribuzin 0.75 kg /ha as PoE at 10% of plant-emergence	19.1	18.5	19.7	19.1	10.3	58.6
Weedy check	10.8	9.1	9.3	9.80	54.0	0.0
Weed free	20.3	20.9	22.8	21.3	0.0	100.0
LSD (p=0.05)	1.04	1.09	1.31	1.10	-	-

recorded the highest WCE. The range of WCE among different weed management practices varied between 58.6 to 100% over the weedy check

Nutrient uptake

Maximum uptake of nutrient, *viz.* nitrogen (113.2 kg/ha), phosphorus (14.5 kg/ha) and potassium (89.4 kg/ha) by potato was recorded with weed free treatments followed by application of metribuzin 0.75 kg/ha as PE which was found significantly superior over other treatments (**Table 4**). Prasad and Singh (1995) reported that adoption of weed control measures significantly increased the NPK uptake by the crop compared with the weedy control. The minimum uptake of the major nutrients (NPK) was recorded under weedy check treatment. This might be due to poor yield of potato under weedy check treatment. Higher yield was directly proportional to the quantity of nutrients uptake either by crop or weeds. More uptake of nutrient by the crop indicated the higher yield and better competitiveness of crop against weeds. Better competitiveness of crop also reduces the losses of nutrients in the form of uptakes by the weeds. Because of the higher bio-efficacy of weed management practices emphasised the uptake of nutrients by the crops and reducing the uptake of nutrients by the weeds. In contrast to weedy check treatment where uptake of nutrients was found more by the weeds than the crop. This indicates there was wastage of nutrients by the weeds instead of utilization of nutrients by the potato crop.

Nutrient balance sheet

Maximum improvement in nutrient balance was recorded under the hand weeding at 50 DAP and weed free (**Table 5**). The competition between potato and weeds was higher due to presence of weeds upto 50 days crop growth stage (Karimmojeni *et al.* 2014). Both potato and weeds were recorded lower uptake of nutrients as compared to other treatments. This might be due to lower dry matter of weeds resulted in poor uptake of nutrient from the soil. Similarly, poor yield of potato due to presence of weeds resulted in poor uptake of nutrients by potato crop. As per treatments, weeding was done at 50 days after planting as just before maturity of weeds resulted in poor uptake of nutrients from the soil. Ultimately total uptake of nutrients was lower than other treatments (besides application of same recommended dose of fertilizers to potato in each treatment) resulted in more build-up of applied unutilized soil nutrients. The proportion of nutrient uptake in total uptake was found more by weeds than potato in weedy check treatments. This was might be due to lower yield of potato due to presence of weeds.

Economics

Application of metribuzin (at 0.75 kg/ha) reduced the cost of potato cultivation as compared to weed free check (**Table 6**). Weed free check required more labour for manual weeding when compared with herbicides application resulting in the higher cost of cultivation. Lower cost of cultivation and higher

Table 4. Impact of weed management practices on nutrient uptake (NPK) by potato and weed (pooled over 3 years)

Treatment	Nutrient uptake by potato kg/ha)			Nutrient uptake by weeds(kg/ha)		
	N	P	K	N	P	K
Hand weeding at 30 days and weed free up to maturity	96.6	12.6	76.7	1.1	0.3	1.1
Hand weeding at 40 days and weed free up to maturity	80.8	10.6	64.5	7.3	1.7	7.0
Hand weeding at 50 days and weed free up to maturity	74.8	10.2	59.7	8.9	2.2	9.0
Metribuzin 0.75 kg/ha as PE	112.1	14.2	86.9	7.5	1.7	7.3
Metribuzin 0.75 kg /ha as PoE at 10% of plant-emergence	106.0	13.2	82.5	7.8	1.8	7.7
Weedy check	43.3	5.4	33.9	56.7	13.0	51.9
Weed free	113.2	14.5	89.4	0.1	0.0	0.1
LSD (p=0.05)	4.6	0.5	3.5	2.4	1.0	2.7

Table 5. Effect of weed management practices on nutrients balance sheet (kg/ha) of soil (pooled over 3 years)

Treatment	Total nutrient applied (kg/ha)			Total uptake of nutrient (kg/ha)			Nutrient balance (kg/ha)		
	N	P	K	N	P	K	N	P	K
Hand weeding at 30 days and weed free up to maturity	140.0	52.5	49.8	97.6	12.9	77.8	42.4	39.6	-28.0
Hand weeding at 40 days and weed free up to maturity	140.0	52.5	49.8	88.1	12.3	71.5	51.9	40.2	-21.7
Hand weeding at 50 days and weed free up to maturity	140.0	52.5	49.8	83.7	12.3	68.7	56.3	40.2	-18.9
Metribuzin 0.75 kg/ha as PE	140.0	52.5	49.8	119.6	15.9	94.2	20.4	36.7	-44.4
Metribuzin 0.75 kg /ha as PoE at 10% of plant-emergence	140.0	52.5	49.8	113.8	15.0	90.2	26.2	37.6	-40.4
Weedy check	140.0	52.5	49.8	100.0	18.4	85.8	40.0	34.1	-36.0
Weed free	140.0	52.5	49.8	113.3	14.6	89.5	26.7	38.0	-39.7
LSD (p=0.05)	-	-	-	4.6	0.9	2.9	3.5	3.3	-3.4

Table 6. Economics of weed management practices in potato (×10³ `/ha) (pooled over 3 years)

Treatment	Seed	Fertilizers	Cultivation	Total cost	Net returns	B:C ratio
Hand weeding at 30 days and weed free up to maturity	30.0	14.3	50.4	94.7	117.8	1.2
Hand weeding at 40 days and weed free up to maturity	30.0	14.3	46.9	91.2	106.9	1.2
Hand weeding at 50 days and weed free up to maturity	30.0	14.3	43.5	87.7	104.0	1.2
Metribuzin 0.75 kg/ha as PE	30.0	14.3	30.8	75.0	176.1	2.3
Metribuzin 0.75 kg/ha as PoE at 10% of plant-emergence	30.0	14.3	30.8	75.0	164.9	2.2
Weedy check	30.0	14.3	27.8	72.1	46.5	0.6
Weed free	30.0	14.3	62.9	107.1	164.7	1.5
LSD (p=0.05)	-	-	3.2	2.4	6.8	0.3

yield in metribuzin application resulted in more net returns than other treatments. The maximum net returns (₹ 176100/ha) and the highest B:C ratio (2.3) was recorded under metribuzin application 0.75 kg/ha as a PE followed by metribuzin 0.75 kg/ha as a PoE at 10% of plant-emergence. Similar result was also reported by Channappagoudar *et al.* (2007)

It may be concluded that application of metribuzin 0.75 kg/ha either PE or as PoE at 10% of plant-emergence was found more effective to control the weeds in potato under the rainfed ecosystem of North-Eastern hill region of India.

REFERENCES

Capinera JL. 2005. Relationships between insect pests and weeds: an evolutionary perspective. *Weed Sciences* **53**(6): 892-901.

Channappagoudar BB, Biradar NR, Bharmagoudar TD and Koti RV. 2007. Crop weeds competition and chemical control of weeds in potato. *Karnataka Journal of Agricultural Sciences* **20**(4): 717-718.

Gugala M and Zarzecka K. 2013. Relationship between potato yield and the degree of weed infestation. *African Journal of Agricultural Research* **8**(46): 5752–5758.

Karimmojeni H, Barjasteh A, Mousavi RS and Bazrafshan AH. 2014. Determination of critical period of weed control in potato (*Solanum tuberosum* L.). *New Zealand Journal of Crop and Horticultural Sciences* **42**(3): 151–160.

Mishra JS, Singh VP and Yaduraju NT. 2002. Effect of methods of planting and metribuzin on weed growth and yield of potato (*Solanum tuberosum*) under *Vertisols.Indian Journal of Agricultural Sciences* **72**(5): 292–294.

Monteiro A, Henriques I and Moreira I. 2011. Critical period for weed control in potatoes in the Huambo province (Angola). *Planta Daninha* **29**(2): 351–362.

Mukherjee PK, Rahaman S, Maity SK and Sinha B. 2012. Weed management practices in potato (*Solanum tuberosum* L). *Journal of Crop and Weed* **8**(1): 178–180.

Prasad K and Singh RS. 1995. Influence of weed-control measures on weed growth, nutrient uptake and tuber yield of potato *(Solanum tuberosum). Indian Journal of Agricultural Sciences* **65**(1): 46–48.

Singh B. 2016. Survey and indexing of weeds growing around potato fields for their role as an inoculum source for potato leaf roll virus (PLRV).*British Biotechnology Journal* **16**(1): 1–8.

Singh Moolchand, Prabhukumar S, Sairam CV and Hanji MB. 2007. Evaluation of different herbicides for weed control in potato. *Indian Journal of Weed Sciences* **39**(3&4): 223–226.

Yadav SK and Srivastava AK. 2014. A review on agronomical aspects of potato production in north-eastern region of India. *International Journal of Applied and Pure Science and Agriculture* **1**(6): 26–34.

Yadav SK, Lal SS, Srivastava AK, Bag TK and Singh BP. 2015. Efficacy of chemical and non-chemical methods of weed management in rainfed potato (*Solanum tuberosum* L.). *Indian Journal of Agricultural Sciences* **85**(3): 382–386.

Yadav SK, Srivastava, AK, Gurjar MS and Bag TK. 2013. Major weeds of potato and thier management in Meghalalya hills. *AgrobiosNewslwtter* **11**(10): 45–46.

Yadav SK, Lal SS, Srivastava AK and Bag TK. 2014. A review on weed management in potato (*Solanum tuberosum*) in north eastern hill region of India. *International Journal of Agriculture. Photon* **125**: 279–284.

Yadav SK, Govindakrshanan PM, Dua VK and Bag TK. 2016. Effect of weed management practices on potato in NEH region of India, pp. 430–431. In: *4th International Agronomy Congress* held at New Delhi from 22-26th November 2016.

Indian Journal of Weed Science **53**(1): 59–66, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Germination ecology of heteromorphic seeds of bur clover (*Medicago denticulata* willd.)

Renu Sethi* and Navjyot Kaur

Department of Botany, Punjab Agricultural University, Ludhiana, Punjab 141004, India
Department of Plant Breeding and Genetics, PAU, Ludhiana, Punjab 141004, India
**Email: sethirenu6@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00008.3

Type of article: Research article

Received : 12 January 2020
Revised : 21 November 2020
Accepted : 24 November 2020

Key words
Burial depth
Light
pH
Salinity
Seed coat colour
Temperature

ABSTRACT

Bur clover (*Medicago denticulata* Willd.) is a winter annual weed commonly found in wheat fields of Punjab, India. We observed it produces heteromorphic seeds varying in seed coat colour - cream and brownish-black. The information on germination ecology of *M. denticulata* seeds varying in seed coat colour is lacking. So, the present study was undertaken under laboratory conditions to study the effect of seed coat colour on germination characteristics of *M. denticulata* seeds in relation to various environmental variables. Germination of both cream and brownish-black seeds was independent of light. Cream seeds germinated in the wide temperature range of 15/5 to 30/20°C; while, brownish-black seeds germinated in a narrow temperature range of 15/5 to 25/15°C. Cream seeds were able to withstand greater salinity stress as some seeds (10%) were able to germinate under NaCl concentration of 200 mM; whereas germination of brownish-black seeds was completely inhibited at 200 mM NaCl. The NaCl concentration required for 50% inhibition of maximum germination for cream and brownish-black seeds was 100 and 70.6 mM NaCl, respectively. The osmotic potential required for 50% inhibition of the maximum germination of cream and brownish-black seeds was -0.37 and -0.32 MPa, respectively. These results indicated a greater ability of cream seeds to tolerate either salinity or osmotic stress. Both seeds germinated under acidic and alkaline pH with >40% germination in pH range 3-10. The highest emergence of cream and brownish-black seeds was recorded when seeds placed on the soil surface.

INTRODUCTION

Seed heteromorphism is an important phenomenon which enables a single plant species to produce seeds with different shape, size, colour and germination behaviour (Baskin and Baskin 2014). The acquisition of seed coat colour depends on environment, sequential developments on the maternal plants and/or may be genetically inherited (Liu *et al.* 2007). Liu and Wei (2007) observed that the rate of germination of brown seeds of *Atriplex micrantha* was significantly higher as compared to black seeds at three tested temperatures *viz*., 5/15°C, 5/25°C and 15/25°C. Environmental factors such as temperature, light, soil pH, moisture and salinity modulate the germination and seedling growth and thereby influence the emergence of weed seedlings in the field (Koger *et al.* 2004). Light has been reported to promote germination of some weed species, *viz*. toothed dock (*Rumex dentatus*) and common lambs quarters (*Chenopodium album*) (Al-Helal 1996, Dekker 2014). On the contrary, some species like *Convolvulus arvensis* and *Lathyrus aphaca* (Kumari *et al.* 2010) best germinated under darkness. Temperature is directly related to water absorption and various biochemical reactions occurring in the seeds thereby regulating the germination process. Moisture is a basic requirement for germination and lack of water may delay, reduce, or prevent seed germination (Javaid and Tanveer 2014). Burial depth has also been reported to influence the germination, dormancy, and viability of seeds by influencing the availability of moisture and light (Chauhan and Johnson 2010).

Bur clover of fabaceae family, is an annual winter weed which has invaded many states of India, *viz*. Punjab, Haryana, Jharkhand, Bihar, Madhya Pradesh and West Bengal. Among the various dicotyledonous weeds, *M. denticulata* is the major problematic weed prevalent in wheat fields of Punjab (Chhokar *et al.* 2006). We observed that *M.*

Plate 1. Heteromorphic seeds (cream and brownish-black) of *Medicago denticulata* Willd.

denticulata produces heteromorphic seeds that differ in seed coat colour- cream and brownish-black (**Plate 1**). Some information is available on the effect of environmental factors on germination ecology of *M. Polymorpha* (Wagner and Spira 1994). However, no information is available regarding dormancy and germination response of heteromorphic seeds of *M. denticulata* in relation to various environmental factors. Detailed information on environmental factors which influence the seed germination process may help to optimize better weed management decisions. So, the present study was undertaken to evaluate the effect of seed coat colour on germination characteristics of *M. denticulata* seeds in relation to various environmental variables.

MATERIALS AND METHODS

Collection of seeds

Pods of *M. denticulata* containing mature seeds were collected from Research Farm, Department of Agronomy during the months of April 2016. Seeds were removed from pods immediately before use. Two seed lots - cream and brownish-black were prepared by visual inspection of seed coat colour. Brownish-black seeds were non-dormant and germinated rapidly after 1 month of harvest; while the cream seeds were dormant. They possessed seed coat imposed dormancy and were scarified by hand with sandpaper for 1 minute for breaking the dormancy before conducting each experiment.

Germination protocol

Seed germination was tested by placing 30 uniform sized seeds of *M. denticulata* from each seed lot in 9 cm Petri dishes lined with Whatman No. 1 filter paper. For studying the effect of light, temperature, moisture stress, salinity and pH, Petri dishes were moistened with 5 ml of treatment solution and incubated at 20°C (optimal temperature) in an environmental chamber (Model MAC MSW-127, Delhi, India). For the control treatment, seeds were germinated using distilled water only.

Temperature

Seed germination was tested under five alternate day/night temperatures (12 h light/12 h dark), *viz.* 15/5, 20/10, 25/15, 30/20 and 35/25°C using three replicates.

Light

To study the effect of light on germination, Petri dishes were kept under three light regimes- continuous light (24 h), light/dark (12/12 hours) using a light intensity of 85 mmol m^{-2} s^{-1} and continuous dark (24 h) at 20°C. In the latter treatment, Petri dishes were wrapped with double layers of aluminum foil immediately after adding distilled water to completely obstruct penetration of light. The data on germination counts were recorded on 15th day after the initiation of the experiment.

Moisture

The ability of seeds to germinate under different levels of moisture stress was tested using solutions of PEG 8000 having water potentials of 0, -0.1, -0.2, -0.4, -0.6, -0.8 and -1.0 MPa (Michel and Kaufmann 1973).

Salinity

The ability of seeds to germinate under different salt stress levels was examined by using NaCl solutions of 25, 50, 75, 100, 150, 200 and 250 mM concentrations.

pH

The effect of pH on seed germination was investigated using buffered solutions with pH ranging from 3 to 10 (Chachalis and Reddy 2000). Unbuffered distilled water (pH 6.6) was used as control.

Burial depth

This experiment was conducted using 25-cm diameter plastic pots placed under field conditions during November-December 2016-17 and 2017-18. Soil filled in these pots was collected from those fields which recorded no previous incidence of this weed. Fifty seeds of both seed lots were sown on the soil surface in pots and covered to a depth of 0, 1, 2, 4, 6, 8 and 10 cm. The pot surface was kept moistened throughout the study period. The emergence was recorded over a period of one month. One set of pots was also kept in which no seeding of this weed was done to eliminate the error. This experiment was conducted using four replications each time.

Observations recorded

Germination counts were daily made for 15 days after start of the experiment. The seeds showing visible protrusion of radicle were considered as germinated. Germination count was calculated as germination (%) = [Number of seeds germinated / total number of seeds] × 100.

Speed of germination (germination index) was calculated as described by Association of Official Seed Analysts (1983). Mean germination time (MGT) was calculated as suggested by Ellis and Roberts (1981). Seedling vigour index (SVI) was calculated using the following formula given by Abdul-Baki and Anderson (1973):

Seedling vigour index I = seedling length (cm) x germination (%)

Statistical analysis

All the experiments, were conducted three times in a completely randomized design using three replicates. data were pooled and analyzed (ANOVA) using statistical analysis software version 9.2 (SAS 2009). Means were separated at $\alpha \leq 0.05$ using Fisher's Protected Least Significant Difference (LSD) test.

RESULTS AND DISCUSSION

Effect of day/night temperature

Cream seeds possessed the ability to germinate in the temperature range of 15/5 to 30/20°C with the highest germination (%) at 25/15°C (**Table 1**). Maximum germination speed and minimum germination time was observed at day/night temperature of 25/15°C. Cream seeds germinated at day/night temperature of 30/20°C took one extra day for initiation of germination along with the reduced speed of germination and increased mean germination time. No germination of cream seeds was observed at day/night temperature of 35/25°C. Germination of brownish-black seeds occurred in a narrow temperature range of 15/5 to 25/15°C with maximum germination at 20/10°C; however, germination was completely inhibited at 30/20°C. Seeds exhibited maximum germination speed and minimum mean germination time at temperature 20/10°C. With an increase in temperature above 20/10°C, there was an increase in mean germination time along with a reduction in germination (%) and speed of germination. Cream seedlings grown at 25/15°C exhibited the greatest seedling vigour index indicating their higher competitiveness than seedlings grown at other temperatures. The highest vigour of brownish-black seedlings was recorded at 20/10°C temperature with a significant decrease in vigour index with further increase in temperature (**Figure 5a**). Like *M. denticulata*, many other dicotyledonous weeds such as *C. album* and *R. dentatus* have been reported to germinate under a wide range of temperature from 5-25°C (Benvenuti *et al.* 2001, Tanveer *et al.* 2009). The ability of weeds to germinate across a wide range of temperatures suggests their ability to emerge throughout the cropping season making weed management difficult. This flexible germination habit of weeds provides opportunities for weed proliferation, leading to abundant seed production. The results of present study indicate that cream seeds can germinate in a broad range of temperatures (15/5-30/20°C) whereas germination of brownish-black seeds can occur only in a narrow temperature range (15/5-20/10°C). This implies robust germination characteristics of cream seeds as compared to brownish-black seeds. It is also important to mention here that cream seeds exhibited germination only after scarification indicating seed coat-imposed dormancy and greater mechanical strength of cream seeds which could contribute to the perpetuation of seeds under adverse environmental conditions. Cream seeds may also be able to emerge in multiple flushes as and when their seed coat-imposed dormancy is relieved under natural conditions. A gradual loss of physical dormancy under natural conditions could be due to the action of soil microbes on the seed coat or abrasion of seed coat by soil particles (Zalamea *et al.* 2015).

Effect of light

Germination of both cream and brownish-black seeds did not differ significantly under light and dark conditions, which indicates that seeds of this species are non-photoblastic (**Figure 1**). However, dark

Table 1. Effect of day/night temperature regime on germination of cream and brownish-black seeds of *M. denticulata*

Temperature (°C) (12 h light/12 h dark)	Germination (%)		Time to start germination (days)		Germination speed		Mean germination time (days)	
	C	B	C	B	C	B	C	B
15/5	65.5	54.4	2.0	2.0	4.4	4.2	6.2	6.4
20/10	88.7	80.0	2.0	2.0	10.1	9.0	3.3	3.4
25/15	96.6	72.2	2.0	2.0	10.4	7.2	3.1	4.6
30/20	54.4	NG	3.0	NG	2.8	NG	6.6	NG
35/25	NG	NG	NG	NG	NG	NG	NG	NG
LSD (p=0.05)	7.67	7.52	3.4×10^{-6}	2.4×10^{-6}	0.17	0.13	0.11	0.12

C-Seeds with cream seed coat; B-Seeds with brownish-black seed coat; LSD- Least significant difference; NG-No germination grown seedlings of both were etiolated having pale yellow coloured leaves and elongated shoots. Dark grown cream and brownish black seedlings exhibited higher values of seedling vigour index I than seedlings growing under light conditions (**Figure 5b**). Light is an important ecological determinant for germination and the absence of light acts as a soil depth indicator that prevents germination of many weed species (Crisraudo *et al.* 2007). Seed germination response to light may vary considerably from species to species.

Ghadiri and Niazi (2005) reported that light effectively stimulated germination of dicotyledonous weeds - *R. dentatus* and *C. album* which indicates that both species are positively photoblastic and germination in the field will be favoured by presence of seeds at the soil surface. The results of present study indicate that unlike these winter weeds, germination of both cream and brownish-black seeds of *M. denticulata* is independent of light, so this weed can emerge not only from soil surface but also from different soil depths. Thus, as a management strategy, tillage operations that invert soil and bury seeds in deeper soil layers may not be successful in preventing the germination of this weed.

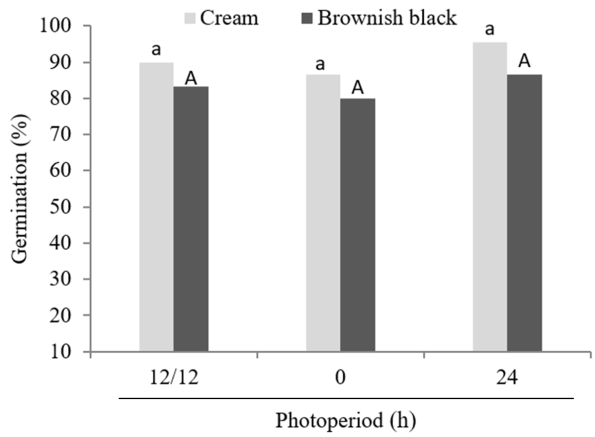


Figure 1. Effect of light on germination of cream and brownish-black seeds of *M. denticulata* Willd. under variable photoperiod. Columns followed by same lower case (cream) and upper-case letters (brownish-black) do not differ significantly at 5% level of significance

Effect of moisture stress

Both cream and brownish-black seeds were sensitive to moisture stress as evident from a progressive decrease in germination with an increase in mean germination time at osmotic potential (**Table 2**). Maximum germination in both the seeds was recorded in control with complete inhibition at osmotic potential of $\alpha \leq -0.6$ MPa. At -0.4 MPa, brownish-black seeds took six days to start germination in comparison to cream seeds in which germination started on 3rd day of incubation. Osmotic potential of -0.4 MPa reduced the germination of cream seeds by 57 percent points with 2.2 fold increase in mean germination time than control. Whereas brownish-black seeds recorded 62 percent point reduction in germination with a 3 fold increase in mean germination time as compared to control. Moisture stress exhibited a more pronounced effect on brownish-black seeds than cream seeds. The osmotic potential required for 50% inhibition of the maximum germination of cream and brownish-black seeds was -0.37 and -0.32 MPa, respectively (**Figure 2a and b**). The cream and brownish-black seedlings grown at osmotic potential -0.4 MPa recorded 79.2 and 88.2% reduction in seedling vigour index I as compared to their respective controls (**Figure 5c**).

Bargali and Bargali (2016) reported that population of *M. denticulata* from the Himalayan region of India recorded a decrease in germination from 51 to 10% as the water stress level increased from 0 to -1.0 MPa with complete inhibition at -1.5 and - 2.0 MPa. In contrast to this, germination of our population was completely inhibited even at osmotic potential of -0.6 MPa which indicates that different biotypes of the same weed have differential tolerance to moisture stress. The results of our study suggest that germination of brownish-black seeds would be more adversely affected by moisture stress.

Table 2. Effect of moisture stress on germination of cream and brownish-black seeds of *M. denticulata*

Osmotic potential (MPa)	Germination (%)		Time to start germination(days)		Germination speed		Mean germination time (days)	
	C	B	C	B	C	B	C	B
0 (Control)	95.5	85.5	2.0	3.0	10.9	9.9	3.0	3.1
-0.1	84.4	80.0	2.0	3.0	9.4	8.8	3.3	3.4
-0.2	78.8	73.3	2.0	3.0	8.4	7.8	3.5	3.6
-0.4	38.8	23.3	3.0	6.0	3.6	2.8	6.6	9.3
-0.6	NG	NG	NG	NG	NG	NG	NG	NG
-0.8	NG	NG	NG	NG	NG	NG	NG	NG
-1.0	NG	NG	NG	NG	NG	NG	NG	NG
LSD (p=0.05)	5.98	6.38	1.4×10^{-5}	1.4×10^{-5}	0.09	0.17	0.14	0.09

C-Seeds with cream seed coat; B-Seeds with brownish-black seed coat; LSD-Least significant difference; NG-No germination

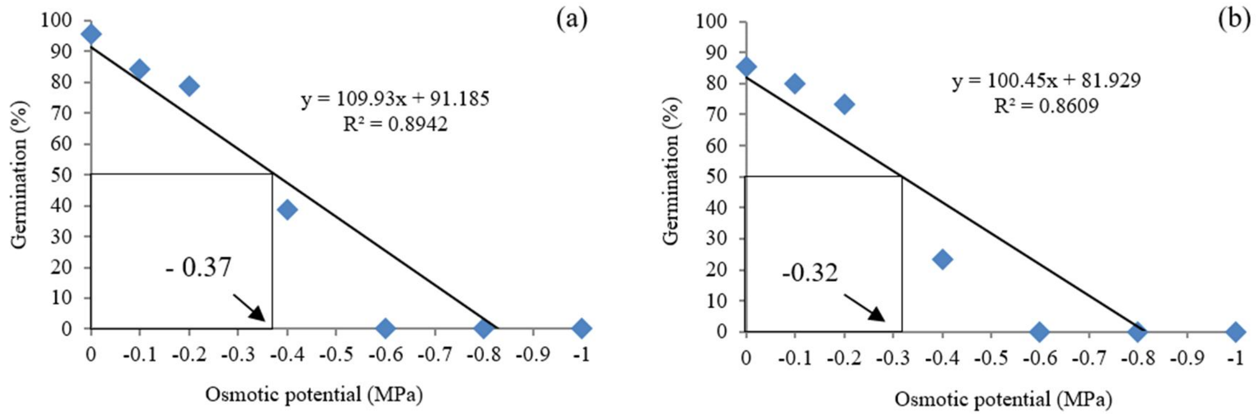


Figure 2. Osmotic potential required for 50% inhibition of maximum germination in (a) seeds with cream seed coat and (b) seeds with brownish-black seed coat. Osmotic potential required for 50% inhibition of germination is shown by an arrow

Tolerance of cream seeds to moisture stress is consistent with their dormancy characteristics whereas brownish-black seeds are more sensitive to moisture stress. The differential response to tolerate moisture stress conditions of heteromorphic seeds might be a survival mechanism in *M. denticulata* under adverse environmental conditions.

Effect of salinity

Salinity stress caused a significant decrease in germination and speed of germination with concomitant increase in mean germination time in both cream and brownish-black seeds (**Table 3**). Increasing NaCl concentrations above 50 mM was more detrimental to germination of brownish-black seeds than cream seeds. At 150 mM NaCl concentration, germination of cream seeds was decreased by 73.3% with a 2.8 fold increase in mean germination time than control. Whereas brownish-black seeds recorded 78.9% reduction in germination with a 2.8 fold increase in mean germination time as compared to control. The NaCl concentration required for 50% inhibition of maximum germination for cream and brownish-black seeds was 100 and 70.6 mM NaCl, respectively (**Figure 3a and b**). Cream seeds were fairly tolerant to salinity stress as some seeds (10%) were able to germinate up to NaCl concentration of 200 mM in contrast to brownish-black seeds whose germination was completely inhibited at 200 mM NaCl. Seedling vigour index of cream and brownish-black seedlings was reduced by 91.1 and 95.6% at NaCl concentration of 150 mM (**Figure 5d**).

Salinity is an important abiotic factor affecting seed germination. It reduces both germination rates as well as root growth of seedlings. The ability to withstand saline conditions may vary from species to species. Guan *et al.* (2009) reported that germination of *M. ruthenica* was maximum in control (100%) with >80% germination at NaCl concentration of 50 and 100 mM. However, salinity stress of 200 mM declined the germination to 55%. In contrast to this, in the present study germination of both cream and brownish-black seeds of *M. denticulata* was <50% at 100 mM with complete inhibition at NaCl concentration of 250 and 200 mM, respectively. These results clearly show that seeds of *M. denticulata* irrespective of their seed coat colour are more sensitive to salinity stress as compared to *M. ruthenica*. Yao *et al.* (2010) exposed heteromorphic seeds (brown and black) of *C. album* to salinity and found that brown seeds were non-dormant and more

Table 3. Effect of sodium chloride (NaCl) on germination of cream and brownish-black seeds of *M. denticulata*

NaCl (mM)	Germination (%)		Time to start germination (days)		Germination speed/index		Mean germination time (days)	
	C	B	C	B	C	B	C	B
0 (Control)	95.5	85.5	2.0	2.0	10.7	9.8	3.1	3.2
25	80.0	73.3	2.0	2.0	9.8	8.6	3.5	3.7
50	72.2	62.2	3.0	3.0	8.6	7.3	3.9	4.3
75	63.3	46.6	3.0	4.0	7.2	6.2	5.2	4.9
100	46.6	20.0	4.0	4.0	3.8	4.4	7.6	6.5
150	22.2	6.6	5.0	5.0	2.3	3.4	9.1	9.1
200	10.0	NG	6.0	NG	0.3	NG	10.1	NG
250	NG	NG	NG	NG	NG	NG	NG	NG
LSD (p=0.05)	5.61	5.92	1.3×10^{-5}	1.3×10^{-5}	0.16	0.10	0.19	0.15

C-Seeds with cream seed coat; B-Seeds with brownish-black seed coat; LSD-Least significant difference; NG-No germination

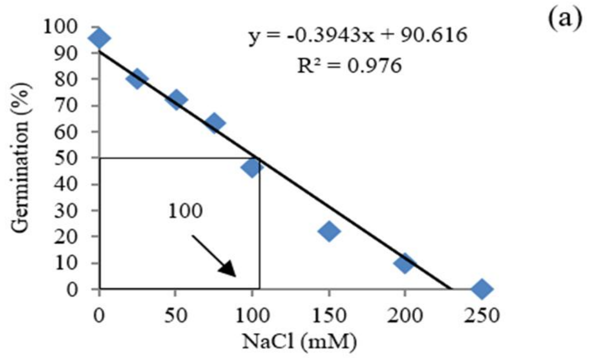


Figure 3. NaCl concentration required for 50% inhibition of maximum germination in (a) seeds with cream seed coat and (b) seeds with brownish-black seed coat of *M. denticulata*. Sodium chloride concentration required for 50% inhibition of germination is shown by an arrow

tolerant of salinity as compared to black seeds which were salt sensitive and a large proportion of seeds was dormant. In contrast to this, the results of our study demonstrate that non-dormant brownish-black seeds were more sensitive to salinity as compared to cream seeds which were dormant and showed increased tolerance against salinity.

Effect of pH

The highest germination of both cream and brownish-black seeds was recorded in control having pH 6.6 and lowest at pH 3 (**Table 4**). However, both seeds were able to germinate under both acidic and alkaline pH with >40% germination in pH range 3-10 which implies that germination of both seeds is not likely to be limited by soil pH. However, at pH 3, germination of brownish-black seeds was reduced to 46.6% as compared to cream seeds with more than 50% germination. This indicates that cream seeds are more tolerant to acidic pH. The maximum time to start germination in both cream and brownish-black seeds was recorded at pH 3 and 4 indicating that acidic conditions delayed the onset of germination. At pH 3, the germination index of both cream and brownish-black seeds was minimum and the mean germination time was longest. The highest values of seedling vigour index I for both cream and brownish-black seeds were recorded in control and lowest at pH 3 **(Figure 5e**).

Bullitta *et al.* (1994) reported that favorable growth of *M. polymorpha* is usually restricted to soils with a pH of 4.7-8. Graziano *et al.* (2010) reported that *M. polymorpha* is well adapted to alkaline soils. However, it has also been shown to grow on

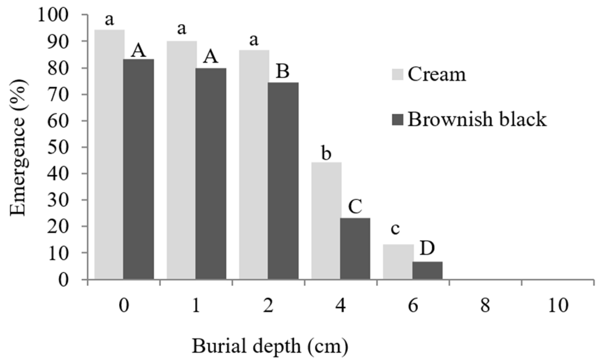


Figure 4. Effect of burial depth on emergence of cream and brownish-black seeds of *M. denticulata*. Columns with same lower case (cream) and upper case letters (brownish-black) do not differ significantly at 5% level of significance

Table 4. Effect of pH on germination of cream and brownish-black seeds of *M. denticulata*

pH	Germination (%)		Time to start germination (days)		Germination speed		Mean germination Time (days)	
	C	B	C	B	C	B	C	B
Control (6.6)	92.2	83.3	2.0	2.0	10.8	9.8	3.0	3.3
3	55.5	46.6	4.0	4.0	6.0	5.2	6.1	7.2
4	60.0	53.3	4.0	4.0	6.4	5.9	5.7	6.2
5	63.3	58.8	2.0	2.0	8.5	8.9	3.7	4.7
6	83.3	76.6	2.0	2.0	10.2	9.3	3.3	3.5
7	86.6	78.8	2.0	2.0	10.5	9.5	3.1	3.4
8	80.0	74.4	2.0	2.0	10.4	9.3	3.5	3.5
9	80.0	72.2	2.0	2.0	10.3	9.1	3.4	3.6
10	76.6	68.8	2.0	2.0	9.8	8.4	3.6	4.1
LSD (p=0.05)	4.66	4.54	1.3×10^{-5}	1.3×10^{-5}	0.18	0.24	0.26	0.25

C-Seeds with cream seed coat; B-Seeds with brownish-black seed coat; LSD-Least significant difference moderately acidic soils due to its tolerance to acidic conditions. In the present study also, germination of both cream and brownish-black seeds occurred in acidic pH range of 3-5. The pH of agricultural lands in Punjab varies from 7 to 8. In this pH range, *M. denticulata* possessed 80-86% germination, indicating that pH is not likely to be a limiting factor for the germination of this weed.

Effect of burial depth

The maximum emergence of both cream and brownish-black seeds was recorded from surface placed seeds (**Figure 4**). There was a progressive decline in emergence of both seeds with an increase in burial depth from 1-4 cm. At 4 cm depth, the emergence of cream and brownish-black seeds was reduced by 52 and 60 percent points as compared to surface placed seeds. The emergence of cream and brownish-black seeds was 13.3 and 6.6%, respectively at burial depth of 6 cm. No emergence was observed from seeds placed at a depth of 8 cm or deeper. The requirement of light and limited availability of storage reserves are major constraints for the reduced emergence of weeds from deeper soil layers (Bullied *et al.* 2012).

Results of our study indicate that germination of both cream and brownish-black seeds of *M. denticulata* was independent of light enabling the weed to emerge from soil depths of 6 cm owing to the bigger seed size (1000 seed weight of cream and brownish-black seeds was 3.56 and 3.65 g respectively). However, small-seeded species like *Poa annua* (1000 seed weight = 0.3 g) and *R. dentatus* (1000 seed weight = 2.33 g) may not have enough energy reserves to support their emergence from deeper soil depths which could be responsible for their emergence only from shallow soil depths (less than 3 cm).

Conclusion

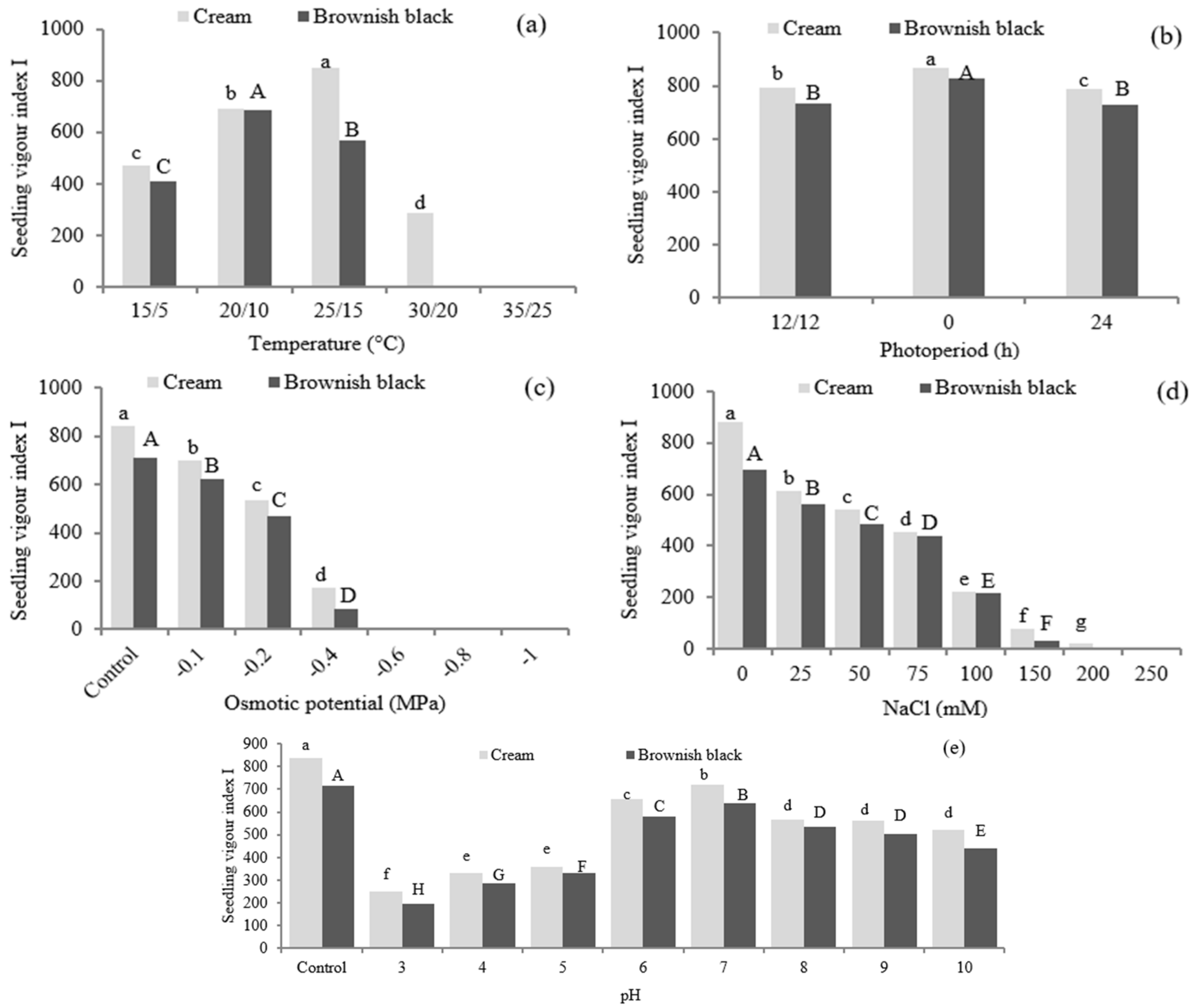


Figure 5. Effect of temperature (a), photoperiod (b), moisture stress (c), salinity (d) and pH (e) on seedling vigour index I of *M. denticulata*. Columns with same lower case (cream) and upper-case letters (brownish-black) do not differ significantly at 5% level of significance

Cream seeds of *M. denticulata* can germinate in a broad range of temperatures whereas germination of brownish-black seeds can occur only in a narrow temperature range. At 30/20°C, germination of brownish-black seeds is completely inhibited and cream seeds exhibited 54.4% germination. Germination of cream as well as brownish-black seeds was independent of light which indicates that both seeds might have an equal chance of germination when present on the soil surface or buried in the soil profile. However, seeds buried to 6 cm or greater depths are most likely to get their food reserves exhausted before the emergence of seedlings. The study also indicates that cream seeds of *M. denticulata* possessed a greater ability to tolerate salinity and moisture stress as compared to brownish-black seeds. Seed germination over a broad pH range (3-10) indicates that pH is not a limiting factor for germination of cream and brownish-black seeds.

REFERENCES

Abdul-Baki AA and Anderson JD. 1973. Vigour determinations in soybean seed multiple criteria. *Crop Science* **13**: 630–633.

Al-Helal AA. 1996. Studies on germination of *Rumex dentatus* L. seeds. *Journal of Arid Environment* **33**: 39–47.

Association of Official Seed Analysts 1983. Rules for testing seeds. *Journal of Seed Technology* **16**:1–113.

Bargali K and Bargali SS. 2016. Germination capacity of seeds of leguminous plants under water deficit conditions: Implication for restoration of degraded lands in Kumaun Himalaya. *Tropical Ecology* **57**: 445–453.

Baskin CC and Baskin JM. 2014. *Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination*, 2nd edition. Academic Press, CA, USA.

Benvenuti S, Macchia M and Miele S. 2001. Light, temperature and burial depth effects on *Rumex obustifolius* seed germination and emergence. *Weed Research* **41**: 177–186.

Bullied WJ, Van Acker RC and Bullock PR. 2012. Review: Microsite characteristics influencing weed seedling recruitment and implications for recruitment modelling. *Canadian Journal of Plant Science* **92**: 627–650.

Bullitta S, Hayward MD, Loi A, Porqueddu C and Veronesi F. 1994. Morphological and biochemical variation in Sardinian populations of *Medicago polymorpha* L. suitable for rain fed Mediterranean conditions. *Euphytica* **77**: 263–268.

Chachalis D and Reddy KN. 2000. Factors affecting *Campsis radicans* seed germination and seedling emergence. *Weed Science* **48**: 212–216.

Chauhan BS and Johnson DE. 2010. The role of seed ecology in improving weed management strategies in the tropics. *Advances in Agronomy* **105**: 221–262.

Chhokar RS, Sharma RK, Chauhan BS and Mongia AD. 2006. Evaluation of herbicides against *Phalaris minor* in wheat in north-western plains. *Weed Research* **46**: 40–49.

Crisraudo A, Gresta F and Resticcia A. 2007. Effects of after harvest period and environmental factors on seed dormancy of *Amaranthus* species. *Weed Research* **47**: 327–334.

Dekker J. 2014. The effects of light, temperature, after-ripening, nitrate and water on *Chenopodium album* seed germination. *Environmental and Ecological Research* **2**: 80–90.

Ellis RA and Roberts EH. 1981. The quantification of ageing and survival in orthodox seeds. *Seed Science and Technology* **9**: 373–409.

Ghadiri H and Niazi M. 2005. Effects of stratification, scarification, alternating temperature and light on seed dormancy of *Rumex dentatus*, *Amaranthus retroflexus* and *Chenopodium album*. *Iranian Journal of Weed Science* **1**: 93–109.

Graziano D, Giorgio G, Ruisi P, Amato G and Giambalvo D. 2010. Variation in pheno-morphological and agronomic traits among burr medic (*Medicago polymorpha* L.) populations collected in Sicily, Italy. *Crop Pasture Science* **61**: 59–69.

Guan B, Zhou D, Zhang H, Tian Y, Japhet W and Wang P. 2009. Germination responses of *Medicago ruthenica* seeds to salinity, alkalinity and temperature. *Journal of Arid Environment* **73**: 135–138.

Javaid MM and Tanveer A. 2014. Germination ecology of *Emex spinosa* and *Emex australis* invasive weeds of winter crops. *Weed Research* **54**: 564–575.

Koger C, Reddy KN and Poston DH. 2004. Factors affecting seed germination, seedling emergence, and survival of texas weed (*Caperonia palustris*). *Weed Science* **52**: 989–995.

Kumari A, Singh K, Yadav A and Singh S. 2010. Factors affecting seed germination of *Convolvulus arvensis* and *Lathyrus aphaca*. *Weed Science* **42**: 203–211.

Liu PW and Wei Y. 2007. Seed dimorphism and germination behaviour of *Atriplex micrantha*, an annual in habiting Junggar desert. *Acta Ecologica Sinica* **27**: 4233–4239.

Liu W, Peffley EB, Powell RJ, Auldb DL and Hou A. 2007. Association of seed coat color with seed water uptake, germination and seed components in guar (*Cyamopsis tetragonoloba* (L.) Taub). *Journal of Arid Environment* **70**: 29–38.

Michel BE and Kaufmann MR. 1973. The osmotic potential of polyethylene glycol 6000. *Plant Physiolology* **51**: 914–916.

SAS. 2009. *Statistical Analysis Systems*, SAS/STAT User's Guide. SAS Institute, Cary, NC, USA.

Tanveer A, Nadeem MA, Ali A, Tahir M and Zamir MSI. 2009. Germination behaviour of seeds from herbicide treated plants of *Chenopodium album* L. *Annals of Brazilian Academy and Sciences* **81**: 873–879.

Wagner LK and Spira T P. 1994. Germination, recruitment and survival in the weedy annual *Medicago polymorpha* in successive wet and dry years. *American Midland Naturalist* **131**: 98–108.

Yao S, Lan H and Zhang F. 2010. Variation of seed heteromorphism in *Chenopodium album* and the effect of salinity stress on the descendants. *Annals of Botany* **105**: 1015–1025.

Zalamea PC, Sarmiento C, Arnold AE, Davis AS and Dalling JW. 2015. Do soil microbes and abrasion by soil particles influence persistence and loss of physical dormancy in seeds of tropical pioneers?. *Frontiers in Plant Science* **5**: 1–14.

Indian Journal of Weed Science **53**(1): 67–72, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Dissipation kinetics and harvest time residues of pyrazosulfuron-ethyl + pretilachlor in rice

Ambily Paul* and Thomas George

College of Agriculture, Vellayani, Thiruvananthapuram, Kerala Agricultural University, Kerala 695 522, India

**Email: ambily.paul@kau.in*

Article information

DOI: 10.5958/0974-8164.2021.00009.5

Type of article: Research article

Received : 3 September 2020
Revised : 7 January 2021
Accepted : 11 January 2021

Key words

Dissipation

Half-life

Pretilachlor

Pyrazosulfuron-ethyl

Residues

Rice

ABSTRACT

The study on dissipation and harvest time residues of pyrazosulfuron-ethyl 0.75% and pretilachlor 30% WG after foliar application at seedling stage in rice at two doses 2000 g/ha (15 + 600 g/ha) and 4000 g/ha (30.0 + 1200 g/ha) was conducted at Integrated Farming System Research Station, Kerala Agricultural University, Thiruvananthapuram, Kerala. The pyrazosulfuron-ethyl and pretilachlor residues were estimated using LCMS/MS. The mean initial deposit of pyrazosulfuron-ethyl at recommended and double the recommended doses were 0.18 and 0.48 mg/kg, respectively. The residue dissipated with time and reached below limit of quantification (LOQ) of 0.01 mg/kg after 5 days in the recommended dose and 7 days in double the recommended dose. The mean initial deposit of pretilachlor at recommended and double the recommended dose were 8.84 and 15.50 mg/kg, respectively. The residue dissipated with time and reached below LOQ of 0.05 mg/kg within 15 days both in the recommended and double the recommended dose. The half-life values (days) were 1.29 and 1.80 for pyrazosulfuron-ethyl and 1.88, 1.37 for pretilachlor at recommended and double the recommended doses, respectively. In addition, the harvest time residues of pyrazosulfuron-ethyl 0.75% + pretilachlor 30% WG were estimated in samples of rice grain, husk, straw and cropped soil and were found below LOQ.

INTRODUCTION

Pyrazosulfuron-ethyl (Ethyl 5-[(4,6-dimethoxypyrimidin-2-ylcarbamoyl) sulfamoyl]-1-methylpyrazole-4-carboxylate) is a sulfonylurea herbicide for rice with excellent herbicidal activity in both pre- and post-emergence applications. It is different from other sulfonylurea herbicides in the substitutions on the pyrazolexring and does not include a triazinic and pyridinic ring (Sarmah and Sabadie 2002). Therefore, common degradation pathways occurring for sulfonylureas, such as O- and N-dealkylation of the group on the triazine ring or triazine ring opening to form a triuret does not take place in pyrazosulfuron-ethyl. Rajkhowa *et al.* (2006) reported that pyrazosulfuron-ethyl at 20 g/ha was as effective as butachlor 1250 g/ha in reducing weed growth and increasing grain yield of rice.

Pretilachlor (2-chloro-N-(2, 6-diethylphenyl)-N-(2-propoxyethyl) acetanilide) belongs to the chloroacetanilide group and is used as pre-emergence and early post-emergence herbicide for the control of annual grasses and some broad-leaved weeds such as *Echinochloa crus-galli* and *Ischaemum rugosum* in both seeded and transplanted fields (Han and Hatzios 1991). Chauhan *et al.* (2014) reported that broad spectrum of weed flora can be easily managed by a lower dosage of pretilachlor in wet-seeded rice; however, the dose needs to be increased to 900 g/ha in order to decrease the weedy rice problem. Increased yield in rice was reported in pretilachlor treated rice as reported in Thailand (Allard *et al.* 2005), China (Shen *et al.* 2013), Vietnam (Chauhan *et al.* 2015). This response was observed mainly due to less crop-weed competition in the pretilachlor treated plots.

Pyrazosulfuron-ethyl 0.75% + pretilachlor 30% WG is the combination product for better weed management and having the highest weed control efficiency (Dibyendu *et al.* 2018). The studies on the dissipation of herbicide mixture, pyrazosulfuron-ethyl 0.75% + pretilachlor 30% WG in rice soil and water was studied by Ezhilarasi *et al.* (2018). In present study, the dissipation of these molecules was studied in rice plant and harvest time residues were also determined in rice grain, husk, straw and soil.

MATERIALS AND METHODS

Chemicals and reagents

Certified reference materials (≥95% purity) of pyrazosulfuron-ethyl and pretilachlor and formulation of pyrazosulfuron-ethyl 0.75% + pretilachlor 30% WG (UPH-814) were received from M/s UPL Ltd, Mumbai. Standard solution of pyrazosulfuron-ethyl and pretilachlor prepared with HPLC grade acetonitrile and suitably diluted to obtain the working standards. Acetonitrile, hexane and methanol of LiChrosolv grade, sodium chloride, anhydrous sodium sulphate, and anhydrous magnesium sulphate of GR grade were purchased from Merck Specialities Private Limited, Mumbai and the solid reagents were activated before use. Primary secondary amine (PSA) sorbent was purchased from Agilent Technologies, USA. All the glass wares were thoroughly washed as per the standard operating procedure to avoid the interferences from any contaminants during analysis. The suitability of solvents and other chemicals were ensured by running reagent blanks before actual analysis.

Recovery experiment

Recovery studies were carried out in order to establish the reliability of the analytical methods and to know the efficiency of extraction and clean up step for the present study by fortifying rice separately with pyrazosulfuron ethyl and pretilachlor. For pyrazosulfuron-ethyl, recovery experiment was done at 0.01mg/kg (limit of quantification- LOQ), 0.05 mg/kg (5 X LOQ) and 0.10 mg/kg (10 X LOQ) level and for pretilachlor at 0.05 mg/kg (LOQ), 0.25 mg/kg (5 X LOQ) and 0.50 mg/kg(10 X LOQ) level.

Field experiment

Persistence of herbicides: Rice (var. *Uma*) was raised at Integrated Farming System Research Station, Kerala Agricultural University, Karamana, Thiruvananthapuram, Kerala (8°28'54.41"N latitude and 76°57'56.69"E longitude at an altitude of 25.22 m above mean sea level) adopting the package of practices recommendations of Kerala Agricultural University to conduct the studies on dissipation of pyrazosulfuron-ethyl and pretilachlor. The trial was laid out in randomized block design (RBD) replicated thrice with a plot size of 25 m^2 with three treatments, *i.e.* recommended (X), double the recommended dose (2X) and control. Pyrazosulfuron-ethyl 0.75% and pretilachlor 30% WG was sprayed in rice plants at two doses, at recommended dose 2000 g/ha (15 + 600 g/ha) and at double the recommended dose 4000 g/ha (30.0 + 1200.0 g/ha). Spraying was done once at seedling stage and the persistence of residues in rice green foliage was carried out from 2 hrs after the application of herbicides. About 500 g samples of rice was collected at 0 (within 2 hrs), 1, 3, 5, 7, 10, 15 days after the application. Three samples were collected from each replication corresponding to each treatment. The harvest time residues of rice grain, straw, husk and soil were also estimated.

Harvest time residues: In order to find out the multi-location harvest time residues of pyrazosulfuron-ethyl 0.75% and pretilachlor 30% WG in rice grain, husk, straw and cropped soil, field trials were conducted at three different locations, *viz*. 1. G.B. Pant University of Agriculture & Technology (GBPUAT), Pantnagar; Uttarakhand 2. Orissa University of Agriculture and Technology (OUAT), Bhubaneshwar, Odisha and 3. National Institute of Biotic Stress Management (NIBSM), Raipur, Chhattisgarh, based on the agro-climatic zone variation. The lay out of the experiment and dosage of spraying and schedule was same as explained in persistence study. Harvested samples of rice grain, husk, straw and cropped soil were collected from the field along with untreated control (weedy check) in all location and received at AINP on Pesticide Residue, Kerala Agricultural University, College of Agriculture, Vellayani, Kerala under dry ice condition for analysis.

Extraction and clean-up

Green foliage and rice grain: 500 g each of green foliage and rice grain was blended and from which 25 g was taken, added 50 ml acetonitrile and homogenized at 14,000 rpm for 2 min. The samples were shaken for 4 min after adding 10 g sodium chloride. The samples were then centrifuged for 5 min at 2500 rpm. A 16 mL supernatant was transferred in to 50 mL centrifuge tube containing 6 g anhydrous Na_2SO_4 and mixed well using high speed vortex shaker for 2 min. 12 ml extract was transferred to a 15 mL centrifuge tube containing 0.2 ± 0.01 g PSA sorbent and 1.2 ± 0.01 g anhydrous $MgSO_4$, shaken and centrifuged for about 3 min at 2500 rpm. five ml of the extract was evaporated in a turbovap and made up to 2 ml using methanol for LC-MS/MS analysis.

Straw/husk: 100 g of straw/husk taken from three treatments were powdered and from which 5 g was taken, added 40 ml distilled water containing 10g sodium chloride and kept for 1 hour, mixed well for uniform wetting and then 50ml acetonitrile was added. The samples were shaken for 10 min and were centrifuged for five min at 2500 rpm. A 25 mL supernatant was transferred in to 50 mL centrifuge tube containing 5 g anhyd. Na_2SO_4 and mixed well using high speed vortex shaker for 2 min, then centrifuged for 3 min at 2500 rpm. 10 ml supernatant was transferred to a 15 mL centrifuge tube containing 0.125 ± 0.01 g PSA sorbent and 2.00 ± 0.01 g anhy. $MgSO_4$. The sample was mixed well using high speed vortex shaker for 2 min and centrifuged for about 3 min at 2500 rpm. 5 ml of the extract was evaporated in a turbovap at 45^0C and made up to 2 ml using methanol for LC-MS/MS analysis. Injected at LC-MS/MS with Atlantic dc-18 column, at 40^0C using methanol-water mobile phase.

Soil: Analysis of soil was done by the method suggested by Asensio-Ramos *et al*. (2010) with slight modification**.** Soil samples (500 g) taken from three treatments were air dried and sieved through 2 mm sieve. Ten-gram soil sample was transferred to a 50 mL polypropylene tube to which 20 mL acetonitrile, 4 g $MgSO_4$ (activated) and 1 g NaCl were added and shaken vigorously for one minute. The contents were centrifuged at 3300 rpm for 4 min and 10 mL of the supernatant was transferred to another 15 mL polypropylene centrifuge tube containing 1.5 g of magnesium sulphate and 0.25 g of primary secondary amine (PSA). The contents were shaken for 30 seconds and then centrifuged for 10 min at 4400 rpm from which 4 mL aliquot of the supernatant was taken and evaporated to dryness using Turbovap at 40 ^{0}C. The dry residue was reconstituted to 1 ml in methanol for LC-MS/MS analysis.

Instrumentation

Pyrazosulfuron-ethyl: Analytical grade (0.0101 g; 99.7%) pyrazosulfuron-ethyl was weighed and transferred to a 25 mL volumetric flask using the methanol. The volume was made up to the mark with methanol to give 400 mg/kg stock solution of pyrazosulfuron-ethyl and from this stock solution, 10 mg/kg intermediate standard was prepared. From 10 mg/L stock, 1.00, 0.50, 0.25, 0.10, 0.05, 0.025 and 0.01 mg/L were prepared.

Pretilachlor: Analytical grade (0.0100 g; 98.4%) pretilachlor was weighed and transferred to a 25 mL volumetric flask using the methanol. The volume was made up to the mark with methanol to give 400 mg/kg stock solution of pretilachlor. From this stock solution, 10 mg/kg intermediate standard was prepared. From this, 1, 0.5, 0.25, 0.10, 0.05 mg/kg concentrations were prepared. Calibration of the equipment was performed using pure analytical standard of the test material at concentration ranging from 0.025 to 1.0 mg/L and the response/area obtained was plotted against concentration. The response was found linear in the concentration tried (0.025 – 1.0 mg/kg) as evident from the calibration curve attached in annexure. The correlation coeficient (r^2) value obtained was 0.9952 indicating perfect linearity.

Estimation of pyrazosulfuron-ethyl and pretilachlor in LC MS/MS

Analysis of pyrazosulfuron-ethyl and pretilachlor was carried out in LC-MS/MS (Applied Biosystems API-3200) triple quadrupole MS/MS with electro spray ionization (ESI) in the positive mode coupled to a Waters LC (Acquity UPLC ™), which includes a binary pump, column oven and auto sampler.

Mass spectrometry parameters

The chromatographic separation was achieved using Waters Acquity UPLC system equipped with a reversed phase Atlantis d C-18 (2.1 × 100 mm, 5-micron particle size) column. A gradient system involving the following two-eluent components: A: 10% methanol in water + 0.1% formic acid + 5 mM ammonium acetate; B: 10% water in methanol + 0.1% formic acid + 5 mM ammonium acetate were used as mobile phase for the separation of residues. The flow rate remains constant at 0.8 mL/min and injection volume was 10 µL. The column temperature was maintained at 40 ºC. The effluent from the LC system was introduced into Triple quadrapole API 3200 MS/MS system equipped with an electrospray ionization interface (ESI), operating in the positive ion mode. The source parameters were temperature 600 ºC, ion gas (GSI) 50 psi, ion gas (GS2) 60 psi, ion spray voltage 5,500 V and curtain gas 13 psi. Under these operating conditions the retention time of pyrazosulfuron-ethyl and pretilachlor was found to be 0.383 and 0.528min, respectively.

LC- Separation: All LC separations were carried out using a reversed phase column, Atlantis d C_{18} (2.1X100 mm) with 5µm spherical porous particles. The elution was performed using gradient between methanol and water. Mobile phase A contained 5 milli molar ammonium acetate in water and B contained 5 milli molar ammonium acetate in methanol. Flow rate 0.80 mL/min, column temperature 40^oC, sample temperature 5^oC, and the injection volume 10 µL were used in all the estimation.

MS/MS: The MS/MS conditions were optimised using direct infusion in to ESI source in positive mode to provide the highest signal/noise ratio for the quantification ion of each analyte. Two MS/MS transitions were made in case of chemical interferences observed in the quantitation ion chromatogram and for qualitative purpose. The ion source temperature was 550°C with ion spray voltage of 5500 V. Chromatographic elution zones were divided into appropriate number of time segments. In each segment, corresponding MS/MS transitions were monitored using multiple reactions–monitoring (MRM) mode.

Certified reference materials of pesticides and stock solutions were prepared using pesticide grade solvents. Single laboratory method validation was performed to establish the recovery of pesticides. Spiking solutions for measuring per cent recovery were prepared from stock solutions of concentration 1000 mg/L. Calibration was performed with six levels of serially diluted standard mixture, prepared from stock solutions. Calibration curves of working standards were used to evaluate the linearity of the gas chromatograph response in each day of analysis and pesticide residues were quantified based on these standards. The concentration of pesticide residue was calculated as given in Beevi *et al.* 2018

Studies on linearity check

Pyrazosulfuron-ethyl: Analytical grade (0.0101 g; 99.7 %) pyrazosulfuron-ethyl was weighed and transferred to a 25 mL volumetric flask using the methanol. The volume was made up to the mark with methanol to give 400 mg/L stock solution of pyrazosulfuron-ethyl. From this stock solution, 10 mg/L intermediate standard was prepared and 1, 0.5, 0.25, 0.10, 0.05, 0.025 and 0.01 mg/L concentrations were prepared from 10 mg/L.

Calibration curve of pyrazosulfuron-ethyl: Calibration of the equipment was performed using pure analytical standard of the test material at concentration ranging from 0.025 to 1 10 mg/L and the response/area obtained was plotted against concentration. The response was found linear in the concentration tried (0.025 – 1 10 mg/L). The correlation coeficient (r^2) value obtained was 0.9925 indicating perfect linearity.

Pretilachlor: A linearity check study was carried out with the help of analytical standard of pretilachlor. In this study calibration curve was prepared by taking the areas corresponding to different concentrations of calibration standard, against which final quantification was done.

Analytical grade (0.0100 g; 98.40%) pretilachlor was weighted and was transfer to a 25 mL volumetric flask using the methanol. The volume was made up to the mark with methanol to give 400 mg/L stock solution of pretilachlor. From this stock solution 10 mg/L intermediate standard was prepared and from this, 1, 0.50, 0.25, 0.10, 0.05 mg/L concentrations were prepared.

Calibration curve of pretilachlor: Calibration of the equipment was performed using pure analytical standard of the test material at concentration ranging from 0.025 to 1.0 mg/kg and the response/ area obtained was plotted against concentration. The response was found linear in the concentration tried (0.025 – 1.0 mg/kg). The correlation coeficient (r^2) value obtained was 0.9952 indicating perfect linearity.

RESULTS AND DISCUSSION

The mean recovery percentage of pyrazosulfuron-ethyl ranged between 92-100 in green foliage, 71-93 in grain, 88-101 in straw, 79-88 in husk and 72-118 in soil with relative standard deviation of repeatability (RSDr) between 3.10-12.30, 0.20-1.10, 0.70-1.90, 2.10-4.80 and 0-8.20%, respectively (**Table 1**), whereas the mean recovery percentage of pretilachlor ranged between 99-117 in green foliage, 75-88 in grain, 72-82 in straw, 73-88 in husk and 113-119 in soil with relative standard deviation of repeatability (RSDr) between 3.70-18.50, 0-8.90,

Table 1. Recovery of pyrazosulfuron-ethyl (%) in green foliage, rice grain, husk, straw and soil

Fortification	Recovery (%)					RSD (%)				
(mg/ kg)	Green foliage	Grain	Straw	Husk	Soil	Green foliage	Grain	Straw	Husk	Soil
0.01	100	71	101	83	72	12.3	0.20	1.90	4.80	1.40
0.05	99	93	100	79	118	3.10	1.10	0.80	2.90	0
0.10	92	72	88	88	109	11.3	0.70	0.70	2.10	8.20

LOQ (Limit of quantification) = 0.01 mg/kg

Table 2. Recovery of pretilachlor (%) in green foliage, rice grain, husk, straw and soil

Fortification	Recovery (%)					RSD (%)				
(mg/ kg)	Green foliage	Grain	Straw	Husk	Soil	Green foliage	Grain	Straw	Husk	Soil
0.05	113	88	72	88	119	18.50	0.70	1.40	4.40	0.10
0.25	117	84	82	82	118	3.70	0	0.60	1.70	2.40
0.50	99	75	75	73	113	8.20	8.90	0.70	2.20	0.70

LOQ (Limit of quantification) = 0.05 mg/kg

0.60-1.40, 1.70-4.40 and 0.10-2.40%, respectively (**Table 2**). The satisfactory recovery values indicated the accuracy and repeatability of the method and were within the accepted range for residue estimation

The mean initial deposit of pyrazosulfuron-ethyl at recommended and double the recommended doses were 0.18 and 0.48 mg/kg, respectively (**Table 3**). The residue dissipated with time and reached below limit of quantification of 0.01 mg/kg after 5 days in the recommended dose and 7 days in double the recommended dose. The dissipation of residues of pyrazosulfuron-ethyl recorded one day after spraying was 11% and three and five days of spraying were 88.88 and 94%, respectively in recommended dose, whereas the percentage dissipation of residue reported one, three, five and seven days after spraying were 35.42, 85.42, 95.83 and 97.92% in double the recommended dose (**Figure 1**).

The dissipation of pretilachlor was slower as compared to pyrazosulfuron-ethyl. The residue reached below quantification level of 0.05 mg/kg after 15 days both in the recommended and double the recommended dose. The mean initial deposit of pretilachlor at recommended and double the recommended dose were 8.84 and 15.50 mg/kg, respectively. The percentage dissipation of pretilachlor after 1, 3, 5,7 and 10 days were 75.23, 97.51, 98.86, 98.52 and 98.98, respectively in recommended dose, whereas in double the recommended dose the corresponding values were 70.77, 91.61, 96.32, 98.19 and 99.16, respectively (**Figure 1**).

The pattern of dissipation of pyrazosulfuron-ethyl and pretilachlor in rice has been presented in several research works whereas the studies on the dissipation of combination product of these two herbicides are so meagre. Mukherjee *et al*. (2006) reported that the dissipation follows first order kinetics in both the alluvial and red lateritic soils under laboratory condition when applied 10 and 20 mg/kg of the active ingredient per gram of soil. About 80% of the initial concentration of the herbicide in soil was dissipated by30 days and further increased to more than 95% by 60 days and the reported half-life of pyrazosulfuron-ethyl was 15 days in both soils. In present study, the half-lives reported were 1.293 and 1.795 days respectively in recommended and double the recommended dose in foliage. This shows the faster degradation of pyrazosulfuron-ethyl in foliage. The findings of the present study were in agreement with Singh *et al*. (2012) and Ezhilarasi *et al*. (2018). Singh *et al*. (2012) reported that the herbicide was the least stable under acidic conditions and the predominant degradation route of pyrazosulfuron-ethyl in water is hydrolysis of sulphonamide linkage. Ezhilarasi *et al*. (2018) reported that both pyrazosulfuron-ethyl and pretilachlor showed rapid dissipation in rice field water than soil and the degradation followed first order reaction kinetics. The half life of both molecules in rice plant was more or less same, whereas the harvest time residue was found below LOQ in rice grain, straw, husk and cropped soil in the present study and it was in agreement with the study of Ezhilarasi *et al*. (2018).

Singh and Singh (2013) reported that half-life of pyrazosulfuron-ethyl varied from 2.6 days (pH 4) to 19.4 days (pH 7) and half-life in distilled water was comparable to half-life at pH 7 buffer. Yu *et al.* (2019) established a simple and reliable QuEChERS method coupled with HPLC-MS/MS and GC-MS methods was to determine pyrazosulfuron-ethyl, residues in rice cropping systems.

Table 3. Persistence of pyrazosulfuron-ethyl and pretilachlor in rice plant at different intervals (days)

Days after treatment	Residues of herbicides (mg/ kg)			
	T1 – Recommended dose 2000 g/ha		T2 – Double the recommended dose 4000 g/ha	
	Pyrazo-sulfuron-ethyl	Pretilachlor	Pyrazo-sulfuron-ethyl	Pretilachlor
0	0.18	8.84	0.48	15.50
1	0.16	2.19	0.31	4.53
3	0.02	0.22	0.07	1.30
5	<LOQ	0.10	0.02	0.57
7	<LOQ	0.13	<LOQ	0.28
10	<LOQ	0.09	<LOQ	0.13
15	<LOQ	<LOQ	<LOQ	<LOQ
Half life (days)	1.293	1.877	1.795	1.372

LOQ (Limit of quantification) of pyrazosulfuron-ethyl -0.01 mg/kg, LOQ of pretilachlor -0.05 mg/kg

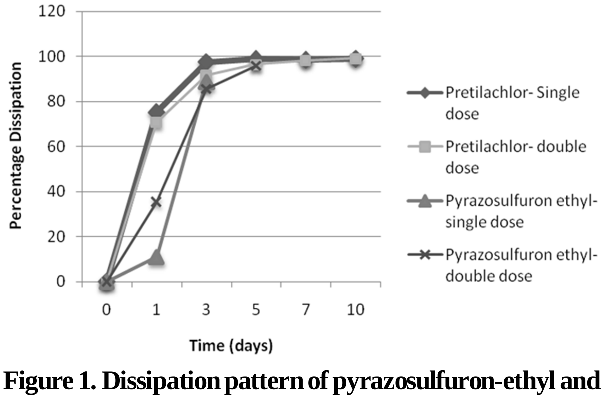


Figure 1. Dissipation pattern of pyrazosulfuron-ethyl and pretilachlor in rice

Dharumarajan *et al.* (2012) revealed that 0.75 kg/ha of pretilachlor dissipated to below detectable limit at 30 days after application, while 1.5 kg/ha persisted up to 60 days after application in rice plant. The difference in dissipation rate of pretilachlor in various studies may be due to the diversity in the agro climatic situation prevailed in experimental locations. Kaur *et al*. (2015) found that the dissipation rate of pretilachlor in paddy field soil and paddy field water followed first-order kinetics with decrease in pretilachlor residues as a function of time. Faster dissipation of pretilachlor was observed in paddy field water than in paddy field soil with half life of 1.89-2.97 days and 7.52-9.58 days, respectively. At harvest, the residues of pretilachlor in the paddy soil and paddy crop samples were below the detection limit and this is in agreement with present study.

Residues of pyrazosulfuron-ethyl and pretilachlor was below quantification level of 0.01 mg/kg in pyrazosulfuron-ethyl and 0.05 mg/kg in pretilachlor in rice grain, straw, husk and cropped soil collected at the time of harvest received from three locations. The result of the present study is in agreement with studies conducted by Rana *et al.* (2018) and they reported that residues of pyrazosulfuron-ethyl in grain and straw at the time of harvest were below quantification level.

A quick, easy, cheap, rugged, safe (QuEChERS) extraction method, coupled with LC MS/MS analysis was developed to determine the dissipation dynamics and residue of pyrazosulfuron-ethyl and pretilachlor in rice. The study could be concluded that the dissipation of pyrazosulfuron-ethyl 0.75% + pretilachlor 30% WG in green leaf ranged from 3-10 days and the harvest time residue was below limit of quantification in rice grain, straw, husk and soil and the result revealed the safety of the combination product to the end users.

REFERENCES

Allard JL, Pradith Wand Kotzian RK. 2005.New application technique of pretilachlor/fenclorim for weedy rice control in direct-seeded wet sown rice in South East Asia, pp 302–305. In: *Proceedings of 20th Asian-Pacific Weed Science Society Conference* held at Ho Chi Minh City, Vietnam.

Asensio-Ramos M, Hernandez-Borges J, Ravelo-Perez LM and Rodriguez-Delgado MA. 2010. Evaluation of a modified QuEChERS method for the extraction of pesticides from agricultural, ornamental and forest soils. *Analytical and Bioanalytical Chemistry* **396**: 2307–2319.

Beevi SN, Paul A, George T, Pratheesh Kumar N, Xavier G and Raj VRS. 2018. Dissipation of chlorpyriphos and profenophos in cabbage (*Brassica oleraceae var. Capitata L*). *Pesticide Research Journal* **30**: 121–125.

Chauhan BS, Ahmed S, Awan TH and Manalil S. 2015. Integrated weed management approach to improve weed control efficiencies for sustainable rice production in dry-seeded systems. *Crop Protection* **71**: 19–24.

Chauhan BS, Ngoc STT, Duong D and Ngoc PL. 2014. Effect of pretilachlor on weedy rice and other weeds in wet-seeded rice cultivation in South Vietnam. *Plant Production Science* **17**: 315–320.

Dharumarajan S, Sankar R and Arun S. 2012. Persistence and dissipation of pretilachlor in soil, plant and water of coastal rice ecosystem. *Indian Journal of Weed Science* **42**: 187–190.

Dibyendu M, Anannya G, Pintoo B and Ratikanta G. 2018. Influence of herbicide mixture on composite weed flora and yield of transplanted rice under system of rice intensification. *Journal of Hill Agriculture* **9**: 49–54.

Ezhilarasi V, Janaki P, Arthanari P, Murali and Chinnusamy C. 2018. Dissipation and fate of ready-mix combination of Pyrazosulfuron-ethyl and pretilachlor in rice field. *Indian Journal of Weed Science* **50**: 250–259.

Han S and Hatzios KK. 1991. Uptake, translocation and metabolism of [14C] pretilachlor in fenclorim–safened and unsafened rice seedlings. *Pesticide Biochemistry and Physiology* **39**: 281–290.

Kaur P, Kaur P and Bhullar MS. 2015. Persistence behaviour of pretilachlor in puddled paddy fields under subtropical humid climate. *Environmental Monitoring and Assessment* **187**: 4756–4763.

Mukherjee A, Dutta S, Roy P, Karmakar R, Kole K and Bhattacharyya A. 2006. Dissipation pattern of the herbicide Pyrazosulfuron- ethyl in Alluvial and red lateritic soils of West Bengal. *Journal of Crop and Weed* **2**: 65-69.

Rajkhowa DJ, Borah N, Barua IC and Delca NC. 2006.Effect of pyrazosulfuron-ethyl on weeds and productivity of transplanted rice during rainy season. *Indian Journal of Weed Science* **38**: 25–28.

Rana A, Rana MC, Rana SS, Sharma N and Kumar S. 2018. Weed control by pyrazosulfuron-ethyl and its influence on yield and economics of transplanted rice. *Indian Journal of Weed Science* **50**: 309–314.

Sarmah AK and Sabadie J. 2002. Hydrolysis of sulfonylurea herbicides in soils and aqueous solutions: a review. *Journal of Agriculture Food and Chemistry* **50**: 6253–6265.

Shen X, Gao X, Eneji AE and Chen Y. 2013. Chemical control of weedy rice in precise hill-direct-seeded rice in South China. *Weed Biology and Manag*ement **13**: 39–43.

Singh SB, Sharma R and Singh N. 2012.Persistence of pyrazosulfuron in rice field and laboratory soil under Indian tropical conditions. *Pest Management Science* **68**: 828–833.

Singh SS and Singh N. 2013. Degradation behaviour of pyrazosulfuron-ethyl in water as affected by pH. *Journal of Environmental Science and Health, Part B* **48**: 266–271.

Yu Q, Zhang P, He W, Xu Z, He X, Hu Y, Zhang H and He L. 2019. Dissipation Dynamics and Residue of Four Herbicides in rice Fields Using HPLC-MS/MS and GC-MS. *International Journal of Environment Research and Public Health* **16**: 1–15.

Indian Journal of Weed Science **53**(1): 73–77, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Farmers' knowledge level and constraints faced in the adoption of weed management technologies

Yogita Gharde* and P.K. Singh

ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482004, India

**Email: yogita_iasri@rediffmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00010.1

Type of article: Research article

Received : 21 December 2020
Revised : 8 February 2021
Accepted : 11 February 2021

Key words
Adoption

Chemical weed control

Factor analysis

Herbicide

Weed management

ABSTRACT

One common problem for the organizations and individuals involved in the transfer of the agricultural technologies is how to accelerate the adoption rate of technologies; which is mainly influenced by many factors such as simplicity of the technology, relative advantages, etc. Further, after the adoption of technology, the question arises that for how many years the farmers practiced the technology. In the present work, knowledge and awareness level of farmers on weed management technologies and constraints faced in the adoption of these technologies were studied. Primary data were collected from the farmers of different parts of India selected by random sampling using detailed pre-tested interview schedule and comprising a total of 412 farmers in the sample. Awareness level of farmers on weed management including chemical method were checked using statistical methods such as descriptive statistics. Parameters explaining the awareness level of the farmers on weed management, in general and chemical weed management, in particular, were subjected to factor analysis. Varimax rotation technique was used as solution pertaining to different factors. Two factors were selected for further interpretation which explained 72.6 and 84.3% variability in the level of awareness among farmers on weed management and chemical method of weed control, respectively. Study showed that the risk associated with the use of herbicides was the major constraint for non-adoption of this technology. Further, other major constraints were lack of technical knowledge about herbicides; lack of awareness about improved weed management technologies and lack of knowledge about the precautions during spray of herbicides.

INTRODUCTION

Problem of weeds has now become a constant issue in agricultural production owing to its dynamic and resilient nature. Weeds compete for light, water, and nutrients with crop plants which results in substantial crop yield losses (Swanton *et al.* 2015, Ramesh *et al.* 2017). In a recent study, total economic loss of about USD 11 billion was estimated due to weeds in 10 major field crops in India (Gharde *et al.* 2018). Therefore, minimizing the yield loss due to weeds in short-term and reducing the weed seeds in soil seed bank are the two simultaneous objectives of weed management (Chauhan *et al.* 2017). Owing to economical in nature, some researchers have recommended the use of herbicides as compared to mechanical method of weed control (Gianessi 2013, Muoni *et al.* 2013). Therefore, herbicides may be considered as efficient tool in controlling weeds, and thus, their appropriate use can lessen the yield losses caused by weeds up to 13% (Oerke and Steiner 1996). However, over dependence on chemicals in many established regions has increased the levels of resistance in some weed species (Culpepper *et al.* 2004; Hall *et al.* 2014), making the use of herbicides more doubtful and less sustainable in the future as far as environment is concerned. Some researchers have shown that other methods such as use of cover crops, and retaining their residues in cropping systems, are very efficient in controlling weeds. However, this may because of other issues such as shift in weed flora, and the value for weed control is dependent on the performance of each specific cover crop (Mhlanga 2015). Research has also highlighted some of the other challenges encountered with the use of cover crops, such as the preferences of the farmer and the availability of seed. In view of the problems associated with different methods, it is obviously expected that Integrated Weed Management (IWM) would stay as the most acceptable and prominent method in near future also.

However, with many prominent technologies for weed management in hand, one common problem for the institutions and individuals involved in the transfer of the agricultural technologies is how to speed up the rate of adoption of technologies among farmers influenced by many factors such as simplicity of the technology, relative advantages, etc. (Rogers 1983). Recently, adoption and impact of weed management technologies in rice and wheat in India was studied (Singh and Gharde 2020). Many researchers have proved that the awareness level of the farmer has significant role on adoption of IWM. Further, knowledge level improves with education, farming experience, training, accessibility to farm machineries, extension contacts and innovativeness (Rajashekhar *et al.* 2017, Singh *et al.* 2018). Keeping these points in view, we studied the awareness level of farmers on weed management in general and chemical weed control technologies in particular along with constraints faced by the farmers in the adoption of these technologies.

MATERIALS AND METHODS

To understand the awareness level of weed management technologies among farmers of India, present study was conducted during 2014-17 at ICAR-Directorate of Weed Research, Jabalpur. Primary data were collected by centers of All India Coordinated Research Project on Weed Management from the farmers of different parts of India selected through random sampling using detailed pre-tested interview schedule and thus comprising a total of 412 farmers (respondents) in the sample. Questions were mostly descriptive and in the form of 4 point Likert scales ranging from 0 (disagree) to 3 (highly agree). Awareness levels of farmers on weed management were checked using statistical methods such as descriptive statistics and factor analysis. Parameters explaining the awareness level of the farmers on weed management and chemical weed management were subjected to factor analysis. This method was applied to decide the most important factors related to the awareness level of famers. Data suitability for factor analysis was checked using Kaiser's Measure of Sampling Adequacy (MSA). The latent root criterion and proportion explained by the factors were used to decide the number of factors to be included in further interpretation of the results. Varimax rotation technique was used as solution pertaining to different factors.

RESULTS AND DISCUSSION

Socio-economic characteristics of the farmers

The data showed that 46% of the respondents were educated upto secondary level, however, some of them (17.7%) were also under-graduate. More than 95% of the farmers had agriculture as the main occupation and major source of income. Among all respondents, almost half (48.7%) of the farmers have 15-30 years of experience in farming. Data also showed that average annual income of the respondents was Rs. 263466/- which is expected to be from their primary occupation i.e. farming. However, more than half of the respondents (55%) have income less than Rs. 2,00,025/-. It was observed that average land holding of the farmers was 2.8 hectare whereas, 37% respondents owned land less than 1 hectare.

Awareness level of the farmers on weed management

Farmers were interacted to give the information on their awareness level on different weed management options and were asked to score their answers in the form of 4 point Likert scale ranging from 0 (disagree) to 3 (highly agree). Data was analyzed using factor analysis to find the important factors which are prominent in explaining the awareness level of farmers on different weed management options. Descriptive statistics and results of factor analysis are presented in **Table 1**. It can be seen from mean values of **Table 1** that the maximum number of farmers strongly felt that weeds are major obstacles in crop production and still majority of the farmers use hand weeding as most

Table 1. Mean, standard deviation and factor analysis component of awareness on weed management technologies

Reaction	Mean	Std. Dev.	Varimax rotated component	
			Factor 1	Factor 2
Weeds are one of the major obstacles in crop production	2.54	0.645	-0.098	0.393
In traditional farming system, weed management was not given due importance	1.33	0.986	0.154	0.463
Use of hand weeding as weed control methods	2.11	0.804	0.052	0.099
Hand weeding is used currently by farmer	1.48	1.01	-0.092	-0.219
Improved Weed Management technologies give better weed control and yield than traditional method	2.04	0.814	-.0177	0.448
Received information on suitable herbicide and their required doses	1.96	0.685	0.848	-.0176
Received information on suitable time and method of application of recommended herbicide	2.06	0.844	0.833	0.112
Use of demonstrated Improved Weed Management technologies by farmer	1.59	1.03	0.052	0.702
Awareness on preventive methods of weed management	1.68	0.709	-0.127	0.042

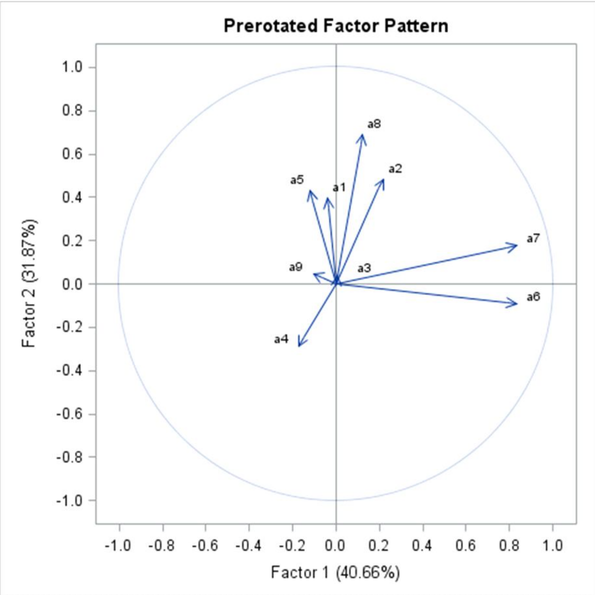


Figure 1. Pre-rotated factor pattern using varimax method in factor analysis for studying awareness level on weed management technologies

preferred weed control method. In factor analysis, Kaiser's MSA was observed as 0.56 which ensures the suitability of data for factor analysis. Factors were selected based on eigenvalues and proportion to be explained by the factors. In this case, two factors were selected which explained 72.6% variability altogether. Factor 1 explained about 40.7% of variability and had loadings from information on suitable herbicides and their doses and suitable time and method of application of herbicides. Whereas, factor 2 accounted for 31.9% of variance and had heavy loadings from use of demonstrated Improved Weed Management technologies by farmers; in traditional farming system, weed management was not given due importance; Improved Weed Management technologies give better weed control and yield than traditional method. **Figure 1** showed the pre-rotated factor pattern using varimax method for studying awareness level of farmers on weed management technologies.

Awareness level of the farmers on chemical method of weed control

Farmers were asked to give the answer of questions pertaining to awareness level of farmers on chemical weed control in two point scale 1 (agree) and 0 (disagree). Descriptive statistics and results of factor analysis performed on factors describing awareness level of the farmers on chemical weed control are presented in **Table 2**. Mean values presented in the **Table 2** showed that most of the farmers felt that herbicide application is better and easy; they avoid herbicide spray during high speed wind and cloudy weather; they know appropriate time of application of post-emergence herbicide. Further, factor analysis of the data with 11 parameters resulted the Kaiser's MSA value as 0.68, ensuring the suitability of the data for factor analysis. Two factors were chosen which accounted for about 84.3% of total variance. Factor 1 explained about 63.4% of variability and had loadings from appropriate time of application of post-emergence herbicide; pre-emergence herbicide; presence of sufficient moisture in soil during application of herbicides. Thus, factor 1 more focused on technical knowledge on use and application of herbicides. Further, factor 2 explained about 20.9% of variability and had more loadings from knowledge on spurious/ adulterated chemical and their availability in local market; precautionary measure used during spraying such as mask/cloth/gloves; use of specific nozzle like flat fan for spraying herbicides. **Figure 2** presents the information on pre-rotated factor pattern obtained using varimax method in factor analysis conducted to explain the awareness level of farmers on chemical weed control.

Table 2. Mean, standard deviation and factor analysis performed on factors describing awareness on chemical method of weed control

Opinion	Mean	Std. Dev.	Varimax rotated component	
			Factor 1	Factor 2
Herbicide application is better and easy	0.955	0.207	0.300	-0.012
Mechanical weeding/hand weeding is better than herbicides	0.810	0.393	0.115	-0.068
Knowledge about appropriate time of application of pre-emergence herbicide	0.873	0.390	0.743	0.113
Knowledge about appropriate time of application of post-emergence herbicide	0.875	0.331	0.809	-0.092
Necessity of sufficient moisture in soil during application of herbicides	0.822	0.383	0.688	0.034
Avoid herbicide spray during high speed wind and cloudy weather	0.914	0.281	0.393	-0.130
Use of precautionary measure during spraying (mask/cloth/gloves)	0.525	0.500	0.116	0.447
Idea about spurious /adulterated chemical and their availability in local market	0.543	0.499	-0.160	0.550
Use of specific nozzle like flat fan for spraying herbicides	0.724	0.448	0.315	0.334
Herbicide container is destroyed after use	0.599	0.491	0.433	0.058
Herbicide is sprayed with other pesticides (by mixing)	0.810	0.393	-0.001	0.151

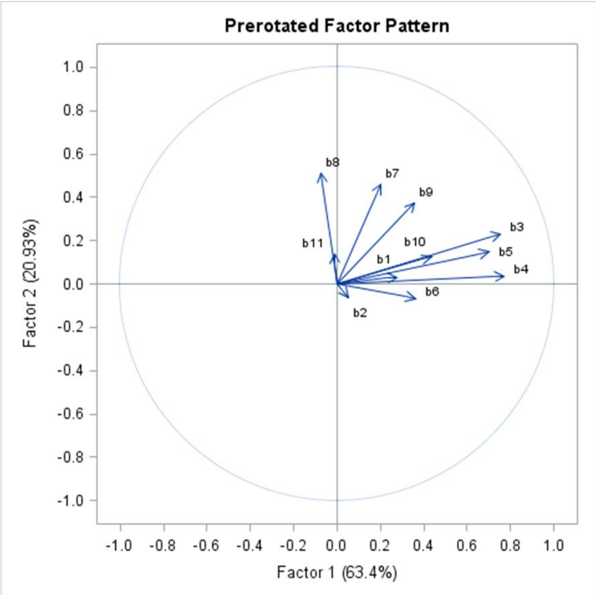
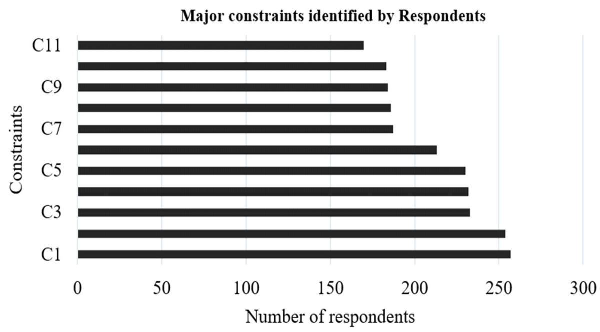


Figure 2. Pre-rotated factor pattern using varimax method in factor analysis component of awareness level of farmers on chemical weed control

Identification and prioritization of constraints faced by farmers in adoption of chemical method of weed control

While the rate of adoption of herbicides in different crops is encouraging, its adoption as profitable method of weed control (in terms of yield increase and cost saving) faces many constraints. Some of the main constraints identified by the farmers in the present study areas are summarized in **Figure 3**. Results showed that risk associated with the use of herbicide was the major constraint for non-adoption of these technologies. Further, other main constraints were lack of technical knowledge about herbicides; lack of awareness about Improved Weed Management technologies; lack of knowledge about the precautions during spray. (Debrah 1994) reported that technical complexity and a non-availability of adequate information may restrict the adoption of weed management technologies for *Striga* in the West African semi-arid tropics. In the present study, there were 170 farmers who endure less risk bearing capacity about new technology. Further, economic concerns also play a major role in farmer decisions related to weed management. They generally adopt the practices that are economically more beneficial in the short term (Liebman *et al.* 2016). For implementing weed management practices in order to adopt them, special attention to their perceptions, goals, and decision-making processes are necessary. Further, educating the extension officers may be one of the best way of delivering scientific information to the farmers and thus to increase the adoption rate of weed management technologies (Liebman *et al.* 2016). Udensi *et al.* (2012) also reported the constraints like technical know-how or application problems (16.5%) and high cost of chemical (14.9%) among main constraints in their study. High cost of herbicides was also found as one of the constraints in our study. (Adesina and Forson 1995) reported that the adoption of any technologies by the farmers reflects decision-making based upon their observation on the appropriateness of the characteristics of the disseminated technologies. Therefore, adoption can be expected to be dependent on the cost of a technology and on whether farmers possess the required resources.

The study indicated that 46% of the farmers were educated upto secondary level with high literacy rate among farmers. It is expected that educated farmers who have exposure to new technologies and innovations, are more interested to new ideas and are ready to adopt (Udensi *et al.* 2012). The findings from study established that most of the farmers possess more knowledge about chemical method of weed control. However, information on suitable herbicides and their doses; suitable time and method of application of herbicide; use of demonstrated Improved Weed Management technologies; Improved Weed Management technologies give better weed control and yield than traditional method.; in traditional farming system, weed management was not given due importance are main factors to explain



C1: If anything happens wrong due to use of herbicide, there is no recovery mechanism; C2: Lack of technical knowledge about mixture of two herbicides for effective broad-spectrum weed control and time / labour saving; C3: Lack of awareness about IWM technologies; C4: Lack of knowledge about the precautions during spray; C5: Lack of proper technical knowledge about herbicides; C6: Lack of knowledge about use of appropriate nozzle; C7: Moisture unavailability at the time of application; C8: Lack of information on method of herbicide application; C9: Lack of knowledge about use of sprayer; C10: High cost of herbicides; C11: Less risk bearing capacity about new technology

Figure 3.

the awareness level of farmers. Whereas, technical knowledge on use and application of herbicides decides the awareness level of farmers on herbicides. The study reported the constraints such as risk associated with the use of herbicides as major constraint for non-adoption of chemical method of weed control. Further, other main constraints were lack of technical knowledge about herbicides; lack of awareness about Improved Weed Management technologies; Lack of knowledge about the precautions to be followed during spray.

REFERENCES

Adesina AA and Forson JB. 1995. Farmers' perceptions and adoption of new agricultural technology: Evidence from analysis in Burkina Faso and Guinea, West Africa. *Agricultural Economics* **13**(1): 1–9. https://doi.org/10.1016/0169-5150(95)01142-8

Chauhan BS, Matloob A, Mahajan G, Aslam F, Florentine SK and Jha P. 2017. Emerging challenges and opportunities for education and research in weed science. *Frontiers in Plant Science* **8**: 1537. doi: 10.3389/fpls.2017.01537

Culpepper AS, Flanders JT, York AC and Webster TM. 2004. Tropical spiderwort (*Commelina benghalensis*) control in glyphosate-resistant cotton (*Gossypium hirsutum*). *Weed Technology* **18**: 432–436. https://doi.org/10.1614/WT-03-175R

Debrah SK. 1994. Socio-economic constraints to adoption of weed control techniques: The case of Striga control in the West African semi-arid tropics. *International Journal of Pest Management* **40**(2): 153–158. https://doi.org/10.1080/09670879409371874

Gharde Y, Singh PK, Dubey RP and Gupta PK. 2018. Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection* **107**:12–18. https://doi.org/10.1016/j.cropro.2018.01.007

Gianessi LP. 2013. The increasing importance of herbicides in worldwide crop production. *Pest Management Science* **69**:1099–1105. https://doi.org/10.1002/ps.3598

Hall LM, Beckie HJ, Low R, Shirriff SW, Blackshaw RE, Kimmel N and Neeser C. 2014. Survey of glyphosate-resistant kochia (*Kochia scoparia* L. Schrad.) in Alberta. *Canadian Journal of Plant Science* **94**(1): 127–130. https://doi.org/10.4141/cjps2013-204

Liebman M, Baraibar B, Buckley Y, Childs D, Christensen S, Cousens R, Eizenberg H, Heijting S, Loddo D, Merotto A Jr, Renton M and Riemens M. 2016. Ecologically sustainable weed management: How do we get from proof-of-concept to adoption? *Ecological Applications* **26**(5): 1352–1369. https://doi.org/10.1002/15-0995

Mhlanga B, Cheesman S, Maasdorp B, Muoni T, Mabasa S, Mangosho E and Thierfelder C.2015. Weed community responses to rotations with cover crops in maize-based conservation agriculture systems of Zimbabwe. *Crop Protection* **69**: 1–8. http://dx.doi.org/10.1016/j.cropro.2014.11.010

Muoni T, Rusinamhodzi L and Thierfelder C. 2013. Weed control in conservation agriculture systems of Zimbabwe: Identifying economical best strategies. *Crop Protection* **53**: 23–28. https://doi.org/10.1016/j.cropro.2013.06.002

Oerke EC and Steiner U. 1996. Abschtzung der Ertragsverlusteim Maisanbau. pp. 63–79. In: *Ertragsverluste Und Pflanzenschutz - Die Anbausituation Fr Die Wirtschaftlich Wichtigsten Kulturpflanzen*. German Phytomedical Society Series, EugenUlmerVerlag, Stuttgart.

Rogers EM. 1983. Diffusion of Innovations. III[rd]edn. The Free Press, Collier Macmillan, New York, London, 453 p.

Rajashekar B, Sudharani V, Neema Parveen SK and Shivacharan G. 2017. Knowledge of farmers about integrated weed management (IWM) practices in major crops. *International Journal of Farm Sciences* **7**(1): 33–36.

Ramesh K, Matloob A, Aslam F, Florentine S and Chauhan BS. 2017. Weeds in a changing climate: vulnerabilities, consequences, and implications for future weed management. *Frontiers in Plant Science* **8**: 95. doi: 10.3389/fpls.2017.0009531

Singh PK and Gharde Y. 2020. Adoption level and impact of weed management technologies in rice and wheat: Evidence from farmers of India. *Indian Journal of Weed Science* **52**(1): 64–68. http://dx.doi.org/10.5958/0974-8164.2020.00011.8

Singh PK, Gharde Y and Choudhary VK. 2018. Adoption of integrated weed management practices correlates with farmers' profile characteristics. *Indian Journal of Weed Science* **50**(1): 69–71. http://dx.doi.org/10.5958/0974-8164.2018.00015.1

Swanton CJ, Nkoa R and Blackshaw RE. 2015. Experimental methods for crop–weed competition studies. *Weed Science* **63**: 2–11. doi: 10.1614/WS-D-13- 00062.1

Udensi UE, Tarawali G, Ilona P, Okoye BC and Dixon AGO. 2012. Adoption of chemical weed control technology among cassava farmers in South Eastern Nigeria. *Journal of Food, Agriculture and Environment* **10**(1): 667–674.

Indian Journal of Weed Science **53**(1): 78–80, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Efficacy of fenoxaprop-p-ethyl and penoxsulam for weed management with special emphasis on *Echinochloa* spp. in transplanted summer rice

Subhaprada Dash[1], B. Duary* and K. Sar[1]

Department of Agronomy, (Institute of Agriculture), Visva-Bharati, Sriniketan, West Bengal 731236, India

[1]Department of Agronomy, Faculty of Agricultural Sciences, IAS, Sikhsha 'O' Anusandhan, Deemed to be University, Bhubaneswar, Odisha 751029, India

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

Article information

DOI: 10.5958/0974-8164.2021.00011.3

Type of article: Research note

Received : 29 September 2020
Revised : 8 January 2021
Accepted : 10 January 2021

Key words

Echinochloa spp.

Fenoxaprop-p-ethyl

Penoxsulam

Summer rice

Weed management

ABSTRACT

An on-farm experiment was conducted during summer (*boro*) season of 2016-17 at farmer's field (Borah village of Nanoor Block) in Birbhum district, West Bengal to study the efficacy of fenoxaprop-p-ethyl and penoxsulam against composite weed flora with special emphasis on *Echinochloa* spp. in transplanted rice. The experiment comprising of eight treatments was laid out in a randomized block design with three replications. The experimental field was dominated with *Echinochloa glabrescens*, *E. crus-galli*, *Panicum* sp. (grasses), *Cyperus iria* (sedge) and *Jussiaea repens* (broad-leaved) throughout the crop growing period. Of these predominant weeds, there was severe infestation of grassy weeds. Among herbicidal treatments, fenoxaprop-p-ethyl 90 and 100 g/ha at 20 days after transplanting (DAT) and penoxsulam 25 g/ha at 20 DAT effectively controlled the *Echinochloa* spp. at 50 DAT. Application of penoxsulam 25 g/ha at 20 DAT exhibited effective management of composite weed flora as well as higher grain yield in summer rice. Lower values of weed density and weed dry weight along with improved weed control efficiency and higher grain yield were registered with penoxsulam 25 g/ha at 20 DAT, which was statistically at par with two rounds of hand weeding at 20 and 40 DAT in summer rice.

Weed infestation is one of the major factors influencing rice productivity to a large extent. Timely weed management is an essential aspect for realizing desired level of crop productivity. Weed flora under transplanted condition is very much diverse in nature. Major weeds of transplanted summer rice in West Bengal include *Echinochloa crus-galli, E. glabrescens, Panicum* sp. (grasses), *Cyperus difformis, C. iria* (sedges), *Marsilea minuta, Jussiaea repens, Alternanthera sessilis, A. philoxeroides* and *Commelina* sp. (broad-leaved). Of these, the grassy weeds, *viz. E. glabrescens* and *E. crus-galli* are reported to cause severe infestation in rice-rice cropping system, causing considerable yield losses (Duary and Mukherjee 2013, Duary *et al.* 2015b). Because of weed mimicry with rice crop, farmers are often compelled to discard nursery bed with severe infestation of *Echinochloa* spp. Manual removal of weeds is labour-intensive, tedious and does not ensure weed removal at critical stage of crop-weed competition. Thus, application of herbicide is one of the viable and economic options to effectively manage the weeds. A few herbicides have been commonly recommended for the management of *Echinochloa* spp. Therefore, the present investigation was undertaken to find out the effect of fenoxaprop-p-ethyl and penoxsulam on weed growth with special emphasis on *Echinochloa* spp. and productivity of transplanted summer rice.

An on-farm experiment was conducted at farmer's field of Borah village ($87^0$47.582 E longitude and $23^0$42.402 N latitude with an altitude of 34 m above mean sea level) under Nanoor Block in the district of Birbhum, West Bengal, India during summer (*boro*) season of 2016-17. Eight treatments comprising of three doses of fenoxaprop-p-ethyl 80, 90 and 100 g/ha at 20 days after transplanting (DAT), three doses of penoxsulam 20, 22.5 and 25 g/ha at 20 DAT, two hand weeding at 20 and 40 DAT, and weedy check were assigned in a randomised block design with three replications. The rice variety '*PAN 5010*' was fertilized with 120 kg N, 60 kg P and 60 kg K/ha. Full doses of phosphate and potash along with half dose of total N were applied at final land preparation before transplanting, while remaining half of total N was applied in two splits as first and second top dressing. The crop was raised with all other recommended package of practices. Weed density was recorded by using quadrat of 50 × 50 cm at 50 DAT in all the treatments and then converted into number of weeds/m^2. The weeds were dried in oven till a constant weight was recorded and then transformed into g/m^2 by using appropriate formula. The data on weed density and weed dry matter were subjected to square root transformation to normalize their distribution. All data were subjected to analysis of variance (ANOVA), and treatment means were separated by Fisher's least significant difference at $\sqrt{x+0.5}$. Weed control efficiency (%) was computed using the dry matter of grasses and total weeds as well. Observations regarding grain and straw yield along with yield components were recorded at crop harvest. Weed indices in respect of different treatments were also worked out.

Effect on weeds

The experimental field was infested with nine weed species, of which *Echinochloa glabrescens, E. cruss-galli* and *Panicum* sp. among grasses, *Cyperus iria* among sedges and *Jussiaea repens* among broad-leaved were found dominant. Grassy weeds accounted for 82.08% of total weed density and 78.08% of total weed dry weight at 50 DAT. *Echinochloa glabrescens* was the major weeds among the grasses. Application of fenoxaprop-p-ethyl both at 90 and 100 g/ha and also penoxsulam at higher dose (25 g/ha) effectively reduced grassy weeds in rice. Even application of penoxsulam 25 g/ha at 20 DAT effected significant reduction in dry weight of grassy weeds as well as total weeds, and was found comparable with two hand weeding at 20 and 40 DAT **(Table 1)**. The results were in conformity with those of previous studies where post-emergence application of penoxsulam effectively controlled major weeds in transplanted rice (Mahajan and Chauhan 2008).

Weed control efficiency and weed index of different treatments

The weed control efficiency (WCE) was the highest under two hand weeding (20 and 40 DAT), followed by penoxsulam 25 g/ha at 20 DAT (**Table 1**). In case of grassy weeds, fenoxaprop-p-ethyl 90 and 100 g/ha at 20 DAT registered higher WCE due to lower weed density as well as lower weed dry weight. The lowest weed index was recorded in two hand weeding at 20 and 40 DAT, which was followed by penoxsulam 25 g/ha at 20 DAT, fenoxaprop-p-ethyl 100 g/ha at 20 DAT and penoxsulam 22.5 g/ha at 20 DAT (**Table 1**). Among the herbicidal treatments, the higher WCE and lower weed index with penoxsulam 25 g/ha at 20 DAT treatment might be due to the effective weed control resulting in reduced density as well as dry matter accumulation of weeds. Similar results were reported by Duary *et al.* (2015a) and Teja *et al.* (2016).

Effect on crop

Penoxsulam 22.5 and 25.0 g/ha at 20 DAT and fenoxaprop-p-ethyl 100 g/ha at 20 DAT were statistically at par with two hand weeding with respect to number of filled grains/panicle (**Table 2**). Similar trend was also recorded in respect of panicle weight. Fenoxaprop-p-ethyl at 90 g/ha at 20 DAT was also found statistically at par with two hand weeding at 20 and 40 DAT. No phytotoxicity was noticed on rice crop due to application of fenoxaprop-p-ethyl or

Table 1. Effect of treatments on density and dry weight of grasses and total weeds at 50 DAT in summer rice

Treatment	Weed density (no./m^2)		Weed dry matter (g/m^2)		WCE (%)		WI (%)
	Echinochloa spp. and other grasses	Total weeds	*Echinochloa* spp. and other grasses	Total weeds	*Echinochloa* spp. and other grasses	Total weeds	
Fenoxaprop-p-ethyl 80 g/ha at 20 DAT	2.96(8.33)	3.57(12.23)	2.69(6.76)	3.34(10.66)	70.37	63.50	15.99
Fenoxaprop-p-ethyl 90 g/ha at 20 DAT	0.71(0.00)	1.70(2.41)	0.71(0.00)	1.70(2.41)	100.00	91.76	13.79
Fenoxaprop-p-ethyl 100 g/ha at 20 DAT	0.71(0.00)	1.55(1.91)	0.71(0.00)	1.55(1.91)	100.00	93.47	6.51
Penoxsulam 20 g/ha at 20 DAT	2.27(4.67)	2.55(6.03)	1.10(0.71)	1.61(2.08)	96.87	92.88	13.07
Penoxsulam 22.5 g/ha at 20 DAT	2.11(4.00)	2.21(4.45)	1.03(0.56)	1.22(1.01)	97.56	96.54	8.71
Penoxsulam 25 g/ha at 20 DAT	1.34(1.33)	1.40(1.49)	0.79(0.13)	0.89(0.28)	99.44	99.03	0.31
Hand weeding at 20 and 40 DAT	0.71(0.00)	0.71(0.00)	0.71(0.00)	0.71(0.00)	100.00	100.00	0.00
Weedy check	5.46(29.33)	6.02(35.73)	4.82(22.80)	5.45(29.20)	0.00	0.00	20.07
LSD (p=0.05)	0.31	0.32	0.20	0.19	-	-	-

DAT: Days after transplanting, WCE: Weed control efficiency, WI: Weed index; ***Original figures in parentheses were subjected to SQRT ($\sqrt{x+0.5}$) before statistical analysis

Table 2. Effect of treatments on yield components and yield of summer rice

Treatment	Panicle length (cm)	Panicle weight (g)	Filled grains/ panicle	1000-seed wt. (g)	Grain yield (t/ha)	Straw yield (t/ha)
Fenoxaprop-p-ethyl 80 g/ha at 20 DAT	22	2.36	104	23.63	4.65	7.30
Fenoxaprop-p-ethyl 90 g/ha at 20 DAT	21	3.13	116	24.57	5.33	7.11
Fenoxaprop-p-ethyl 100 g/ha at 20 DAT	21	3.34	138	23.67	5.78	7.82
Penoxsulam 20 g/ha at 20 DAT	22	2.20	109	23.60	4.74	7.04
Penoxsulam 22.5 g/ha at 20 DAT	21	3.27	128	23.73	5.65	7.74
Penoxsulam 25 g/ha at 20 DAT	22	3.36	140	25.27	6.17	8.09
Hand weeding at 20 and 40 DAT	22	3.45	141	25.10	6.19	8.177
Weedy check	21	2.02	82	23.03	4.14	7.00
LSD (p=0.05)	NS	0.72	8	NS	0.55	0.41

DAT: Days after transplanting, NS: Not significant

penoxsulam at any of the doses applied at 20 DAT. Panicle length and test weight of grains did not vary significantly among different herbicides tested under the study.

Weed competition in weedy check resulted in 49.52 and 49.03% reduction in grain yield than hand weeding twice and penoxsulam 25 g/ha treatments, respectively Both the herbicides with all the doses of application in the present experiment recorded significantly higher grain yield over the untreated control. This was due to effective management of weeds, which facilitated better crop growth and ultimately increased the grain yield. The highest grain yield (6.19 t/ha) was obtained with two rounds of hand weeding at 20 and 40 DAT. Application of penoxsulam 22.5 or 25.0 g/ha at 20 DAT and fenoxaprop-p-ethyl 100 g/ha at 20 DAT were statistically at par with two hand weeding in respect of grain yield. These results were in agreement with those of Singh *et al*. (2004) and Mahajan and Chauhan (2008). Penoxsulam 25 g/ha at 20 DAT and fenoxaprop-p-ethyl 100 g/ha at 20 DAT were statistically at par with hand weeding twice at 20 and 40 DAT with respect to straw yield (**Table 2**).

Thus, it might be concluded that fenoxaprop-p-ethyl 100 g/ha at 20 DAT and penoxsulam 25 g/ha at 20 DAT provided excellent control of *Echinochloa* spp. However, in particular, penoxsulam 25 g/ha at 20 DAT offered promising control of broad-spectrum weeds and registered higher grain yield of transplanted summer rice.

REFERENCES

Duary B and Mukherjee A. 2013. Distribution pattern of predominant weeds of wet season and their management in West Bengal, India. pp. 191–199. In: *Proceedings 24th Asian-Pacific Weed Science Society Conference*, October 22-25, 2013, Bandung, Indonesia.

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

Duary B, Mukherjee A and Bhowmick MK. 2015b. Phyto-sociological attributes of weed flora in major crops of red and lateritic belt of West Bengal. *Indian Journal of Weed Science* **47**(1): 89–92.

Mahajan G and Chauhan BS 2008. Performance of penoxsulam for weed control in transplanted rice. *Pest Technology* **2**(2): 114–116.

Singh VP, Singh G and Singh M. 2004. Effect of fenoxaprop-p-ethyl on transplanted rice and associated weeds. *Indian Journal of Weed Science* **36**(3&4): 190–192.

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

Indian Journal of Weed Science **53**(1): 81–84, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

In situ green manuring and herbicide on weed biomass, productivity and profitability of upland rice

Y. Basila*, S. Anitha, Meera V. Menon, K. Sreelakshmi and V.I. Beena

Department of Agronomy, College of Horticulture, Vellanikkara, Thrissur, Kerala 680 656

**Email: basilayoosaf1234@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00012.5

Type of article: Research note

Received : 24 September 2020
Revised : 14 January 2021
Accepted : 18 January 2021

Key words

Brown manuring
In situ green manuring
Oxyfluorfen and pyrazosulfuron-ethyl
Upland rice
Weed management

ABSTRACT

Field experiment was conducted at Agronomy Farm, College of Horticulture, Vellanikkara during *Kharif* (rainy season) 2019 to develop cost-effective weed management strategy for upland rice in Kerala. Treatments consisted of brown manuring (cowpea) by application of 2,4-D 1.0 kg/ha at 25 days after sowing (DAS); *in situ* green manuring (cowpea) at 25 DAS; oxyfluorfen 0.15 kg/ha on the day of sowing *fb* hand weeding (HW) at 30 DAS; oxyfluorfen 0.15 kg/ha on the day of sowing *fb* bispyribac-sodium 0.025 kg/ha at 20 DAS; pyrazosulfuron-ethyl 0.03 kg/ha at 6 DAS *fb* HW at 30 DAS; pyrazosulfuron-ethyl 0.03 kg/ha at 6 DAS *fb* bispyribac-sodium 0.025 kg/ha at 20 DAS. Hand weeded control and unweeded control were also maintained. Results revealed that application of oxyfluorfen at 0.15 kg/ha on the day of sowing *fb* hand weeding at 30 DAS recorded lesser weed density and dry matter production, higher grain (2.74 t/ha) and straw (5.89 t/ha) yields and net monetary returns. It was at par with pyrazosulfuron-ethyl 0.03 kg/ha at 6 DAS *fb* hand weeding at 30 DAS.

Rice is one of the most important food crops in Kerala and it is cultivated mainly in three seasons, *viz.* autumn, winter and summer. Rice can be grown in wetland and upland conditions. In Kerala, upland rice cultivation is known as *'Modan'* cultivation and crop is raised during *'Virippu'* season. Upland rice is grown in rainfed, naturally well drained soils with bunded or unbunded fields without surface water accumulation. Moisture stress, weed infestation, poor soil fertility and incidence of pest and diseases are major problems associated with upland rice cultivation. Among these, weeds are considered to be the most serious problem which reduces yield and quality of produce. Low productivity of upland rice is due to severe weed infestation as aerobic soil conditions and alternate wetting and drying favour the weed growth (Kumar and Rana 2013). Arunbabu and Jena (2018) reported loss of 94-97% grain yield in upland rice due to weeds. Weeds are highly competitive for light, space, water and nutrients which cause tremendous yield reduction and increase the cost of production. In upland rice cultivation, entire crop growth period is considered as critical period of weed competition. Hand weeding is the mostly adopted method of weed management in rice and is highly tedious and labour intensive. Chemical method of weed management is most effective and economical. Success of upland rice production depends upon how effectively weeds are managed. Hence effective and timely management of weeds is essential to achieve maximum productivity in upland rice. In this background, a study was conducted to develop cost effective weed management strategy for upland rice in Kerala.

The field experiment was conducted at Agronomy Farm, College of Horticulture, Vellanikkara located at 10° 31¹ N latitude and 76° 13¹ E longitude at an altitude of 40.3 m above Mean Sea Level (MSL)on sandy loam soil during *Kharif* 2019. Treatments consisted of brown manuring (cowpea 20 kg/ha) by application of 2,4-D 80 WP 1.0 kg/ha at 25 DAS; *in situ* green manuring (cowpea 20 kg/ha) at 25 DAS; oxyfluorfen 23.5 EC 0.15 kg/ha on the day of sowing *fb* HW at 30 DAS; oxyfluorfen 23.5 EC 0.15 kg/ha on the day of sowing *fb* bispyribac-sodium 10 SC 0.025 kg/ha at 20 DAS; pyrazosulfuron-ethyl 10 WP 0.03 kg/ha at6 DAS *fb* HW at 30 DAS; pyrazosulfuron-ethyl 10 WP 0.03 kg/ ha at 6 DAS *fb* bispyribac-sodium 10 SC 0.025 kg/ha at 20 DAS, hand weed in and unweeded control, were replicated thrice in a randomized block design. *'Vaisakh'*, medium duration (117-125 days) rice variety was selected as seed material. A local variety of cowpea was used for *in situ* green manuring and brown manuring. Plot size adopted was 5m × 4m and seeds were dibbled at a spacing of 20×10 cm.

Fertilizers were applied as urea, rajphos (phosphatic fertilizer) and murate of potash at the rate of 50: 35: 35 N, P and K kg/ha. Pre-emergence application of oxyfluorfen at 0.64 kg/ha was done on the day of sowing. Pyrazosulfuron-ethyl at 0.30 kg/ha was sprayed at 6 DAS. Post-emergence application of bispyribac-sodium 0.25 kg/ha was done at 20 DAS. Herbicide application was done with knap-sack sprayer fitted with a flood-jet nozzle using 500 L water per ha as spray volume. For *in situ* green manuring, cowpea plants were uprooted and placed between the rows. Brown manuring was done by spraying of 2,4-D at 1.0 kg/ha at 25 days after sowing. Weed observations were recorded at 20 and 45 DAS. Biometric observations on crop were recorded at 30, 60 DAS and at harvest. Yield and yield attributes were recorded at harvest. Weed density, weed dry matter production, number of tillers/hill, number of hills/m² and number of panicles/hill were estimated by placing quadrate with size of 1m² in four spots at random in each plot. Grain and straw yields were recorded from each plot after harvesting, threshing and winnowing. Benefit: cost ratio was calculated by dividing the gross returns with cost of cultivation. Gross returns was calculated from grain yield and straw yield from the respective treatments. Prevailing price for grain and straw in the market were considered. Cost of cultivation from each treatment was calculated by taking into account field preparation cost, input cost, labour cost extra treatment cost *etc.* and it was expressed in rupees per ha. Data obtained from the experiment were analysed statistically by applying "analysis of variance" as per randomized block design with the help of online statistical package "OP" stat. In some of the treatments sedges were absent, square root transformation was done and original values for sedge density were given in parenthesis.

Weed flora

Twenty-two weed species were identified in the experimental field (grasses-6, Broad Leaf Weeds (BLWs) -15 and sedge-1). Among grassy weeds, *Setaria* spp., *Digitaria sanguinalis*, *Echinochloa colona*, *Eleusine indica*, *Panicum maximum* and *Brachiaria* spp. were dominant. *Alternanthera bettzickiana, Lindernia crustacea, Mollugo disticha, Ludwigia perennis, Ageratum conyzoides, Mitracarpus hirtus, Euphorbia hirta, Euphorbia geniculata, Scoparia dulcis, Phyllanthus amarus, Cleome burmannii, Commelina benghalensis, Catharanthus pusillus, Trianthema portulacastrum* and *Hemidesmus indicus* were identified as broad-leaf weeds and *Cyperus iria* was only sedge identified in the experimental field.

Weed density

All the weed management practices recorded significantly lower total weed density as compared to unweeded check. Weed density at 20 and 45 DAS were influenced significantly by various treatments **(Table 1)**. Lowest weed density was recorded by the application of oxyfluorfen *fb* HW at 30 DAS due to timely application of pre-emergence herbicides and hand weeding resulted in less weed infestation. Application of oxyfluorfen 0.15 kg/ha followed by HW at 20 DAS recorded minimum number of grass, broad leaf weeds and sedges at all stages of observation in aerobic rice (Reshma *et al.* 2015). Highest weed density was recorded in unweeded control (Bhurer *et al.* 2013).

Weed dry weight

Weed dry matter production at both stages of crop were found significant **(Table 2)**. At 20 DAS hand weeded control recorded lesser dry matter

Table 1. Effect of treatments on weed density(no. /m²) at 20 and 45 DAS

Treatment	Weed density at 20 DAS (no./m²)				Weed density at 45 DAS (no./m²)			
	Grass	Broad-leaf weeds	*Sedges	Total weed density	Grass	Broad-leaf weeds	*Sedges	Total weed density
Brown manuring (cowpea) by application of 2,4-D 1.0 kg/ha at 25 DAS	100.66	128.66	5.42(28.7)	259.00	79.00	13.66	1.00(0.00)	92.667
In situ green manuring (cowpea) at 25 DAS	65.33	145.00	4.08(15.7)	226.00	53.33	62.66	2.15(3.66)	120.33
Oxyfluorfen 0.15 kg/ha on the day of sowing *fb* HW at 30 DAS	31.66	22.00	2.01(4.0)	58.00	19.66	24.66	1.00(0.00)	44.33
Oxyfluorfen 0.15 kg/ha on the day of sowing *fb* bispyribac-sodium 0.025 kg/ha at 20 DAS	68.33	50.66	1.00(0.0)	119.00	19.33	32.33	2.30(4.33)	56.00
Pyrazosulfuron-ethyl 0.03 kg/ha at 6 DAS *fb* HW at 30 DAS	133.00	70.66	1.00(0.0)	210.33	39.66	19.00	1.00(0.00)	58.66
Pyrazosulfuron-ethyl 0.03 kg/ha at 6 DAS *fb* bispyribac-sodium at 20 DAS	153.00	144.33	1.00(0.0)	297.33	120.66	42.33	1.00(0.00)	163.00
Hand weeded control (15, 30 and 45 DAS)	15.66	39.33	2.23(4.0)	59.00	2.33	73.33	1.73(2.00)	76.00
Unweeded control	238.00	239.00	5.14(26.0)	503.00	77.66	90.66	1.27(0.66)	169.00
LSD (p=0.05)	33.87	26.52	1.06(8.0)	41.14	19.00	12.14	0.25(0.93)	40.50

*Transformed values are given in parentheses production which was at par with application of oxyfluorfen on the day of sowing *fb* HW at 30 DAS and application of oxyfluorfen *fb* bispyribac-sodium at 20 DAS. At 45 DAS hand weeded control recorded lesser dry matter production, which was on par with application of oxyfluorfen on the day of sowing *fb* HW at 30, oxyfluorfen on the day of sowing *fb* bispyribac-sodium at 20 DAS and pyrazosulfuron-ethyl at 6 DAS *fb* HW at 30 DAS.

Weed control efficiency

Higher weed control efficiency (WCE) was recorded with the application of oxyfluorfen on the day of sowing *fb* HW at 30 DAS (92.60% at 20 DAS and 98.58% at 45 DAS). Significantly lowest weed index (WI) was recorded by application of oxyfluorfen on the day of sowing *fb* HW at 30 DAS (5.02%) followed by pyrazosulfuron-ethyl at 6 DAS *fb* HW at 30 DAS (10.35%). Higher WCE and lower WI by these treatments might be due to reduction in weed biomass by broad spectrum action of herbicide and also timely control of weeds by HW at 30 DAS. Porwal (1999) revealed that application of oxyfluorfen at 0.2 kg/ha recorded higher WCE (96.5%). Priya *et al.* (2017) suggested oxyfluorfen application 250 g/ha *fb* hand weeding at 45 DAS can reduces weed density, weed dry matter and increases grain and straw yield in transplanted rice. Mondal *et al.* (2005) reported that application of pyrazosulfuron-ethyl as pre-emergence can effectively control all types of weeds in transplanted rice. *In situ* green manuring and brown manuring resulted in reduction in weed dry matter production and high WCE at early stages of crop growth as compared to unweeded control and it might be due to smothering effect of cowpea could reduce the weed infestation, but it was not effective as herbicide application.

Grain yield

Grain yield and straw yield in upland rice were influenced significantly by various weed management practices **(Table 3)**. Hand weeded control recorded higher grain yield closely followed by oxyfluorfen on the day of sowing *fb* HW at 30 DAS and pyrazosulfuron-ethyl at 6 DAS *fb* HW at 30 DAS. The increased grain yield might be due to reduction in weed density, weed dry matter production, WI and higher WCE which contributed to better growth and yielding attributing characters. Application of oxyfluorfen on the day of sowing *fb* HW at 30 DAS recorded highest number of tillers per hill and number of hills/m². Hand weeded control recorded highest grain yield and was at par with pre-emergence application of oxyfluorfen 150 g/ha in transplanted rice (Abraham *et al*. 2010). According to Saini (2003), pyrazosulfuron application resulted in higher grain yield due to improved growth and yield parameters due to minimum weed growth. Weed competition resulted in 78.05% yield reduction in upland rice and it might be due to heavy infestation of weeds. Lowest grain yield of 1075 kg/ha was recorded by weeded control in direct seeded upland rice (Roy 2016). *In situ,* green manuring recorded 57.89% and brown manuring recorded 72.23% higher grain than unweeded control but it was not effective as herbicide treatments. Oxyfluorfen on the day of sowing *fb* HW at 30 DAS recorded highest straw yield which was found at par with pyrazosulfuron-ethyl at 6 DAS *fb* hand weeding at 30 DAS and hand weeded control. It might be due to effective control of all types of weeds from initial stage of crop growth and lead to better crop growth.

Application of oxyfluorfen on the day of sowing *fb* HW at 30 DAS recorded highest gross return, net return and B:C ratio which was closely followed by pyrazosulfuron-ethyl at 6 DAS *fb* HW at 30 DAS and unweeded control recorded lowest B:C ratio **(Table 3)**. It might be due to better weed management, which decreased the weed dry matter production and increased WCE and resulted in better growth and yield parameters of upland rice. Higher gross return and reduced cost of cultivation in both the treatments resulted in higher B:C ratio. Reshma *et al*. (2015)

Table 2. Effect of treatments on weed dry matter production, weed control efficiency (WCE) and weed index (WI)

Treatment	Weed dry matter production (g/m²)		WCE (%)		WI (%)
	20 DAS	45 DAS	20 DAS	45 DAS	
Brown manuring (cowpea) by application of 2,4-D 1.0 kg/ha at 25 DAS	23.00	117.66	71.02	53.99	62.81
In situ green manuring (cowpea) at 25 DAS	11.00	84.00	86.14	67.53	65.33
Oxyfluorfen 0.15 kg/ha on the day of sowing *fb* HW at 30 DAS	5.87	3.60	92.60	98.58	5.02
Oxyfluorfen 0.15 kg/ha on the day of sowing *fb* bispyribac-sodium 0.025 kg/ha at 20 DAS	9.07	31.53	88.56	87.76	12.81
Pyrazosulfuron-ethyl 0.03 kg/ha at 6 DAS *fb* HW at 30 DAS	29.33	6.66	63.05	97.39	10.35
Pyrazosulfuron-ethyl 0.03 kg/ha at 6 DAS *fb* bispyribac-sodium at 20 DAS	34.66	120.00	56.33	52.66	42.34
Hand weeded control (15, 30 and 45 DAS)	5.80	3.33	92.55	98.69	0.00
Unweeded control	79.40	256.33	0.00	0.00	78.04
LSD (p=0.05)	11.02	29.18	18.88	28.46	7.93

Table 3. Effect of treatments on grain yield, straw yield, harvest index, cost of cultivation, gross return, net return and B:C ratio

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	HI (%)	Cost of cultivation ($x10^3$ `/ha)	Gross returns ($x10^3$ `/ha)	Net returns ($x10^3$ `/ha)	B:C ratio
Brown manuring (cowpea) by application of 2,4-D 1.0 kg/ha at 25 DAS	1.09	1.74	0.39	36.77	45.88	9.11	1.24
In situ green manuring (cowpea) at 25 DAS	1.00	2.21	0.30	36.40	48.14	11.74	1.32
Oxyfluorfen 0.15 kg/ha on the day of sowing *fb* HW at 30 DAS	2.74	5.89	0.31	44.68	130.31	85.63	2.91
Oxyfluorfen 0.15 kg/ha on the day of sowing *fb* bispyribac-sodium 0.025 kg/ha at 20 DAS	2.51	4.21	0.37	40.05	107.60	67.55	2.68
Pyrazosulfuron-ethyl 0.03 kg/ha at 6 DAS *fb* HW at 30 DAS	2.58	5.88	0.30	43.94	126.20	82.26	2.87
Pyrazosulfuron-ethyl 0.03 kg/ha at 6 DAS *fb* bispyribac-sodium at 20 DAS	1.66	4.10	0.29	39.31	84.38	123.69	2.14
Hand weeded control (15, 30 and 45 DAS)	2.88	5.41	0.34	59.00	129.27	70.27	2.19
Unweeded control	0.63	0.943	0.40	35.00	25.92	-9.08	0.74
LSD (p=0.05)	0.47	1.30	0.07	-	-	-	-

revealed that oxyfluorfen 0.15 kg/ha *fb* HW at 20 DAS resulted in higher net income and B:C ratio in aerobic rice. Rana *et al.* (2018) observed application of pyrazosulfuron-ethyl at different doses recorded higher net return and B:C ratio as compared to weed free and weedy check.

Result of the study indicated that application of either oxyfluorfen 23.5 EC at 0.15 kg/ha on the day of sowing or pyrazosulfuron-ethyl 10 WP at 0.03 kg/ha on 6 DAS followed by one hand weeding at 30 DAS can be recommended as cost-effective weed management in upland rice.

REFERENCES

Abraham CT, Prameela P and Lakshmi MP. 2010. Efficacy of oxyfluorfen for weed control in transplanted rice. *Journal of Crop and Weed* **6**(2): 67–71.

Arunbabu T and Jena SN. 2018. Weeds and progressive weed management techniques in rice (*Oryza sativa*. L.): a review. *Bulletin of Environment, Pharmacology and Life Sciences***7**(2): 108–117.

Bhurer KP, Yadav DN, Ladha JK, Thapa RB and Pandey K. 2013. Effect of integrated weed management practices on performance of dry direct seeded rice (*Oryza sativa* L.). *Agronomy Journal of Nepal* **3**: 53–63.

Kumar S and Rana SS. 2013. Bio-efficacy of bispyribac-sodium for weed control in direct seeded rice. *Pesticide Research Journal* **25**(2): 123–127.

Mondal DC, Hossain A and Duary B. 2005. Effect of pyrazosulfuron-ethyl on weeds and yield of transplanted rice under lateritic belt of West Bengal. *Indian Journal of Weed Science* **37**(3&4): 263–264.

Poddar R, Ghosh RK, Paul T and Bera S. 2014. Weed management through oxyfluorfen in direct seeded rice and its impact on soil micro-organisms and succeeding crops. *Annals of Agricultural Research* **35**(3): 337–342.

Porwal MK. 1999. Weed management through herbicides in direct drilled upland rice in rainfed situations of southern Rajasthan. *Indian Journal of Weed Science* **31**(3&4): 196–198.

Priya RS, Chinnusamy C, Arthanari PM and Janaki P. 2017.Pre-emergence herbicide of oxyfluorfen on weed control in transplanted rice. *International Journal of Chemical Studies* **5**(5): 271–275.

Rana A, Rana MC, Rana SS, Sharma N and Kumar S. 2018. Weed control by pyrazosulfuron-ethyl and its influence on yield and economics of transplanted rice. *Indian Journal of Weed Science* **50**(4): 309–314.

Reshma RS, Pillai PS and Sansamma G. 2015. Efficacy and economics of weed management strategies in aerobic rice (*Oryza sativa* L.). *Current Advances in Agricultural Sciences* **7**(1): 73–75.

Roy JBB. 2016. *Weed dynamics and yield of direct seeded upland rice (Oryza sativa* L.*) under integrated weed management practices*. M.Sc. (Ag) thesis, Orissa University of Agriculture and Technology, Bhubaneswar, 87p.

Saini JP. 2003. Efficacy of pyrazosulfuron-ethyl against mixed weed flora in transplanted rice. *Pesticide Research Journal* **15**(2): 157–159.

Sunil CM, Shekara BG, Ashoka P, Murthy KNK, Mahantesh V and Madhukumar V. 2011. Effect of integrated weed management practices on nutrient uptake in aerobic rice. *Research on Crops* **12**(3): 629–632.

Indian Journal of Weed Science **53**(1): 85–87, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Weed management in aerobic rice with sequential application of pendimethalin and bispyribac-sodium under coastal deltaic ecosystem

M. Pavithra*, R. Poonguzhalan, A.L. Narayanan and P. Saravanane

Department of Agronomy, Pandit Jawaharlal Nehru College of Agriculture & Research Institute, Karaikal, Puducherry 609 603, India

**Email: pavimuthukumar@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00013.7

Type of article: Research note

Received : 21 November 2020
Revised : 26 January 2021
Accepted : 28 January 2021

Key words

Aerobic rice, Pendimethalin, Bispyribac-sodium, Weed management

ABSTRACT

A field experiment was conducted at Pandit Jawaharlal Nehru College of Agriculture and Research Institute (PAJANCOA&RI), Karaikal during September 2013 - January 2014 with ten treatments replicated thrice in a randomized block design to evaluate the weed management efficacy of sequential application of pendimethalin and bispyribac-sodium in aerobic rice. *Echinochloa colona* (28.1%), *Ludwigia abyssinica* (28%) and *Cyperus difformis* (19.8%) among grasses, broad-leaved weeds and sedges, respectively were the predominant in the experimental field. Among the weed control treatments, pendimethalin 1.0 kg/ha at 3 days after seeding (DAS) *fb* bispyribac-sodium 30 g/ha at 30 DAS was found to be effective recording lowest weed density and biomass and superior growth attributes, yield attributes and yield of rice (4.86 t/ha).

Rice is widely grown under flooded irrigated conditions for better establishment and easy weed control. The traditional rice cultivation requires about 3000-5000 litres of water for producing one kg rice (Thiyagarajan and Selvaraju 2001). It is no longer feasible to flood rice field to ensure better crop establishment and control weeds as well. In the present situation, aerobic rice system has huge potential as a water-wise technology, wherein the crop is established through direct seeding in non-puddled and non-flooded fields (Rao *et al.* 2007, 2017). Rice cultivation using this system can save about 50 to 60 per cent irrigation water and increase the water productivity by around 200 per cent as compared to lowland flooded system. In aerobic rice system, the dry tillage practices and aerobic soil conditions are highly conducive for germination and growth of weeds which results in higher weed pressure coupled with greater grain yield losses as compared to flooded rice (Mahajan *et al*.2009). Morphological similarity between grassy weeds and rice seedlings makes hand weeding difficult at early stages of growth. Over the years, chemical weed control has emerged as promising solution as it is easy, quick, economical and feasible. Application of pre-emergence herbicides mainly control weeds during the earlier stages of crop growth, but second flush of weeds at 25 to 30 days after sowing becomes a problem. Heavy infestation of weeds at later stages of rice growth are not controlled effectively by the pre-emergence herbicides alone. This situation warrants for initiating research efforts to evaluate and identify suitable early post-emergence herbicides for successful cultivation of aerobic rice which have wider applicability and weed control spectrum under coastal deltaic ecosystem.

Keeping these in view, a field experiment was conducted during September 2013-January 2014 at research farm of PAJANCOA&RI, Karaikal, Puducherry (11°56' N latitude, 79°53'E longitude, 4 m above mean sea level) India. The soil texture in the experimental site was loamy sand with alkaline pH (8.2). The soil was low in available nitrogen (60.6 kg/ha) and phosphorus (10.5 kg/ha) and medium in available potassium (184.4 kg/ha). A medium duration rice cv. '*ADT(R)46*' was sown and the recommended package of practices for aerobic rice was followed. The experiment was laid out in a randomized block design with ten treatments, replicated thrice (**Table 1**).

Observations on weeds were recorded with the help of quadrate 0.25 x 0.25 m placed randomly at four spots in each plot at specified period. Growth parameters, yield parameters and grain yield were recorded at harvest. The data on weed density and biomass was then analysed using square root transformation ($\sqrt{x + 0.5}$) to normalize their distribution. The data collected from the experiments was subjected to the Fisher's method of Analysis of Variance (ANOVA).

Effect on weeds

The experimental field was infested with diverse weed flora comprising 35.7% grasses [*Echinochloa colona* (L.), *Echinochloa crus-galli* (L.) Beauv.], 21.8% sedges [*Cyperus difformis* (L.)., *Cyperus iria* (L.)] and 42.5% broad-leaved weeds [*Ludwigia abyssinica* A. Rich., *Lindernia oppositifolia* (L.) Mukerjee]. Application of pendimethalin at 1.0 kg/ha at 3 DAS integrated with hand hoeing at 40 DAS recorded the lowest weed density (7.6/m^2) and was at par with application of pendimethalin at 1.0 kg/ha at 3 DAS *fb* bispyribac-sodium 30 g/ha at 30 DAS (9.5/m^2) and hand hoeing at 20 and 40 DAS (10.5/m^2). This may be attributed to the reason that pendimethalin was effective against *E. colona* and *L. chinensis* up to 30 DAS as reported earlier by Saravanane *et al*. (2016). When compared to application of bispyribac-sodium alone, application of pendimethalin at 3 DAS *fb* bispyribac-sodium at 30 DAS was observed to have less population of *L. chinensis* and *L. abyssinica*. The grasses and sedges started drying after application of bispyribac-sodium at 30 DAS. Brar and Bhullar (2012) also reported that bispyribac-sodium was effective in controlling complex weed flora of grasses like *E. colona, E. crus-galli*, sedges and broad-leaved weeds. Application of pendimethalin 1.0 kg/ha at 3 DAS integrated with hand hoeing at 40 DAS (4.2 g/plant) and hand hoeing at 20 and 40 DAS (5.2 g/plant) also recorded significant lower weed biomass due to effective reduction in weed density by pendimethalin during initial period and by hand hoeing at later periods. Highest weed control efficiency was recorded with application of pendimethalin 1.0 kg/ha at 3 DAS integrated with hand hoeing at 40 DAS (96.9%), which was followed by hand hoeing at 20 and 40 DAS (95.4%) and pendimethalin 1.0 kg/ha at 3 DAS *fb* bispyribac-sodium 30 g/ha at 30 DAS (86.5%).

Effect on rice

Application of pendimethalin 1.0 kg/ha at 3 DAS *fb* bispyribac-sodium 30 g/ha at 30 DAS recorded the tallest rice plants (72.9 cm). Whereas 70.2% reduction in plant height, resulting in stunted rice plants was observed under unweeded control. Plant height had a significant positive correlation (r = 0.764**) (**Table 2**) with weed control efficiency and significant negative correlation with weed density (r = - 0.805**) and biomass (r = - 0.752**). When bispyribac-sodium was applied earlier at 15 DAS, slight yellowing was observed on the rice leaves, but later the rice plants recovered from this symptom. Pendimethalin 1.0 kg/ha at 3 DAS *fb* bispyribac-sodium 30 g/ha at 30 DAS recorded maximum LAI (7.69), dry matter production (30.07 g/plant), number of tillers/m^2 (546.7), number of productive tillers/m^2 (508.0), test weight (27.3 g) and grain yield (4.86 t/ha). Baloch *et al*. (2005) also found that rice without weed competition recorded higher number of productive tillers due to greater space use by rice and earlier canopy closure due to better competitive ability and nutrient use efficiency. The increase in panicle production occurred due to the increase in tillers

Table 1. Effect of weed control treatments on weed and crop attributes of aerobic rice

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	Weed control efficiency (%)	Plant height (cm)	Rice DMP (g/plant)	Rice LAI	No. of productive tillers/m^2	No. of spikelets/ panicle	No. of grains/ panicle	Grain yield (t/ha)
Pendimethalin 1.0 kg/ha at 3 DAS *fb* bispyribac-Na20 g/ha at 30 DAS	13.5(184)	11.0(127)	78.2	69.3	5.41	4.50	404.0	98.0	87.1	4.00
Pendimethalin 1.0 kg/ha at 3 DAS *fb* bispyribac-Na 25 g/ha at 30 DAS	12.9(165)	9.3(87)	85.1	69.4	5.55	5.16	410.7	99.4	89.0	4.20
Pendimethalin 1.0 kg/ha at 3 DAS *fb* bispyribac-Na 30 g/ha at 30 DAS	9.5(99)	8.8(79)	86.5	72.9	6.87	7.62	510.7	102.1	92.7	4.86
Bispyribac-sodium 20 g/ha at 15 DAS	21.5(467)	14.0(199)	65.8	64.4	4.08	3.66	393.3	86.5	74.2	2.58
Bispyribac-sodium 25 g/ha at 15 DAS	19.8 391)	11.4(130)	77.7	69.0	5.34	4.71	425.3	98.2	86.4	3.56
Bispyribac-sodium 30 g/ha at 15 DAS	20.4(416)	12.8(166)	71.6	64.7	4.54	3.52	352.0	88.0	76.0	2.63
Pendimethalin 1.0 kg/ha at 3 DAS *fb* 2,4-D Na salt 1.0 kg/ha at 40 DAS	17.1(291)	15.9(256)	56.1	60.9	3.29	3.11	260.0	82.1	69.2	1.71
Pendimethalin 1.0 kg/ha at 3 DAS and hand hoeing at 40 DAS	7.6(61)	4.2(18)	96.9	69.9	5.71	5.82	433.3	99.5	89.6	4.49
Hand hoeing at 20 and 40 DAS	10.5(113)	5.2(27)	95.4	70.3	6.04	6.16	441.3	100.7	90.6	4.67
Unweeded control	35.9(1291)	24.0(583)	-	52.2	1.98	1.47	157.3	50.0	37.3	0.33
LSD (p=0.05)	4.5	3.7	NA	8.3	1.12	1.27	89.7	8.5	5.6	0.57

Table 2. Correlation coefficient (r) values for rice growth and yield parameters with weed parameters

Parameters	Weed density	Weed dry matter production	Weed control efficiency
Plant height	-0.805	-0.752	0.764
Leaf area index	-0.760	-0.747	0.741
Number of tillers/ m^2	-0.738	-0.698	0.670
Dry matter production of rice	-0.730	-0.768	0.755
Number of productive tillers/m^2	-0.753	-0.737	0.750
Panicle length	-0.741	-0.719	0.751
Panicle weight	-0.772	-0.729	0.770
Test weight	-0.535	-0.456	0.531
Number of spikelets/panicle	-0.841	-0.814	0.834
Number of grains/panicle	-0.852	-0.836	0.853
Grain yield	-0.789	-0.816	0.843

Significant at 1%

number. The weed control efficiency had a significant and positive correlation with grain yield (r = 0.843**). Unweeded control recorded the lowest growth, yield attributes and yield might be due to higher physical suppression and competition with increasing weed density.

It was concluded that application of pendimethalin at 1.0 kg/ha at 3 DAS *fb* bispyribac-sodium at 30 g/ha at 30 DAS is the most suitable weed management option for achieving higher yield in aerobic rice under coastal deltaic ecosystem.

REFERENCES

Baloch MS, Hassan G and Morimoto T. 2005. Weeding techniques in transplanted and wet-seeded rice. *Weed Biology and Management* **5**: 190–196.

Brar HS and Bhullar MS. 2012. Dry-seeded rice productivity in relation to sowing time, variety and weed control. *Indian Journal of Weed Science* **44**(3): 193–195.

Mahajan G, Chauhan BS and Johnson DE. 2009. Weed management in aerobic rice in North-western Indo-Gangetic Plains. *Journal of Crop Improvement* **23**: 366–382.

Rao AN, Wani SP, Ahmed SH, Ali H and Marambe B. 2017. An Overview of Weeds and Weed Management in Rice of South Asia. pp. 247–281. In: *Weed Management in Rice in the Asian-Pacific region. Asian-Pacific Weed Science Society (APWSS)*; The Weed Science Society of Japan, (Eds. Rao AN and Matsumoto H). Japan and Indian Society of Weed Science, India

Rao AN, Johnson DE, Sivaprasad B, Ladha JK and Mortimer A. 2007. Weed management in direct-seeded rice. *Advances in Agronomy* **93**: 155–257.

Saravanane P, Mala S and Chellamuthu V. 2016. Integrated weed management in aerobic rice. *Indian Journal of Weed Science* **48**(2): 152–154.

Thiyagarajan TM and Selvaraju R. 2001. Water-saving in rice cultivation in India. pp. 15–45. In: *Proceedings of International Workshop on Water Saving Rice Production Systems*, Nanjing University.

Indian Journal of Weed Science **53**(1): 88–91, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Efficacy of pre- and post-emergence ready-mix herbicides in rainfed lowland wet-seeded rice

M.S.S. Reddy and M. Ameena*

Department of Agronomy, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala 695522, India

**Email: drameenaubaid@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00014.9

Type of article: Research note

Received : 8 September 2020

Revised : 16 December 2020

Accepted : 19 December 2020

Key words

Early post-emergence, Pre-emergence, Rainfed lowland rice, Ready mix herbicides, Weed management, Wet-seeded rice

ABSTRACT

The experiment was conducted during *Kharif* (rainy) season of 2019 to assess comparative efficacy of low dose high efficiency herbicides in providing season-long weed control in direct wet-seeded rainfed lowland rice at Integrated Farming System Research Station (IFSRS), Karamana, Kerala. The rice yield reduction due to unmanaged weeds in unweeded control in rainfed lowland rice was estimated to be 59.75%. Rice grain yield obtained was 159.9% higher in bensulfuron-methyl + pretilachlor *fb* HW at 40 DAS (5.46 t/ha) compared to weedy check with a B: C ratio of 1.83 and was at par with penoxsulam + cyhalofop-butyl *fb* HW at 40 DAS (5.35 t/ha) with a B:C ratio of 1.77. Application of ready mix of either bensulfuron-methyl + pretilachlor 60 + 600 g/ha at 3 DAS or penoxsulam + cyhalofop-butyl 150 g/ha at 20 DAS both *fb* HW at 40 DAS was observed as the most effective weed management strategy in wet-seeded lowland rainfed rice.

Rice (*Oryza sativa* L.) is one of the most important cereal crops of the world and the total milled rice consumption was about 490 million tonnes in 2018 and projected to reach 550 million tonnes by 2030 and 590 million tonnes by 2040 (Bhandari 2019). Rice is cultivated over widely varying environments, such as rainfed upland, rainfed lowland and irrigated upland ecosystems. The productivity of rice in India is low due to pest, disease and weed infestation of which weeds pose a greater threat in direct-seeded rainfed rice. In Kerala, area under rice cultivation during 2018-19 was estimated to be 0.17 million hectares with a productivity of 2.55 t/ha (Anonymous 2019). In a study on rainfed lowland wet-seeded paddy in Kerala, Umkhulzum and Ameena (2019) reported that unchecked weed growth could cause a reduction of 81% in net income. As farmers are shifting from transplanted to direct-seeded rice due to shortage of labour and high labour wages, direct-seeding in lowlands during *Kharif* (rainy season) becomes a widely adopted system of rice cultivation especially in Kerala. Direct-seeding of rice excludes nursery and transplanting that in turn decreases labour requirement and cost of cultivation apart from minimizing crop growth period by 8-10 days (Prasad *et al.* 2016, Rao *et al.* 2017).

The factors affecting the crop yield losses due to weeds depend upon the rice establishment methods and associated environment (Rao *et al.* 2017). Weed infestation reduces the rice yields upto 62.6, 70.6 and 75.8% in transplanted, wet-seeded and dry-seeded rice, respectively (Singh *et al.* 2005). Competition due to weeds is more severe in direct-sown rice due to simultaneous emergence of rice and weed seedlings whereas in transplanted rice, aged transplanted rice seedlings are able to compete with weeds better (Saha 2008, Rao *et al.* 2017a). In wet direct-seeded rice, initial 15-60 days is considered as critical period of crop-weed competition during which the field should be weed free to reduce losses (Rao *et al.* 2017a). Among different weed management practices, hand weeding (HW) and herbicide application were found effective in wet-seeded rice. However, HW is not possible and feasible during the very initial stages as certain grassy weeds look similar to rice and cannot be identified and hand weeded at its 4-6 leaf stage. To evade this cumbersome process, various pre-emergence (PE), early post-emergence (PoE) applied broad-spectrum herbicides can be made use of and many of the low dose high efficiency herbicides recently available are reported to be more effective than conventional herbicides in wet-seeded rice (Umkhulzum *et al.* 2018). Bensulfuron-methyl + pretilachlor and pyrazo-sulfuron-ethyl are effective as pre- and early PoE herbicides to manage the initial weed flora in rice

(Arya and Ameena 2016). Bispyribac-sodium and penoxsulam + cyhalofop-butyl are PoE herbicides with broad-spectrum activity. Metsulfuron-methyl + chlorimuron-ethyl and ethoxysulfuron are effective in controlling broad-leaved weeds and sedges in rice (Gopinath and Kundu 2008, Umkhulzum *et al.* 2018). In this context, the present experiment was conducted.

The field experiment was conducted in the lowland rice fields of Integrated Farming System Research Station (IFSRS), Karamana, Thiruvananthapuram situated geographically at 8^0 47' N latitude and 76^0 96' E longitude. Crop was grown during *Kharif* (rainy) season extending from June to October 2019 and the mean rainfall during the crop growing season was 99.05 mm. The soil type was sandy clay loam, strongly acidic, low in available nitrogen (273.9 kg/ha), high in available phosphorus (38.8 kg/ha) and low in available potassium (238 kg/ha). For the past several years, rice was being cultivated in the experimental site. The red kernelled, with medium bold grains, high yielding (8-10 t/ha), medium duration (120-135 days) rice variety *Uma* (*MO-16*) extensively grown in Kerala was used in the experiment. Farmyard manure 5 t/ha was provided as basal dose of organic manure and nutrient schedule of 90:45:45 NPK kg/ha was followed as per Kerala Agricultural University (KAU) package of practices.

The experiment was laid out in a randomized block design with 8 treatments replicated thrice having individual plot size of 20 m^2. The PE herbicides were applied using 300 litre/ha spray solution and the post-emergence herbicides were applied using 500 litres/ha spray solution. The weed density (no./m^2) and biomass (g/m^2) were recorded by placing a quadrat of size 0.5 x 0.5 m at two spots in each treatment and average was worked out. B:C ratio was worked out by considering prevailing market price for paddy and the price for different inputs and farm operations were considered for cost of cultivation. Analysis of variance was done for the statistical analysis of data.

Effect on weeds

During the cropping season, a variety of grasses, sedges and broad-leaved (BLW) weeds occurred in the field. From the initial stages of crop emergence up to critical growth stages, BLWs dominated the rice field. Among BLWs, *Sphenoclea zeylanica* was predominant along with *Ludwigia parviflora, Bergia capensis, Lindernia rotundifolia, Alternanthera sessilis, Limnocharis flava* and *Monochoria vaginalis* while *Ludwigia parviflora* dominated during later stages. *Sphenoclea zeylanica* was the predominant BLW seen up to the first 2.5 to 3 months because of its persistent infestation during the past seasons. Saha and Rao (2010) also stated the domination of BLW population, especially *Sphenoclea zeylanica* under wet-seeded condition. Grasses like *Echinochloa colona*, *Leptochloa chinensis* and *Ischaemum rugosum* were seen from initial stages. *Oryza sativa f. spontanea* was observed from 60 DAS onwards due to the difficulty in identifying the weedy rice plants before flowering. Sedges commonly associated with the crop were *Fimbristylis miliacea, Cyperus difformis* and *Cyperus iria.*

Effect on weed density, biomass and weed control efficiency

At 15 DAS, PE herbicide bensulfuron-methyl + pretilachlor (60 + 600 g/ ha) at 3 DAS registered 94.59% reduction in weed density over unweeded control while early PoE herbicide pyrazosulfuron ethyl 25 g/ha at 6 DAS recorded 89.57% reduction in direct wet-seeded lowland rice (**Table 1**). Though puddling and wet-seeding provided a favourable condition for flourishing of weed flora during the initial weeks of wet-seeding, PE bensulfuron-methyl + pretilachlor and early PoE herbicide pyrazosulfuron-ethyl 25 g/ha could bring about significant reduction in weed density upto one month. Weed biomass was statistically reduced by bensulfuron-methyl + pretilachlor and pyrazosulfuron-ethyl for a month over other treatments as the effect of herbicides sprayed on 3^{rd} and 6^{th} day prolonged till 30 DAS. Umkhulzum and Ameena (2019) reported 98.35% decline in weed density in relation to weedy check at 15 DAS in bensulfuron-methyl + pretilachlor treated wet-seeded rice while Yakadri *et al.* (2016) observed reduction in weed biomass with pyrazosulfuron-ethyl 25 g/ha. Rest of the experimental plots reported higher weed densities at 15 DAS owing to non-treatment up to that stage.

At 45 and 60 DAS, ready mix of penoxsulam + cyhalofop-butyl (150 g/ha) at 20 DAS *fb* HW, registered lower weed biomass due to broad-spectrum weed control compared to bispyribac-sodium sprayed at the same time. Weed biomass was 88.97 and 62.97% lower in PoE ready-mix herbicide treatments than the control HW twice. During the critical stages of crop weed competition at 30, 45 and 60 DAS, penoxsulam + cyhalofop-butyl *fb* HW at 40 DAS caused significant decline in weed density of 98.78, 94.64 and 96.01%, respectively. A steady increase in weed biomass of 12.20, 170.27, 306.10 and 400.84 g/m^2 at 15, 45 and 60 DAS, respectively was recorded in unweeded plots. This progressive increase in dry weight parallel to decline in weed density could be ascribed to higher dry matter contribution from individual weeds. At all crop growth stages, un-weeded plots also recorded in higher weed density of 345.33 at 15 DAS to 250.75 per m^2 at 60 DAS. The declining trend in weed density from the initial count to that at harvest could be attributed to the completion of life-cycle of some weeds and also could be due to the suppression of late emerged weeds by other competitive weeds.

Weed control efficiency indicates the relative efficacy of weed management treatments over weedy check. Amongst the weed management treatments, higher WCE of 99.28 and 96.23% was recorded in bensulfuron-methyl + pretilachlor upto 30 DAS, which was at par with pyrazosulfuron-ethyl with WCE of 96.18% (**Table 1**). Similar observations were made by Saha and Rao (2010). The pre-mix herbicide penoxsulam + cyhalofop-butyl applied at 20 DAS *fb* HW recorded superior weed control efficiencies from second month onwards due to effective suppression of sedges, grasses and BLWs during initial stages of crop growth followed by manual weeding at late emerging weeds.

Growth and yield

Bensulfuron-methyl + pretilachlor at 3 DAS *fb* HW at 40 DAS recorded 159.9% increase in rice grain yield over unweeded control and at par with penoxsulam + cyhalofop-butyl *fb* HW at 40 DAS, which recorded 154.8% gain in yield **(Table 2)** due to extended period of effective weed control at critical growth stages of the crop that helped the crop to utilize the inputs effectively resulting in better growth. Rice straw yield followed similar trend. Yadav *et al.* (2018) also observed superior rice yield similar to weed free with penoxsulam + cyhalofop 135 g/ha or 150 g/ha. Minimum grain and straw yields were recorded under weedy check due to greater weed infestation and weed biomass. Unrestricted weed growth led to 59.75% grain yield and 39.14% straw yield reduction compared with the hand weeding twice practice due to the lesser crop stand establishment and greater weed competition.

Weed index

Weed index (WI) is a parameter to describe yield loss occurred due to weed infestation in comparison with weed free plots. Negative or superior weed index was registered with ready mix herbicides bensulfuron-methyl + pretilachlor (-5.14%) and penoxsulam + cyhalofop-butyl (-2.96%) than HW twice indicating their greater efficacy in managing weeds than HW. Even though manual weeding was effective, identifying weeds in initial growth stages in direct wet-seeded rice is an arduous task necessitating the need for a pre- or early PoE herbicide. Singh *et al.* (2008) stated the common flaws in HW such as weed regrowth and weed escape leading to its ineffectiveness.

Economics of cultivation

The adoption of any technology is found feasible and acceptable to farmers only if it is economically viable and hence the actual comparison between two performing treatments can be done based on economic viability. In the present study, bensulfuron-

Table 1. Effect of weed management practices on weed density, biomass and weed control efficiency of direct-seeded rainfed lowland rice at 15, 30, 45 and 60 DAS

Treatment	Weed density (no./ m^2)				Weed biomass (g/m^2)				Weed control efficiency (%)			
	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS
Bensulfuron-methyl + pretilachlor 60 + 600 g/ha at 3 DAS *fb* HW at 40 DAS	18.67	24.00	60.33	60.00	0.08	6.4	15.57	22.49	99.28	96.22	94.92	94.39
	(4.43)	(4.99)	(7.82)	(7.80)	(1.04)	(2.71)	(4.07)	(4.84)	(10.01)	(9.86)	(9.79)	(9.77)
Pyrazosulfuron-ethyl 25 g/ha at 6 DAS *fb* HW at 40 DAS	36.00	36.67	77.67	62.67	0.22	8.48	19.88	27.64	98.16	95.02	93.26	93.08
	(6.08)	(6.13)	(8.86)	(7.97)	(1.11)	(3.08)	(4.56)	(5.35)	(9.96)	(9.80)	(9.71)	(9.70)
Bispyribac-sodium 25 g/ha at 20 DAS *fb* HW at 40 DAS	272.00	13.33	45.33	44.00	10.17	14.25	7.87	22.23	16.78	91.62	97.42	94.46
	(16.52)	(3.78)	(6.80)	(6.68)	(3.34)	(3.90)	(2.98)	(4.82)	(4.14)	(9.62)	(9.21)	(9.77)
Penoxsulam + cyhalofop-p-butyl 150 g/ha at 20 DAS *fb* HW at 35- 40 DAS	291.33	4.00	14.67	10.00	9.87	10.94	1.35	4.61	18.50	93.55	99.54	98.85
	(17.09)	(2.24)	(3.95)	(3.31)	(3.29)	(3.45)	(1.53)	(2.37)	(4.32)	(9.72)	(10.03)	(9.99)
Metsulfuron-methyl + chlorimuron-ethyl 4 g/ha at 20 DAS *fb* HW at 40 DAS	281.00	8.00	18.67	23.00	9.94	11.66	3.12	10.28	18.49	93.13	98.98	97.22
	(16.78)	(2.95)	(4.41)	(4.84)	(3.31)	(3.56)	(2.03)	(3.31)	(4.41)	(9.70)	(10.00)	(9.91)
Ethoxysulfuron 15 g/ha at 20 DAS *fb* HW at 40 DAS	279.33	12.00	42.00	37.83	10.30	15.93	8.39	15.99	15.62	90.86	97.25	96.01
	(16.66)	(3.58)	(6.55)	(6.23)	(3.36)	(4.07)	(3.06)	(4.12)	(4.05)	(9.58)	(9.91)	(9.85)
Hand weeding at 20 and 40 DAS	256.33	13.33	61.00	28.67	10.40	7.09	12.24	12.45	14.78	95.82	96.01	96.88
	(15.93)	(3.78)	(7.84)	(5.44)	(3.37)	(2.84)	(3.62)	(3.67)	(3.95)	(9.84)	(9.85)	(9.89)
Weedy check (un-weeded control)	345.33	257.00	273.6	250.75	12.20	170.27	306.10	400.84	0.00	0.00	0.00	0.00
	(18.55)	(16.06)	(16.57)	(15.84)	(3.63)	(13.08)	(17.52)	(20.04)	(1.00)	(1.00)	(1.00)	(1.00)
LSD (p=0.05)	2.191	0.796	0.557	0.918	0.468	0.275	0.259	0.187	1.116	0.05	0.027	0.033

The data were subjected to square root transformation $\sqrt{x+0.5}$ and transformed values are given in parentheses; DAS: Days after seeding; *fb*: Followed by; HW: Hand weeding

Table 2. Effect of weed management treatments on yield and economics of direct-seeded rainfed lowland rice

Treatment	Rice grain yield (t/ha)	Rice straw yield (t/ha)	Harvest index	Weed index (%)	Gross income (x10^3 Rs/ha)	Net income (x10^3 Rs/ha)	B:C ratio
Bensulfuron-methyl + pretilachlor 60 + 600 g/ha at 3 DAS *fb* HW at 40 DAS	5.46	7.71	0.42	-5.14	164.15	74.32	1.83
Pyrazosulfuron-ethyl 25 g/ha at 6 DAS *fb* HW at 40 DAS	4.60	6.71	0.41	8.98	139.39	51.09	1.58
Bispyribac-sodium 25 g/ha at 20 DAS *fb* HW at 40 DAS	4.37	6.56	0.40	15.95	133.34	43.62	1.49
Penoxsulam + cyhalofop-p-butyl 150 g/ha at 20 DAS *fb* HW at 35-40 DAS	5.35	7.65	0.42	-2.96	161.38	70.51	1.77
Metsulfuron-ethyl + chlorimuron-ethyl 4 g/ha at 20 DAS *fb* HW at 40 DAS	5.09	7.34	0.41	2.18	153.79	65.27	1.74
Ethoxysulfuron 15 g/ha at 20 DAS *fb* HW at 40 DAS	4.75	6.83	0.41	8.75	143.39	55.41	1.63
Hand weeding at 20 and 40 DAS	5.20	7.18	0.42	0.00	155.59	52.19	1.50
Weedy check (un-weeded control)	2.10	4.69	0.31	59.75	71.79	-1.77	0.97
LSD (p=0.05)	0.216	0.468	0.025	5.892	-	-	-

methyl + pretilachlor *fb* HW fetched higher gross income (₹ 1,64,151/ha), net income (₹ 74,320/ha), and B:C ratio (1.83) because of superior grain and straw yield along with lesser herbicide cost. Despite higher herbicide cost, penoxsulam + cyhalofop-butyl registered the next best returns and BC ratio of 1.77. Eventhough, HW was efficient, herbicidal treatment was simple, economical, time and labour saving than manual weeding. Gross income (₹ 1,55,590/ha), net income (₹ 52,186/ha), and B: C ratio (1.50) obtained in manual weeding was lesser due to higher wage rates. Thus, application of ready-mixture of herbicides either PE bensulfuron-methyl + pretilachlor at 3 DAS or PoE penoxsulam + cyhalofop-butyl at 20DAS both *fb* HW at 40 DAS could be suggested as a practicable option for effective and season long weed management in rainfed lowland direct wet-seeded rice.

REFERENCES

Anonymous. 2019. Farm Information Bureau. Department of Agriculture Development and Farmers Welfare. 307 p.

Arya SR and Ameena M. 2016. Efficacy of new generation herbicides for weed management in semidry rice. *Journal of Tropical Agriculture* **54**(1): 55–59.

Bhandari H. 2019. Global rice production, consumption and trade: trends and future directions [abstract]. p. 5. In: *Proceedings of the Korean Society of Crop Science Conference*; September 30, 2019, The Korean Society of Crop Science.

Gopinath KA and Kundu S. 2008. Evaluation of metsulfuron-methyl and chlorimuron-ethyl for weed control in direct seedee rice. *Indian Journal of Agricultural Sciences* **78**(5): 466–469.

Prasad TVP, Reddy CV, Bharathalakshmi Mand Satyanarayana PV. 2016. Efficacy of new herbicide molecules for weed management in wet direct-seeded rice. *ORYZA-International Journal of Rice* **53**(1): 98–101.

Rao AN, Wani SP, Ramesha MS and Ladha JK. 2017. Rice Production Systems. Chapter 8. Pp. 185-205, In: Rice Production Worldwide. (Eds. Chauhan BS, Jabran K and Mahajan G), Springer International Publishing AG 2017 185. DOI 10.1007/978-3-319-47516-5_8.

Rao AN, Wani SP, Ahmed S, Ali HH and Marambe B. 2017a. An overview of weeds and weed management in rice of South Asia. pp. 247 to 281. In: *Weed Management in Rice in the Asian-Pacific region.* Asian-Pacific Weed Science Society (APWSS); The Weed Science Society of Japan, (Eds. Rao AN and Matsumoto H). Japan and Indian Society of Weed Science, India

Rao AN, Johnson DE, Sivaprasad B, Ladha JK and Mortimer AM. 2007. Weed management in direct-seeded rice. *Advances in Agronomy* **93**: 155–257.

Saha S. 2008. Sustaining high rice productivity, the IWM way. *Indian Farming* **58**(3): 18–22

Saha S and Rao KS. 2010. Evaluation of bensulfuron-methyl for weed control in wet direct-sown summer rice. *ORYZA-International Journal of Rice* **47**(1): 38–41.

Singh VP, Singh G, Singh SP, Kumar A, Singh Y, Johnson DE and Mortimer M. 2005. Effect of rice wheat establishment methods and weed management in irrigated rice–wheat production system. In: *Workshop on 'Direct Seeded Rice in the Rice–wheat System of the Indo-Gangetic Plains'*, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttaranchal, India.

Singh G, Singh, OP, Kumar V and Kumar T. 2008. Effect of methods of establishment and tillage practices on productivity of rice (*Oryza sativa*) wheat (*Triticum aestivam*) cropping system in lowlands. *Indian Journal of Agricultural Science* **78**: 163–166.

Umkhulzum SF and Ameena M. 2019. Integrated management of rock bulrush (*Schoenoplectus juncoides*) in wet seeded rice. *Journal of Crop and Weed* **15**(3): 139–144.

Umkhulzum SF, Ameena M and Pillai PS. 2018. Comparative efficacy of herbicides against rock bulrush (*Schoenoplectus juncoides*) in wet seeded rice. *Indian Journal of Weed Science* **50**(4): 395–398.

Yadav DB, Singh N, Duhan A, Yadav A and Punia SS. 2018. Penoxsulam + cyhalofop-butyl (premix) evaluation for control of complex weed flora in transplanted rice and its residual effects in rice-wheat cropping system. *Indian Journal of Weed Science* **50**(4): 333–339.

Yakadri M, MadhaviM, Rampraksh T and Rani L. 2016. Herbicide combinations for control of complex weed flora in transplanted rice. *Indian Journal of Weed Science* **48**(2): 155–157.

Indian Journal of Weed Science **53**(1): 92–94, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Performance of rice cultivars with weed management practices in dry direct-seeded rice

K. Pooja and P. Saravanane*

Department of Agronomy, Pandit Jawaharlal Nehru College of Agriculture & Research Institute, Karaikal, Puducherry 609603, India

**Email: psaravanane@rediffmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00015.0

Type of article: Research note

Received : 5 October 2020
Revised : 12 February 2021
Accepted : 15 February 2021

Key words

Dry direct-seeded rice

Grain yield

Rice cultivars

Weed management

ABSTRACT

Weeds are the most important biotic constraint in direct-seeded rice (DSR) production. A field experiment was carried out in split plot design replicated thrice during September 2019 to evaluate the performance of different cultivars integrated with weed management practices under DSR at Pandit Jawaharlal Nehru College of Agriculture & Research Institute, Karaikal, Puducherry UT, India. The treatment combination consisted of three cultivars in main plot (*ADT 46*, *CO 52* and *White Ponni*) and five levels of weed management practices in the sub-plots (application of pendimethalin 1.0 kg/ha as pre-emergence herbicide at 3 DAS, bispyribac-sodium 0.02 kg/ha as post-emergence herbicide at 20 DAS, sequential application of pendimethalin 1.0 kg/ha followed by bispyribac-sodium 0.02 kg/ha, hand weeding twice at 20 and 40 days after sowing (DAS) and unweeded control. Results revealed that rice cultivar *ADT 46* integrated with sequential application of pendimethalin *fb* bispyribac-sodium (1.0 kg/ha *fb* 0.02 kg/ha) reduced the weed density and weed dry weight, and increased the growth, yield attributes and rice grain yield. Uncontrolled weeds caused 51.9 % yield loss in dry-DSR under coastal deltaic ecosystem.

Rice is an important cereal crop cultivated in India. Transplanting is the most common establishment method of rice in India. However, scenario of escalated resource costs in transplanting method forces the rice farmers to switch to a cheaper and alternative establishment method of direct seeding in India. DSR is practiced as wet seeding and dry seeding. Pre-germinated rice seeds are sown in the puddled soil under wet seeding whereas the dry seeds are sown in the unpuddled soil under dry seeding. Major bottleneck in the dry direct-seeding is weeds. Such weeds invite severe competition between weeds and rice thus reducing the crop yield on an average of 50-90% (Mahajan and Chauhan 2013).

Rice cultivars with weed-suppressing characters such as diverse morphological traits, canopy structure and relative growth rate are an important aspect of weed management in DSR (Mahajan *et al.* 2015). Herbicide use becomes more important when weeds and rice emerge simultaneously in DSR, and some of the weeds have morphological similarity to rice like *Echinochloa colona* and *Echinochloa crus-galli*, which are difficult to be differentiated at early stages of growth. So, evaluating the performance of promising rice cultivars of the region integrated with suitable weed management practices in dry-DSR is need of the hour.

Hence, a field experiment was conducted at Pandit Jawaharlal Nehru College of Agriculture & Research Institute, Karaikal, Puducherry UT, India during September 2019 (*Thaladi* season). The soil was sandy clay loam, pH 6.45, low in available N (82 kg/ha), high in available P (57 kg/ha) and medium in available K (254 kg/ha). The experiment comprised of three cultivars and five weed management practices (**Table 1**). Cultivars *viz. ADT 46, CO 52* and *White Ponni* (WP) were assigned to main plots, and five weed management practices, *viz.* pendimethalin at 1.0 kg/ha sprayed at 3 days after sowing (DAS), bispyribac-sodium 0.02 kg/ha sprayed at 20 DAS, sequential application of pendimethalin at 1.0 kg/ha followed by bispyribac-sodium at 0.02 kg/ha, hand weeding twice at 20 and 40 DAS and unweeded control were allotted to sub-plots, replicated three times in a split-plot design. Shallow and narrow furrows were opened at 20 cm interval with the help of hand hoe. Dry rice seeds with seed rate of 75 kg/ha were manually sown in 10 cm gap between plants and covered with soil. Herbicides were sprayed using knap-sack sprayer fitted with flat-fan nozzle using spray fluid of 500 L/ha for pre-emergence and 375 L/ha for post-emergence application. Data on weed density and dry matter accumulation were recorded at 60 DAS using four quadrates of size 0.5 x 0.5 m (Saravanane 2020). Data on weed density and dry weight were transformed with square root transformation ($\sqrt{x + 0.5}$) before analyses. Grain yield and weed biomass relationships at harvest were assessed using linear regression analysis. Data were subjected to statistical scrutiny as per the procedures given by Panse and Sukhatme (1967).

Twelve weed species (*Echinochloa colona* L., *Echinochloa crus-galli* L. and *Leptochloa chinensis* L. among grasses; *Cyperus iria* L., *Cyperus difformis* L. and *Fimbristylis miliacea* L. among sedges; *Bergia capensis* L., *Eclipta alba* (L.) Hassk, *Ludwigia perennis* L., *Marsilea quadrifolia* L., *Sphaeranthus indicus* L. and *Aeschynomene indica* L. among broad -leaved weeds) were observed in experimental field.

Cultivars significantly reduced the weed density and weed dry weight except grass weed density at 60 DAS (**Table 1**). Sedges, broad-leaved weeds and total weed density and dry weight were significantly lower under cultivar *ADT 46* which was comparable to *CO 52*. High productive tillers with improved plant height under cultivar *ADT 46* might have helped to register low density and dry weight of weeds compared to other cultivars. Caton *et al*. (2003) indicated that plants with high tillering ability and taller stature is essential for weed competitiveness. Further, cultivars differ in their weed competitiveness by virtue of their genotypic differences (Mahajan *et al*. 2015). Higher total weed density (213.6 no./m^2) and dry weight (59.5 g/m^2) was recorded under IWP, which resulted in lower weed control efficiency of 58.1% as compared to all other cultivars.

Weed management practices significantly reduced the weed density and weed dry weight at 60 DAS. Sequential application of pendimethalin 1.0 kg/ha followed by bispyribac-sodium 0.02 kg/ha has recorded lower total weed density (113.5 no./m^2) and weed dry weight (21.1 g/m^2), resulted in higher weed control efficiency (78.3%). However, it was followed by hand weeding twice (74.6%). It is earlier reported that single use of either pre-emergence or post-emergence herbicide was not effective against complex weed flora in DSR (Mahajan and Chauhan 2013). However, sequential application of pre-emergence (pendimethalin) and post-emergence herbicides (bispyribac-sodium) found to be effective against wide spectrum of weeds (Saravanane 2020). Early control of weeds by pendimethalin herbicide was due to its persistence nature, which has half-life period of 10.5 to 44 days depending upon soil temperature and moisture (Ramirez and Plaza 2015) and late emergence weed control by bispyribac-sodium due to its ALS (acetolacto synthase) enzyme inhibition. Unweeded control recorded higher total weed density (241.3 no./m^2) and total weed dry weight (92.4 g/m^2).

Cultivars and weed management influenced the growth, yield parameters and yield except plant height under cultivars (**Table 2**). *ADT 46* has recorded better growth, yield parameters and in turn, resulted in 19 and 31% higher rice yield compared to *Co 52* and WP. This might be due to better weed competitive

Table 1. Effect of cultivars and varying weed management treatments on weed density, weed dry weight and weed control efficiency in dry-DSR

Treatment	Weed density (no./ m^2)				Weed dry weight (g/m^2)				Weed control efficiency (%)
	Grasses	Sedges	BLW	Total weed density	Grasses	Sedges	BLW	Total weed dry weight	
Cultivars									
ADT 46	4.77(26.2)	3.22(16.9)	9.13(83.7)	11.03(126.9)	3.04(13.6)	1.57(3.4)	3.95(15.6)	5.37(32.8)	69.9
Co 52	5.31(29.1)	4.00(22.0)	9.34(88.1)	11.68(139.3)	3.35(13.9)	1.98(5.1)	4.18(17.4)	5.77(36.3)	69.8
White Ponni	5.61(32.8)	4.83(28.7)	12.26(152.1)	14.43(213.6)	4.64(25.0)	2.08(5.3)	5.42(29.5)	7.52(59.5)	58.1
LSD (p=0.05)	NS	0.96	2.44	2.07	0.73	0.38	1.15	1.44	
Weed management									
Pendimethalin 1.0 kg /ha	5.34(28.8)	4.67(25.6)	10.53(112.9)	12.78(167.3)	3.64(13.4)	1.98(4.3)	4.68(21.9)	6.24(39.6)	57.5
Bispyribac-sodium 0.02 kg /ha	4.82(23.3)	3.01(17.8)	10.30(109.1)	12.05(150.2)	3.28(11.4)	1.73(3.9)	4.56(21.2)	5.89(36.4)	61.4
Pendimethalin 1.0 kg/ha *fb* bispyribac-sodium 0.02 kg/ha	4.07(16.8)	2.45(8.2)	9.28(88.4)	10.48(113.5)	1.92(3.7)	1.32(1.4)	3.96(15.9)	4.52(21.1)	78.3
Hand weeding twice (20 & 40 DAS)	4.30(20.0)	2.87(11.1)	9.69(96.2)	11.13(127.3)	2.22(5.0)	1.47(2.5)	4.15(17.5)	4.91(24.9)	74.6
Unweeded control	7.62(58.0)	7.09(50.0)	11.42(133.3)	15.47(241.3)	7.32(54.1)	2.87(10.8)	5.24(27.5)	9.55(92.4)	-
LSD(p=0.05)	0.42	1.47	0.62	0.79	0.50	0.79	0.37	0.59	

LSD, least significant difference; BLW- Broad- leaved weeds; NS- Non-significant; figures in parentheses were original values; *fb*- followed by

Table 2. Effect of cultivars and varying weed management treatments on growth, yield parameters, yield and weed index in dry DSR

Treatment	Plant height (cm)	Productive tiller/m^2	Panicle weight (g)	1000 seed weight (g)	Grain yield (t/ha)	Weed index
Cultivars						
ADT 46	123.3	362.6	3.37	23.65	3.76	18.2
Co 52	119.9	359.2	3.11	16.80	3.05	33.6
White Ponni	116.9	342.2	2.45	14.76	2.58	43.9
LSD (p=0.05)	NS	15.78	0.52	2.36	0.30	
Weed management						
Pendimethalin 1.0 kg/ha	117.8	360.8	2.93	18.07	2.98	35.2
Bispyribac-sodium 0.02 kg/ha	120.2	367.3	3.08	18.41	3.19	30.7
Pendimethalin 1.0 kg/ha *fb* bispyribac-sodium 0.02 kg/ha	124.7	378.1	3.58	19.05	3.73	18.8
Hand weeding twice (20 and 40 DAS)	122.4	376.0	3.23	19.24	3.54	23.0
Unweeded control	115.2	291.2	2.07	17.24	2.21	51.9
LSD (p=0.05)	2.78	12.01	0.23	NS	0.23	

LSD, least significant difference; NS- Non-significant; *fb*- followed by

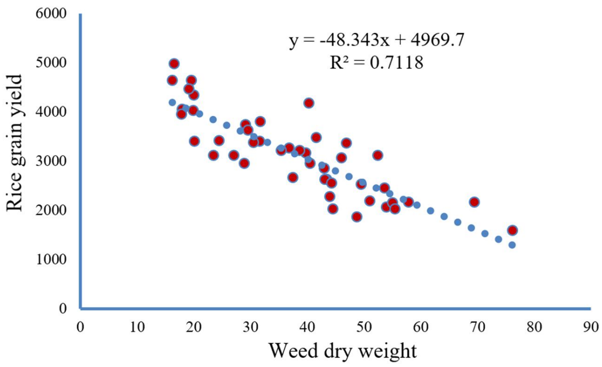


Figure 1. The relationship between grain yield and total weed dry weight at harvest

environment prevailed under *ADT 46*. Sequential application of pendimethalin 1.0 kg/ha followed by bispyribac-sodium 0.02 kg/ha has recorded higher plant height (124.7 cm), productive tillers (378.1 tillers), panicle weight (3.58 g) and grain yield (3.73 t/ha) of rice. The increase in grain yields under sequential application of herbicides due to effective control of weeds was earlier reported by Mahajan and Chauhan (2013) and Saravanane (2020). Grain yield was statistically comparable with hand weeding twice (3.54 t/ha). Shorter rice plants, lesser number tillers, poor filling of grains and less panicle weight due to the vigorous crop-weed competition for growth factors like nutrient, space, light and carbon dioxide (Tindall *et al.* 2005) under unweeded control resulted in lesser grain yield (2.21 t/ha). Rice grain yield and total weed dry weight at harvest stage showed negative linear relationship with co-efficient of determination of 0.712 (**Figure 1**).

Current study clearly indicated that weed interference contributed to the negative influence on the growth and yield attributes of the crop, which cumulatively reduced the grain yield of DSR. Uncontrolled weeds resulted in 51.9% yield reduction in DSR.

It was concluded that farmers can cultivate *ADT 46* integrated with sequential application of pendimethalin 1.0 kg/ha followed by bispyribac-sodium 0.02 kg/ha in labour scarcity areas or hand weeding twice at 20 and 40 DAS in labour sufficient areas to effectively manage the diverse weed flora, enhance rice yield of dry DSR in the coastal deltaic ecosystem.

REFERENCES

Caton BP, Cope AE and Mortimer M. 2003. Growth traits of diverse rice cultivars under severe competition. Implications for screening for competitiveness. *Field Crop Research* **83**: 157–172.

Mahajan G and Chauhan BS. 2013. Herbicide options for weed control in dry-seeded aromatic rice in India. *Weed Technology* **27**: 682–689.

Mahajan G, Ramesha MS and Chauhan BS. 2015. Genotypic differences for water- use efficiency and weed competitiveness in dry direct-seeded rice. *Agronomy Journal* **107**(4): 1573–1583.

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

Ramirez JG and Plaza G. 2015. Effect of post-emergence herbicide applications on rice crop weed communities in Tolima, Colombia. *Planta Daninha* **33**(3): 499–458.

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

Tindall KV, Williams BJ, Stout MJ, Geaghan JP, Leonard BR and Webster EP. 2005. Yield components and quality of rice in response to graminaceous weed, weed density and rice stink bug population. *Crop Protection* **24**: 991–998.

Indian Journal of Weed Science **53**(1): 95–98, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Weed dynamics in pulses cultivated in summer-fallows of double cropped lowland rice fields of Northern Kerala

S. Adarsh*[1] and Jacob John[2]

[1]*Department of Agronomy, College of Agriculture, Kerala Agricultural University, Padannakkad, Kasaragod, Kerala 671314, India*

[2]*Integrated Farming Systems Research Station, KAU, Karamana, Kerala 695002, India*

**Email: sssadarshsss@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00016.2

Type of article: Research note

Received : 9 January 2020
Revised : 12 January 2021
Accepted : 15 January 2021

Key words
Pulse
Summer-fallow
Rice
Weed dynamics

ABSTRACT

A field study was undertaken to find the weed dynamics in different pulse crops in summer-fallows of lowland rice fields under varying nitrogen doses during summer 2018. Among grasses, sedge and broad-leaved weeds *Oryza sativa*, *Cyperus rotundus* and *Boerhavia diffusa*, respectively were dominant in the field where pulses are grown. Absolute density of weeds was lesser in plots where red gram was cultivated with 75% and 50% of the recommended dose of nitrogen (RDN). Blackgram (50% RDN) was effective in smothering weeds. The dry matter production of weeds was the highest in fallows. The N removal by weeds was higher in fallow and that of P and K were at par in all treatments. The leaf area index (LAI) (100 and 50% RDN), crop growth rate (CGR) (50% RDN), yield (50% RDN) were significant for cowpea. Cowpea and red gram performed better among the different pulses in terms of yield. There was no significant difference in yield of pulses under varying levels of N, indicating that the lower level of N (50% RDN) will be sufficient.

Utilisation of summer-fallows by raising different crops increases system productivity (Varughese *et al.* 2007, Adarsh *et al.* 2019). Pulse crops are potential candidates for considering in summer rice-fallows as they fix atmospheric nitrogen (Pillai *et al.* 2007, Porpavai *et al.* 2011) and enhance the physical, chemical and biological properties of soil. They are very good sources of protein with low glycaemic index, low gluten and even acts as a functional food (Rao 2002). Weeds are the major impediment to crop production. A major approach to reduce the predominance of any given weed species is to increase the diversity of crops within the cropping system. Hence, the inclusion of crops with different growth habits and requiring change in land configuration during summer in rice-based sequences can bring about changes in the weed species diversity and their population. In this context, a study was undertaken to assess the weed dynamics in different pulses grown during summer in the lowland double cropped rice-fallows.

The field study was undertaken in the double cropped lowland rice fields of Regional Agricultural Research Station, Pilicode, Kerala Agricultural University during summer 2018 (February to May 2018). Cowpea (var. *PGCP 6*), black gram (var. *Co 6*), green gram (var. *Co. 8*) and red gram (var. *APK 1*) were raised in the field selected for the study. Total rainfall of 110.5 mm was received during cropping season. The maximum and minimum temperature varied between 33°C and 34.5°C and 20.5°C and 26°C, respectively during the summer. The soil of the experimental site, which falls under the order Ultisol, was sandy clay loam in texture, extremely acidic in pH and, high in available nitrogen, phosphorus and potassium contents. The experiment was laid out in a randomised block design with thirteen treatments and replicated thrice. The treatments were a combination of 4 pulse crops (cowpea, blackgram, green gram and red gram) with 3 levels of nitrogen (100% RDN, 75% RDN and 50% RDN) and fallow during summer. Cowpea variety *PGCP 6*, green gram variety *Co 8*, black gram variety *Co 6* and red gram variety *APK 1* were used under the study. The plot size was 5 x 4 m. Dry matter of the weeds was estimated by sampling of weeds from 1 m^2 area. Weeds were uprooted from each plot with minimum damage to roots and dried under shade and then oven dried at 70 ± 5°C till constant weight was obtained, and expressed as g/m^2. The weed population was estimated by counting the number of weeds in each category *i.e.*, grasses, broad-leaved weeds and sedges and expressed in number/m^2. The plant analysis was done in such a way that samples were dried to constant weight in an electric hot air oven at 70 ± 5°C, ground into fine powder and analysed. Modified micro Kjeldahl method, Vanado-molybdo phosphoric yellow colour method using spectro-photometer and flame photometry method have been used for chemical analysis of N, P and K, respectively (Jackson, 1973). Content of nutrients removed by weeds were calculated from the values of dry matter content and per cent nutrient content of weed. Weed smothering efficiency (WSE) was calculated as:

$$\text{WSE} = \frac{\text{WdwC} - \text{WdwT}}{\text{WdwC}} \times 100$$

where,

WdwC: Weed dry weight in control (g/m^2)

WdwT: Weed dry weight in treated plot (g/m^2)

$$\text{Nutrient removal by weed (kg/ha)} = \frac{\text{Nutrient content (\%)} \times \text{Dry matter (kg/ha)}}{100}$$

LAI and CGR (expressed in g/m^2/day) were worked out using the formula suggested by Watson (1947). The net assimilation rate (NAR) was calculated by the formula given by Gregory (1926) and expressed in g/cm^2/day. SPAD Chlorophyll Meter Reading (SCMR) was taken by "Chlorophyll meter SPAD 502 plus" manufactured by Spectrum Technologies, USA (Model 2900P). The observation was taken during morning (between 09.00 a.m. to 11.00 a.m.). The third apical leaf of pulse crop was selected for the measurement. The data generated from the experiment was analysed by following the techniques of analysis of variance (ANOVA) for randomized block design (Cochran and Cox 1965). Significant differences among treatments were observed, and LSD (least significant difference) values at 5 per cent level of significance were calculated for comparison of means.

The weed composition during summer season at 20 and 40 DAS (days after sowing) are furnished in **Tables 1** and **2,** respectively. The weeds comprised of grasses, *viz. Oryza sativa* and *Eleusine indica*, sedge, *viz. Cyperus rotundus* and broad-leaved weeds *viz. Boerhavia diffusa*, *Mollugo* sp. and *Euphorbia hirta*. At 20 DAS, there was no significant difference between treatments in the population of *Oryza sativa*, *Cyperus rotundus*, *Mollugo* sp. and *Euphorbia hirta*. The population of *Eleusine indica* was the highest in cowpea with 50% RDN, which was at par with black gram with 50% RDN, green gram with 50% RDN) and red gram with 50% RDN. The population of *Boerhavia diffusa* was the highest in fallow during summer which was at par with all the treatments except red gram with 100, 75 and 50% RDN, where the population was significantly less. At 40 DAS, there was no significant difference in the population of different weeds between treatments. But, the *Mollugo* sp. was absent in majority of the treatments (except cowpea with 100% RDN, cowpea with 50% RDN and green gram with 100% RDN, while certain new broad-leaved weeds, *viz. Euphorbia hirta* (green gram with 75% RDN), *Cleome rutidospermum* (cowpea with 75% RDN, cowpea with 50% RDN, green gram with 100% RDN and fallow during summer) and *Oldenlandia umbellata* (green gram with 75% and 50% RDN) appeared newly in certain treatments. Absolute density of weeds was no significant difference between treatments in the population of grasses and sedges at 20 and 40 DAS. With regard to broad-leaved weeds, at 20 DAS, the population was significantly less in red gram with 100, 75 and 50% RDN. However, at 40 DAS, all

Table 1. Effect of treatments on composition of weeds during summer crop at 20 DAS (no./m^2)

Treatment	Grasses					Sedge		Broad-leaved weeds				
	Oryza sativa		*Eleusine indica*		Sub total	*Cyperus rotundus*		*Boerhavia diffusa*		*Mollugo* sp.	*Euphorbia hirta*	Sub total
	Raw data	Trans-formed value	Raw data	Trans-formed value		Raw data	Trans-formed value	Raw data	Trans-formed value			
Cowpea with 100% RDN	65.9	9	17.6	4.1	83.5	206	13.7	548.3	23	14.3	18.3	580.9
Cowpea with 75% RDN	48.2	8.3	14.6	3.8	62.8	224	14.9	714	26	14	15.6	743.6
Cowpea with 50% RDN	81.8	11.6	47.6	6.7	129.4	241.6	13.5	429.3	20.6	14	16.7	460
Black gram with 100% RDN	40.3	8.8	14	3.7	54.3	212.3	14	575	23.9	6.3	20.6	601.9
Black gram with 75% RDN	107.2	12.4	16.3	4	123.5	201	13.9	603	24.5	18.6	14.3	635.9
Black gram with 50% RDN	125.1	12.1	40	6.3	165.1	44.6	6.4	479.3	21.7	15.3	18.6	513.2
Green gram with 100% RDN	66.2	8.9	21	4.5	87.2	62.3	7.54	409.6	19.9	16.3	23	448.9
Green gram with 75% RDN	71	10	20.6	4.4	91.6	240.3	14.4	450.6	21.2	19	18.6	488.2
Green gram with 50% RDN	71.6	8.1	43.6	6.1	115.2	86	8.5	526.3	22.8	14.6	20.6	561.5
Red gram with 100% RDN	51.2	8.3	15.6	3.9	66.8	123.3	10.8	304	16.2	18.3	17.3	339.6
Red gram with 75% RDN	69.9	9	18.7	4.3	88.6	87	7.84	266.3	15.6	15.6	21.3	303.2
Red gram with 50% RDN	76	10.3	39	5.6	115	29.3	5.05	249.6	15.4	17	19	285.6
Fallow during summer	49.3	9.7	18.3	4.2	67.6	179	13.1	774	27.2	19.3	21	814.3
LSD (p=0.05)	NS		1.9			NS		7.36		NS	NS	

treatments were at par with respect to broad-leaved weeds. The total population of weeds was significantly less in green gram with 100% RDN and red gram with 100, 75 and 50% RDN at 20 DAS. But at 40 DAS, the total weed population was significantly less in black gram and red gram with 50% RDN. At 20 DAS, the dry matter of weeds was significantly higher in cowpea with 50% RDN, green gram with 75% RDN and fallow during summer **Table 3**. At 40 DAS, the dry weight of weeds was significantly more in black gram with 100% RDN, green gram with 50% RDN and fallow during summer. At 20 DAS, there was no significant difference in weed smothering efficiency. At 40 DAS, the highest weed smothering efficiency was recorded in black gram with 50% RDN, which was at par with cowpea and black gram with 75% RDN, green gram with 100 and 75% RDN, red gram with 100, 75 and 50% RDN. At 20 DAS, the removal of N by weeds was significantly more in fallow during summer while it was at par in all other treatments. The removal of P and K did not significantly differ between treatments. At 40 DAS, N removal was significantly higher in fallow during summer which was at par with black gram with 100% and green gram with 50% RDN. The removal of P exhibited a trend similar to that of N. K removal did not differ significantly between treatments (**Table 3**).

The influence on LAI was obvious only in cowpea both at 20 DAS and 40 DAS whereas other pulses showed no significant difference among the treatments. The higher and on par LAI in cowpea at 100 and 50% did not have any adverse effect (**Table 4**). CGR was significantly more at red gram at 20 and

Table 2. Effect of treatments on composition of weeds during summer crop at 40 DAS (no./m²)

Treatment	Grasses					Sedge		Broad-leaved weeds										
	Oryza sativa		*Eleusine indica*		Sub total	*Cyperus rotundus*		*Boerhavia diffusa*		*Mollugo* sp.		*Euphorbia hirta*		*Cleome rutidospermum*		*Oldenlandia umbellate*		Sub total
	Raw data	Transformed value	Raw data	Transformed value		Raw data	Transformed value	Raw data	Transformed value	Raw data	Transformed value	Raw data	Transformed value	Raw data	Transformed value	Raw data	Transformed value	
Cowpea with 100% RDN	102.6	10	6.6	1.9	109.2	372	18.5	510.6	19.9	6.7	1.9	0	0.7	0	0.7	0	-0.7	517.3
Cowpea with 75% RDN	109.3	10.2	20	3.8	129.3	241.3	14.7	460	21.3	0	0.7	0	0.7	32	3.7	0	-0.7	492
Cowpea with 50% RDN	152	11.6	20	3.8	172	392	18.3	422.6	20.3	13.3	2.5	0	0.7	13.3	2.5	0	0.7	449.2
Black gram with 100% RDN	89.3	8.8	13.3	3.2	102.6	221.3	13.7	536	22.8	0	0.7	0	0.7	0	0.7	0	0.7	536
Black gram with 75% RDN	102.6	10	20	3.8	122.6	228	14.8	529.3	22.2	0	0.7	0	0.7	0	0.7	0	0.7	529.3
Black gram with 50% RDN	52	7.1	6.6	1.9	58.6	64	6.6	302.6	17.2	0	0.7	0	0.7	0	0.7	0	0.7	302.6
Green gram with 100% RDN	158.6	12.5	6.6	1.9	165.2	64	6.7	441.3	20.9	13.3	3.2	0	0.7	26.7	4.3	0	0.7	481.3
Green gram with 75% RDN	96	7.6	20	3	116	234.6	14.9	366.7	19.1	0	0.7	6.6	1.9	0	0.7	6.7	1.9	380
Green gram with 50% RDN	177.3	12.9	0	0.7	177.3	360	18.5	421.3	20.4	0	0.7	0	0.7	0	0.7	6.7	1.9	428
Red gram with 100% RDN	121.3	10.9	0	0.7	121.3	290.6	16.1	486.6	21.1	0	0.7	0	0.7	0	0.7	0	0.7	486.6
Red gram with 75% RDN	178.7	12.8	26.6	5.1	205.3	121.3	10.8	360	17.9	0	0.7	0	0.7	0	0.7	0	0.7	360
Red gram with 50% RDN	126.7	9.3	6.6	1.9	133.3	133.3	8.9	158.6	12.2	0	0.7	0	0.7	0	0.7	0	0.7	158.6
Fallow during summer	89.3	9.3	0	0.7	89.3	145.3	10.5	868	29.4	0	0.7	0	0.7	6.6	1.9	0	0.7	874.6
LSD (p=0.05)	NS		NS			NS		NS		NS		NS		NS		NS		

Table 3. Effect of treatments on dry matter production and smothering efficiency and nutrient removal (NPK) of weeds during summer crop

Treatment	Dry matter production (g/m²)		Weed smothering efficiency (%)		N (kg/ha)		P (kg/ha)		K (kg/ha)	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
Cowpea with 100% N	30.80(3.28)	81.84	70.27	58.33	6.66(1.79)	15.50	0.78	2.50	3.51	11.00(2.30)
Cowpea with 75% N	35.62(3.55)	112.46	65.43	42.94	7.39(1.99)	16.70	0.55	2.20	2.50	10.90(2.20)
Cowpea with 50% N	47.39(3.76)	131.81	53.48	33.07	8.54(2.13)	22.50	1.14	3.20	5.07	11.00(2.30)
Blackgram with 100% N	43.65(3.70)	182.56	56.99	7.17	9.37(2.00)	29.70	0.73	5.50	2.93	18.60(2.70)
Blackgram with 75% N	34.13(3.50)	103.76	66.30	47.15	7.40(1.99)	15.90	0.87	2.80	3.55	11.90(2.30)
Blackgram with 50% N	21.62(3.04)	61.56	78.99	68.82	7.09(1.94)	12.40	0.64	1.10	2.89	6.90 (1.90)
Green gram with 100% N	22.78(3.09)	69.72	77.33	64.39	6.06(1.74)	12.80	0.62	1.20	3.38	7.00 (1.90)
Green gram with 75% N	61.44(4.06)	119.88	38.75	39.65	17.39(2.82)	17.00	1.43	3.30	5.62	14.10(2.60)
Green gram with 50% N	35.63(3.38)	156.71	65.15	20.10	8.25(2.00)	26.80	0.89	3.90	3.61	13.50(2.50)
Red gram with 100% N	26.44(3.21)	108.53	74.12	44.79	7.77(1.99)	24.70	0.59	2.40	2.94	14.50(2.60)
Red gram with 75% N	37.01 (3.32)	100.80	63.65	48.14	9.92(2.01)	20.20	1.07	2.40	3.05	12.80(2.40)
Red gram with 50% N	17.80(2.75)	66.94	82.99	66.07	6.03(1.64)	14.30	0.45	2.10	2.43	9.10(2.20)
Fallow during summer	102.45(4.62)	197.54	0*	0 †	134.89(4.06)	36.00	1.92	6.00	9.13	21.70(2.90)
LSD (p=0.05)	0.86	49.32	NS	25.89	1.09	11.00	NS	2.10	NS	NS

Figures in parentheses denote transformed values; *Values were not used for statistical analysis

Table 4. Effect of treatments on LAI, CGR, NAR, SCMR, yield attributes and grain weight (yield) of summer crop

Treatment	Leaf area index		Crop growth rate(g/m²/day)		Net assimilation rate (g/cm²/day)		SPAD chlorophyll meter reading		No. of pods per plant	Grain weight (kg/ha)
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS		
Cowpea with 100% N	0.291	1.160	1.18	4.00	1.40 x 10^{-3} (0.037)	0.28 x 10^{-3} (0.016)	43.36	58.69	22.8 (4.73)	1268
Cowpea with 75% N	0.212	0.858	0.89	3.03	1.40 x 10^{-3} (0.037)	0.28 x 10^{-3} (0.016)	44.64	60.62	15.8 (3.97)	1094
Cowpea with 50% N	0.362	1.288	1.44	4.57	1.41 x 10^{-3} (0.037)	0.26 x 10^{-3} (0.015)	44.39	59.24	27.4 (5.22)	1681
Blackgram with 100% N	0.035	0.209	0.35	1.69	2.58 x 10^{-3} (0.050)	0.70 x 10^{-3} (0.026)	35.32	41.44	22.4 (4.71)	418
Blackgram with 75% N	0.046	0.247	0.29	2.01	1.95 x 10^{-3} (0.043)	0.70 x 10^{-3} (0.025)	34.82	39.39	21.8 (4.63)	410
Blackgram with 50% N	0.036	0.214	0.33	1.62	2.34 x 10^{-3} (0.048)	0.62 x 10^{-3} (0.024)	32.19	39.69	25.4 (4.89)	521
Greengram with 100% N	0.102	0.390	0.57	1.82	1.67 x 10^{-3} (0.040)	0.35 x 10^{-3} (0.018)	34.56	42.86	15.6 (3.91)	337
Greengram with 75% N	0.056	0.472	0.33	2.51	1.63 x 10^{-3} (0.040)	0.54 x 10^{-3} (0.023)	30.04	38.35	35.2 (5.89)	842
Greengram with 50% N	0.065	0.477	0.40	2.73	1.75 x 10^{-3} (0.041)	0.54 x 10^{-3} (0.023)	29.56	39.52	33.2 (5.72)	753
Red gram with 100% N	0.075	0.499	3.73	11.19	14.69 x 10^{-3} (0.120)	2.29 x 10^{-3} (0.047)	44.60	44.68	140.3 (11.77)	1498
Red gram with 75% N	0.066	0.675	3.67	11.02	16.78 x 10^{-3} (0.128)	1.89 x 10^{-3} (0.043)	46.59	45.54	151.7 (12.02)	1852
Red gram with 50% N	0.073	0.623	3.76	11.20	15.20 x 10^{-3} (0.122)	2.18 x 10^{-3} (0.045)	44.84	44.08	178.3 (13.20)	1903
LSD (0.05)	0.077	0.381	0.31	2.21	0.015	0.009	5.32	4.81	2.10	527

Figures in parentheses denote transformed (square root) values

40 DAS, when compared to other pulses. At 20 DAS, CGR in cowpea was second highest but it was at par with black gram and green gram at 40 DAS. The CGR did not differ with varying levels of N in all the pulses at 40 DAS. The CGR did not differ with varying levels of N in all the pulses at 40 DAS (**Table 4**). NAR was recorded significantly higher in red gram among the pulses. The varying levels of N caused no appreciable difference in NAR of pulses at 20 and 40 DAS (**Table 4**). The SCMR was the highest in red gram followed by cowpea at 20 DAS but at 40 DAS cowpea had the highest SCMR (**Table 4**).This shows that the growth deciding physiological parameters were not detrimentally affected when the RDN was reduced to 50 per cent. The highest grain yield was obtained from red gram (irrespective of N level) and was at par with grain yield of cowpea at 50 per cent RDN. The reduced yield for black gram and green gram might be due to the weed competition and sudden change in temperature, relative humidity besides the irregular rainfall that occurred during the pod filling stage. Reducing the level of N did not result in a yield in a remarkable yield decline in any of the pulses. The higher grain yield obtained from red gram can be attributed to higher number of pods per plant, NAR and CGR. During summer, cowpea and red gram performed better among the different pulses, in terms of yield by effectively competing with weeds. This indicates that the lower level of N (50% RDN) will be sufficient for crops to get good crop canopy. The residual effect of the preceding two crops of rice can contribute to reduce N dose when pulses are raised during summer in double cropped rice lowlands (Meetei *et al.* 2020).

Among the summer crops the leaf area index of cowpea treated with 100 and 50 per cent RDN was significantly better. The yield was significantly higher in cowpea (with 50% of RDN) and in green gram with 75 and 50% of RDN. The highest yield was obtained in red gram with 50% of RDN. The overall nutrient uptake was the highest in red gram. The nutrient removal by weeds was the higher for N in fallow and was at par for P and K in all the treatments. It showed that cowpea and red gram effectively competes with weeds, gives maximum yield in minimum N added.

REFERENCES

Adarsh S, John J, and Thomas G. 2019. Role of pulses in cropping systems: A review. *Agricultural Reviews* **40**(3): 185–191. http://doi.org/10.18805/ag.R-1888.

Cochran WG and Cox GM. 1965. *Experimental Designs*. John Willey and Sons Inc., New York, 182p.

Gregory FG. 1926. The effect of climatic conditions on the growth of barley. *Annals of Botany* **10**: 11–26.

Jackson ML. 1973. *Soil Chemical Analysis* (2nd Ed.). Prentice Hall of India, New Delhi, 498p.

Meetei TT, Kundu MC and Devi YB. 2020. Long-term effect of rice-based cropping systems on pools of soil organic carbon in farmer's field in hilly agroecosystem of Manipur, India. *Environmental Monitoring and Assessment* **192**(4): 1–17.

Pillai PS, Geethakumari VL and Issac SR. 2007. Balance sheet of soil nitrogen in rice (*Oryza sativa*) based cropping systems under integrated nutrient management. *Indian Journal of Agronomy* **52**(1): 16–20.

Porpavai S, Devasenapathy P, Siddeswaran K and Jayaraj T. 2011. Impact of various rice-based cropping systems on soil fertility. *Journal of Cereals and Oilseeds* **2**: 43–46.

Rao BSN. 2002. Pulses and legumes as functional foods. *Bulletin of Nutrition Foundation of India* **23**(1): 1–9.

Varughese K, Jacob J, Rani B and Vijayan M. 2007. Scope of crop diversification in paddy fields. pp. 59–70. In: *Paddy Cultivation in Kerala*, 19th Kerala Science Congress, 29-31 January 2007, Kannur. Kerala State Council for Science, Technology and Environment, Government of Kerala.

Watson DJ. 1947. Comparative physiological studies in the growth of field crops. I: Variation in assimilation rate and leaf area between species and varieties and within and between years. *Annals of Botany* **11**: 41–76.

Indian Journal of Weed Science **53**(1): 99–103, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Assessment of bioefficacy of novel pyroxasulfone for controlling weeds in summer maize

R. Mohan Kumar*, Yamanura and B. Boraiah

Zonal Agricultural Research Station, University of Agricultural Sciences, GKVK, Bangalore, Karnataka 560 065, India

**Email: mohankumarr@uasbangalore.edu.in*

Article information

DOI: 10.5958/0974-8164.2021.00017.4

Type of article: Research note

Received : 28 October 2020
Revised : 7 January 2021
Accepted : 10 January 2021

Key words
Herbicide
Pyroxasulfone
Summer maize
Weed control

ABSTRACT

An experiment was conducted during summer 2020 at Zonal Agricultural Research Station, UAS, GKVK, Bangalore to study the bio-efficacy of pyroxasulfone for controlling weeds in summer maize. Treatment consisted of pre-emergence application of pyroxasulfone 85% WG at 125, 150, 175 and 300 g/ha and was compared with atrazine 50% WP at 2000 g/ha along with unweeded control and weed-free treatment. Treatments were arranged under randomised complete block design with 3 replications. Weeds caused yield reduction to the tune of 32% in summer maize. Results revealed that application of pyroxasulfone reduced weed-crop interference effectively which was significantly superior over atrazine. The per cent increase in maize yield due to pyroxasulfone treatment in its corresponding doses of 125, 150, 175 and 300 g/ha was 21, 18, 14 and 7%, respectively over unweeded control treatment. Increasing the dose of pyroxasulfone beyond 125 kg/ha reduced the yield of maize.

Maize (*Zea mays* L.) is an important cereal crop cultivated in India. Although maize was an untouched part of Indian green revolution, due to its unbeatable performance in both rainfed and irrigated ecosystem tempts the growers and therefore, area under maize is picking up steadily (Joshi *et al.* 2005, Kumar *et al.* 2015 and Hiremath *et al.* 2016). Presently, in India maize occupied 9.18 million hectares area with the average productivity of 2.96 t/ha and the country produces about 27.23 million tonnes of maize kernels (DES-GOI 2020). Responding to its multiple uses, the demand for maize is constantly increasing. In spite of evolution of elite cultivars, herbicide and drought-tolerance technology offered by bio-technological innovations imparted great promise in maize productivity (Joshi *et al.* 2005). The contemporary cultural and chemical weed management strategies have been evolved and advocated to growers, but unattainability and higher cost results in unsatisfactory management with manual and cultural methods. In-spite of good number of chemicals no single chemical found effective in full season weed control. However, since long time, pre-emergent herbicide like atrazine is said to be the most popular chemical for management of weeds in maize. However, repeated application of atrazine over the years developed the herbicide resistance in many weeds. In this backdrop identification of novel herbicide molecule which could offers full season weed control is need of the hour. Study conducted by earlier scholar in USA, Canada, Australia, and South Africa opined that pre-emergent herbicide pyroxasulfone resulted in satisfactory weed control in corn (Odero and Wright 2013), soybeans (Soltani *et al.* 2019), cotton (Cahoon *et al.* 2015) and wheat (Kaur *et al.* 2019) in recent past. Further, from their study it was observed that pyroxasulfone 127.5 g/ha has been even found effective against the weeds reported to be resistant. This led to the need to investigate bio-efficacy and phytotoxicity of pyroxasulfone 85% WG at various dosages in comparison with atrazine 50% WP 1000 g/ha in summer maize during summer season of 2020.

A field experiment was conducted to investigate bioefficasy of pyroxasulfone against weed complexes in during summer season of 2020 at Zonal Agricultural Research Station, University of Agricultural Sciences, Bangalore (UASB), (12° 58' 17.7564 N, 77° 35' 40.4268 E,924 m above sea level), Karnataka, India. The soil of the experimental site was sandy loam in texture, moderately acidic (5.93) and electrical conductivity (0.11dS/m), medium in organic carbon (0.56 %), available nitrogen (386.56 kg/ha) and available phosphorus (29.67 kg/ha) and high in available potassium (428.40 kg/ha). The secondary and micro nutrient status of the experimental site was in the range of medium for magnesium and sulphur and sufficient for iron, manganese, zinc and copper.

The study included seven treatments namely pyroxasulfone 85% WG applied the commercial dose at the rate of 125 g/ha, 150 g/ha, 175 g/ha and 300 g/ha and atrazine 50% WP 2000 g/ha in comparison with weed-free treatment and unweeded control (**Table 1**). The treatments were imposed in randomized complete block design (RCBD) with three replications. The herbicides were applied immediately after sowing in moist soil with a knapsack sprayer fitted with a flat fan nozzle using a spray volume of 500 L/ha. Well decomposed farmyard manure at the rate of 10 t/ha was incorporated two weeks before sowing. The recommended doses of fertilizers *i.e.* nitrogen 150 kg/ha, phosphorus 75 kg/ha, potassium 37.5 kg/ha and 25 kg zinc sulphate were applied uniformly to seed rows. The sources of NPK were used as urea, single super phosphate (SSP) and muriate of potash (MoP), respectively.

The singe cross maize hybrid *'Hema (NAH-1137)'* was sown in first fortnight of April 2020 by using the seed rate of 15 kg/ha. The seeds were treated with phosphate solubilizing bacteria and *Azospirillum* with the dose of 750 g/ha each prior to sowing. Two seeds per hill were dibbled manually at an interval of 30 cm in seed rows opened at 60 cm apart in 4.5 x 4.8 m plot. At the time of sowing 50 kg nitrogen and entire dose of phosphorus and potassium were applied and remaining quantity of nitrogen was applied in two equal splits at 30 and 50 days after sowing. Irrigation was given at every 5 days interval so as to avoid possible water stress. All the recommended plant protection measures were carried out as per the local recommendations of the state. The data on weed density was recorded from five randomly selected spots in each plot at 15, 30 and 45 days after herbicide treatment (DAHT) using 0.5 × 0.5 m quadrat. The weeds of different species of weeds were uprooted at 15, 30 and 45 days after herbicide treatment. The weeds were placed in paper bag and were dried in an oven at 65 degree until the weeds attained a constant weight. Dried biomass was recorded as dry weight of weeds. Observations on growth, yield attributes, kernel and stover yields were recorded as per the standard procedure. The data collected on weeds were subjected to square root transformation ($\sqrt{x+0.5}$) to meet assumption of variance for statistical analysis. Weed control efficiency (WCE) was calculated on the basis of data recorded at 15, 30 and 45 days after herbicide treatment as per the formula suggested by Mani *et al.* (1976). The data were subjected to ANOVA and means were separated at p=0.05 with Fishers' LSD test.

Weed floristic composition

A total of 23 weed species were observed from 15 quadrats belonging to 18 genera and 8 families indicated infestation of divers category of weeds in *summer* maize. The Poaceae was the leading families having 6 weeds species in grassy category. In broad leaved weeds, member of Amaranthaceae family found abundant. The *Cyperus rotundus, Cyperus tenuispica* and *Cyperus compressus* were also abundant in the experimental site (**Table 2**).

Effect of pyroxasulfone on weed density and weed dry weight

Pyroxasulfone at its different dosages significantly influenced the weed density and weed dry weight of BLW, grasses and sedges at 15, 30 and 45 DAHT in *summer* maize (**Table 3**). Excellent control of BLW was recorded with pyroxasulfone treatments. Pre-emergent herbicide pyroxasulfone reduced the infestation of BLW - and there were no weeds with 150 and 300 g/ha at 15 DAHT Similar trends were observed at 30 and 45 DAHT. Irrespective of dosage, the reduction in BLW and grasses population with pyroxasulfone application was significantly superior over pre-emergent herbicide atrazine (**Table 3**). The values of weed density with pyroxasulfone treatment especially at 175 and 300 g/ha was numerically comparable with that of weed free treatment (**Table 3**). Similarly, data on density of grassy weeds indicated that pyroxasulfone at its different dosages significantly influenced the grassy weed density at 15, 30 and 45 DAHT (**Table 3**). The results indicated that pyroxasulfone controlled the grasses effectively up to 30 DAHT with the dose of 175 and 300 g/ha**.** On account of significantly lower density of both broad-

Table 1. Treatments of the experiment

Treatment	Concentration of active ingredient (g/ha)	Dose of commercial product (g/ha)	Date of application/execution
Pyroxasulfone 85% WG	106.25	125	16 April 2020
Pyroxasulfone 85% WG	127.50	150	16 April 2020
Pyroxasulfone 85% WG	148.75	175	16 April 2020
Pyroxasulfone 85% WG	225.00	300	16 April 2020
Atrazine 50% WP	1000.0	2000	16 April 2020
Weed-free	-	-	April 23, May 3, May 20, June 3and June 17
Unweeded control	-	-	-

leaf and grassy weeds, weed dry weight was also significantly lower with pyroxasulfone -300 g/ha **(Table 4)** and was statistically comparable with that of pyroxasulfone 175 g/ha. These results are in accordance with the earlier reports of Knezevic *et al.* (2009), Geier *et al.* (2006) and Gregory *et al.*(2005) where pyroxasulfone treated at 200 to 300 g/ha provided excellent control of green foxtail (*Setaria viridis*), field sandbur (*Cenchrus spinifex* Cav.), large crabgrass (*Digitaria sanguinalis*), palmer amaranth (*Amaranthus palmeri*), puncturevine (*Tribulus terrestris* L.), Texas panicum (*Panicum texanum*) and velvetleaf (*Abutilon theophrasti* Medik.).

Effective and persistent control of sedges was not observed with herbicide treatments, however, density of sedges decreased gradually with successive increase in pyroxasulfone dose. Slight reduction in growth of sedges with higher doses of pyroxasulfone (175 and 300 g/ha) at early phase of its application could be due to higher absorption rates of herbicidal solution by infant sedge seedlings. Similar observations are also reported by Tanetani *et al.* (2009) and Jha *et al.* (2015).

Weed control efficiency of pyroxasulfone

Data of the experiment revealed that pre-emergent herbicide pyroxasulfone exhibited excellent control of broad-leaf and grassy weeds over atrazine (**Table 3**). The maximum weed control efficiency recorded with pyroxasulfone at 300 g/ha (100, 100 and 97%, respectively at 15, 30 and 45 DAHT in broadleaf weeds and 100, 100 and 94.72%, respectively at 15, 30 and 45 DAHT in grasses) and the values were closely followed by pyroxasulfone at 175 g/ha (100, 98 and 97%, respectively at 15, 30 and 45 DAHT in broad-leaf weeds and 98, 100 and 94.98%, respectively at 15, 30 and 45 DAHT in grasses) **(Table 5)**. These results are in harmony of the findings of Mahoney *et al.* (2014) who found 100% control of most of broad-leaf and grassy weeds in soybean with application of pyroxasulfone at 89 g/ha.

Table 2. Floristic composition of weed flora in experimental site

Common name	Scientific name	Category	Family	Relative density (%)
Cock's comb	*Celosia argentea L*	BLW	Amaranthaceae	3.51
Tick weed	*Cleome viscosa L.;*	BLW	Capparidaceae	3.72
Tropical spiderwort	*Commelina benghalensis L*	BLW	Commelinaceae	3.51
Climbing dayflower	*Commelina diffusa*	BLW	Commelinaceae	4.13
Wild poinsettia	*Euphorbia geniculata*	BLW	Euphorbiaceae	2.68
Goat weed	*Ageratum conyzoides*	BLW	Asteraceae	3.92
Sessile joyweed	*Alternanthera sessilis;*	BLW	Amaranthaceae	5.26
Bristly starbur	*Acanthospermum hispidum*	BLW	Asteraceae	3.51
Khaki weed	*Alternanthera pungens*	BLW	Amaranthaceae	2.68
Spiny pigweed	*Amaranthus spinosus*	BLW	Amaranthaceae	2.79
Spanish needles	*Bidens pilosa*	BLW	Asteraceae	4.33
Asthma herb	*Euphorbia hirta*	BLW	Euphorbiaceae	2.99
Five leaved carpetweeds	*Mollugo pentaphylla*	BLW	Molluginaceae	4.13
Congress grass	*Parthenium hysterophorus*	BLW	Asteraceae	4.33
Bermuda grass	*Cynodon dactylon*	Grass	Poaceae	5.26
Goose grass	*Eleusine indica*	Grass	Poaceae	7.12
Jungle rice	*Echinochloa colona*	Grass	Poaceae	3.92
Crowfoot grass	*Dactyloctenium aegyptium*	Grass	Poaceae	5.37
Browntop millet	*Brachiaria ramose*	Grass	Poaceae	4.44
Large crabgrass	*Digitaria sanguinalis*	Grass	Poaceae	5.99
Purple nutsedge	*Cyperus rotundus*	Sedge	Cyperaceae	7.22
Slender spiked sedge	*Cyperus tenuispica*	Sedge	Cyperaceae	5.57
Poorland flatsedge	*Cyperus compressus*	Sedge	Cyperaceae	3.61

Table 3. Effect of treatments on weed density of broad-leaf, grasses and sedges (no./m^2)

Treatment	Broad-leaf weeds			Grasses			Sedges		
	15 DAHT	30 DAHT	45 DAHT	15 DAHT	30 DAHT	45 DAHT	15 DAHT	30 DAHT	45 DAHT
Pyroxasulfone 85% WG 125 g/ha	(2.0)1.6*	(12.0)3.5	(27.3)5.3	(8.0)2.9	(12.0)3.5	(24.7)5.0	(3.67)2.0	(17.67)4.3	(22.7)4.8
Pyroxasulfone 85% WG 150 g/ha	(3.3)2.0	(14.3)3.8	(16.7)4.1	(7.0)2.7	(7.3)2.8	(22.3)4.8	(6.3)2.6	(14.7)3.9	(30.7)5.6
Pyroxasulfone 85% WG 175 g/ha	(5.3)2.4	(15.3)4.0	(18.3)4.3	(7.0)2.7	(5.7)2.5	(21.7)4.7	(6.7)2.7	(12.7)3.6	(23.3)4.9
Pyroxasulfone 85% WG 300 g/ha	(0.0)0.7	(3.0)1.9	(6.3)2.6	(1.3)1.3	(0.0)0.7	(5.3)2.4	(0.0)0.7	(10.7)3.3	(19.3)4.4
Atrazine 50% WP 2000 g/ha	(5.7)2.5	(16.0)4.1	(32.3)5.7	(9.3)3.1	(32.3)5.7	(43.7)6.6	(15.7)4.0	(35.7)6.0	(40.7)6.4
Weed free	(0.0)0.7	(0.0)0.7	(0.0)0.7	(2.7)1.8	(0.0)0.7	(0.0)0.7	(7.0)2.7	(11.3)3.4	(2.3)1.67
Unweeded control	(113.3)10.7	(166.3)12.9	(197.3)14.0	(77.0)8.8	(103.7)10.2	(127.3)11.3	(22.3)4.8	(52.7)7.3	(71.0)8.4
LSD (p=0.05)	0.29	0.53	0.60	0.47	0.53	0.80	0.25	0.49	0.64

Data in the parentheses indicates original values; *indicates transformed values ($\sqrt{x+0.5}$) DAHT-Days after herbicide treatment

Effect of pyroxasulfone on growth and yield of maize

In this experiment, different doses of pyroxasulfone did not register significant variation in germination of maize **(Table 6).** However, different doses of the herbicide recorded significant variation in growth, yield attributes and yields of maize **(Table 6 and 7)** and this variation was mainly due to the variation on weed control**.** Weed-free condition produced taller plants at harvest (170.0 cm) as compared to all herbicide treatments except atrazine 2000 g/ha (161.0 cm). Significant reduction in plant height was noticed with pyroxasulfone applied at 300 g/ha (137.8 cm) and was comparable with that of plant height obtained with weedy check. These results were similar with the findings of Khalil *et al*. (2018) who found significant shoot-length inhibition of Italian ryegrass with pyroxasulfone application. The reduction in growth of leaf was also observed by recording significantly lower leaf area index of maize with application of pyroxasulfone over weed-free treatment and atrazine 2000 g/ha (**Table 6**). Further it was also observed that quality of chlorophyll pigmentation was badly affected with application of pyroxasulfone. Significantly lower SPAD chlorophyll meter reading was registered with the plots treated with pyroxasulfone at the dose of 300 g/ha and was remain comparable with other doses of pyroxasulfone. Plots treated with pyroxasulfone taken significantly higher time to attain 50% tasselling and silking than weed-free, atrazine and unweeded control treatments. So far, no published paper has highlighted the effect of pre-emergent herbicide pyroxasulfone on the developmental stages of maize. Further, as per as yield attributes are concern, generally yield attributes are the manifestation of growth attributing character in maize (Kumar *et al*. 2015a). Due to

Table 4. Effect of treatments on weed dry weight of broad-leaf, grasses and sedges (gm/m^2)

Treatment	Broad-leaf weeds			Grasses			Sedges		
	15 DAHT	30 DAHT	45 DAHT	15 DAHT	30 DAHT	45 DAHT	15 DAHT	30 DAHT	45 DAHT
Pyroxasulfone 85% WG 125 g/ha	(1.1)1.3*	(7.3)2.8	(18.3)4.3	(3.7)2.0	(5.8)2.5	(12.6)3.6	(1.1)1.3	(6.9)2.7	(9.5)3.2
Pyroxasulfone 85% WG 150 g/ha	(1.8)1.5	(8.7)3.0	(11.2)3.4	(3.2)1.9	(3.5)2.0	(11.4)3.4	(2.0)1.6	(5.7)2.5	(12.9)3.7
Pyroxasulfone 85% WG 175 g/ha	(2.9)1.8	(9.3)3.1	(12.3)3.6	(3.2)1.9	(2.7)1.8	(11.0)3.4	(2.1)1.6	(4.9)2.3	(9.8)3.2
Pyroxasulfone 85% WG 300 g/ha	(0.0)0.7	(1.8)1.5	(4.2)2.2	(0.6)1.0	(0.0)0.7	(2.7)1.8	(0.0)0.7	(4.2)2.2	(8.1)2.9
Atrazine 50% WP 2000 g/ha	(3.1)1.9	(9.8)3.2	(21.7)4.7	(4.3)2.2	(15.5)4.0	(22.3)4.8	(7.0)2.7	(13.9)3.8	(17.1)4.2
Weed free	(0.0)0.7	(0.0)0.7	(0.0)0.7	(1.2)1.3	(0.0)0.7	(0.0)0.7	(2.2)1.6	(4.4)2.2	(1.0)1.2
Unweeded control	(61.2)7.8	(101.5)10.1	(132.2)11.5	(35.4)6.0	(49.8)7.1	(64.9)8.1	(12.5)3.6	(20.5)4.6	(29.8)5.5
LSD (p=0.05)	0.09	0.52	0.52	0.26	0.29	0.51	0.26	0.51	0.50

Data in the parentheses indicates original values; *indicates transformed values ($\sqrt{x+0.5}$) DAHT-Days after herbicide treatment

Table 5. Effect of treatments on weed control efficiency (%)

Treatment	Broad-leaf weeds			Grasses			Sedges		
	15 DAHT	30 DAHT	45 DAHT	15 DAHT	30 DAHT	45 DAHT	15 DAHT	30 DAHT	45 DAHT
Pyroxasulfone 85% WG 125 g/ha	98.24	92.79	86.15	89.61	88.42	79.80	90.91	66.46	68.08
Pyroxasulfone 85% WG 150 g/ha	97.06	91.38	91.55	90.91	92.93	81.63	84.29	72.15	56.81
Pyroxasulfone 85% WG 175 g/ha	95.29	90.78	90.71	90.91	94.53	82.15	83.47	75.95	67.14
Pyroxasulfone 85% WG 300 g/ha	100.00	98.20	96.79	98.27	100.00	94.98	100.00	78.48	72.77
Atrazine 50% WP 2000 g/ha	95.00	90.38	83.61	87.88	68.81	64.88	43.79	32.28	42.72
Weed free	100.00	100.00	100.00	96.54	100.00	99.17	82.64	79.75	96.71
Unweeded control	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DAT-Days after herbicide treatment

Table 6. Effect of treatments on germination, plant height, leaf area index, chlorophyll content, days to 50% tasselling and silking

Treatment	Germination (%)	Plant height at harvest (cm)	Leaf area index at 90 DAS	SPAD at 90 DAS	TDMP at harvest (g/plant)	Days to 50% tasseling	Days to 50% silking
Pyroxasulfone 85% WG 125 g/ha	96.41	152.0	4.35	36.14	188.8	58.56	64.74
Pyroxasulfone 85% WG 150 g/ha	96.71	148.8	4.09	32.11	196.7	61.12	66.84
Pyroxasulfone 85% WG 175 g/ha	96.84	145.1	4.02	30.15	193.4	63.45	66.21
Pyroxasulfone 85% WG 300 g/ha	97.12	137.8	4.02	30.17	185.6	64.14	66.84
Atrazine 50% WP 2000 g/ha	96.42	161.0	4.74	41.12	193.4	54.14	58.15
Weed free	96.84	170.0	5.20	48.65	228.5	53.12	56.98
Unweeded control	94.41	154.2	4.44	37.45	181.3	55.74	59.47
LSD (p=0.05)	NS	22.5	0.58	4.06	19.12	2.60	2.89

Table 7. Effect of treatments on yield parameters, yield of summer maize

Treatment	Cob length (cm)	Cob girth (cm)	No. kernel rows/cob	No. of kernel /row	100 kernel weight(g)	Kernel yield per plant (g)	Kernel yield (t/ha)	Stover yield (t/ha)	Harvest index (%)
Pyroxasulfone 85% WG 125 g/ha	17.5	16.1	14.4	33.6	27.3	131.6	5.54	6.94	44.43
Pyroxasulfone 85% WG 150 g/ha	17.1	16.0	14.8	33.3	26.7	129.6	5.40	6.88	43.92
Pyroxasulfone 85% WG 175 g/ha	16.8	15.9	14.0	33.7	26.2	126.1	5.20	6.96	42.77
Pyroxasulfone 85% WG 300 g/ha	13.14	13.19	14.0	26.41	25.6	109.3	4.87	6.54	42.68
Atrazine 50% WP 2000 g/ha	17.8	16.1	14.8	34.2	28.2	136.4	5.73	7.22	44.30
Weed-free	18.9	17.4	15.2	36.1	28.5	138.7	6.04	7.31	45.31
Unweeded control	15.5	14.3	13.5	27.8	27.2	120.3	4.57	6.35	41.81
LSD (p=0.05)	0.6	0.4	NS	1.6	NS	10.6	0.23	0.41	1.36

profound impact of pyroxasulfone application on growth of maize, yield attributing characters were greatly reduced (**Table 6** and **7**). Significantly lower kernel yield per plant was recorded with pyroxasulfone at 300 g/ha (109.3 g/plant) on account of significantly lower cob length and girth, number of kernels per row (**Table 7**) and these values were comparable with that of unweeded control treatment. However, yield attributing characters of maize with pyroxasulfone applied at 175, 150 and 125 g/ha were statistically comparable with atrazine at 2000 g/ha.

In summer maize, weed-crop interference caused 32% yield reduction in comparision to weed-free treatment (**Table 7**). there was per cent increase in maize yield due to pre-emergent herbicide pyroxasulfone at 125, 150, 175 and 300 g/ha was 21, 18, 14and 7%, respectively over unweeded control treatment. The data of the experiment clearly indicated the phytotoxic effect of pyroxasulfone at the dose more than 125 g/ha. Based on the findings of the present study, it can be concluded that pre-emergent herbicide pyroxasulfone provided satisfactory weed control and grain yield when it was applied at the dose of 125 and beyond this dose the performance of the crop in terms of lowering plant height, leaf growth, chlorophyll content and finally kernel yield got reduced significantly. This may be due to the phytotoxic effect of pyroxasulfone beyond the dose of 125 kg/ha. However, further investigation is required to confirm the findings.

REFERENCE

Cahoon WC, York CA, Jordan LD, Seagroves WR, Everman JW and Jennings MK. 2015. Cotton response and palmer amaranth control with pyroxasulfone applied Pre- and post-emergence. *The Journal of Cotton Science* **19**: 212–223.

DES-GoI. 2020. *Department of Economics and Statistics*, Government of India. https://eands.dacnet.nic.in/.

Geier PW, Stahlman PW and Frihauf JC. 2006. KIH-485 and Smetolachlor efficacy comparisons in conventional and notillage corn. *Weed Technology* **20**: 622–626.

Gregory LS, Porpiglia PJ and Chandler JM. 2005. Efficacy of KIH-485 on Texas panicum (*Panicum texanum*) and selected broad-leaf weeds in corn. *Weed Technology* **19**: 866–869.

Hiremath SM, Kumar RM and Gaddi AK. 2016. Influence of balanced nutrition on productivity, economics and nutrient uptake of hybrid maize (*Zea mays*) - chickpea (*Cicer arietinum*) cropping sequence under irrigated ecosystem. *Indian Journal of Agronomy* **60**(3): 75-79

Jha P, Kumar V, Garcia J and Reichard N. 2015. Tank mixing pendimethalin with pyroxasulfone and chloroacetamide herbicides enhances in-season residual weed control in corn. *Weed Technology* **29**(2): 198-206.

Joshi P, Singh NP, Singh NN, Gerpacio RV and Pingali PL. 2005. *Maize in India: Production Systems, Constraints, and Research Priorities.* Mexico, D.F.: CIMMYT pp-1-50.

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

Khalil Y, Siddique KHM, Ward P, Piggin C, Bong SH, Nambiar S, Trengove R and Flower K. 2018. A bioassay for prosulfocarb, pyroxasulfone and trifluralin detection and quantification in soil and crop residues. *Crop and Pasture Science* **69**: 606-616. https://doi.org/10.1071/CP18026

Knezevic SZ, Datta A, Scott J and Porpiglia PJ. 2009. Doseresponse curves of KIH-485 for pre-emergence weed control in corn. *Weed Technology* **23**: 34–39.

Kumar RM, Hiremath SM and Nadagouda BT. 2015a. Effect of single-cross hybrids, plant population and fertility levels on productivity and economics of maize (*Zea mays*). *Indian Journal of Agronomy* **60** (3): 75-79.

Kumar RM, Nadagouda BT and Hiremath SM. 2015. Studies on farmers perception about maize based cropping system in irrigated ecosystem of Gataprabha left bank cannel. *Plant Archives* **15**(2): 959-961

Mahoney KJ, Shropshire C and Sikkema PH. 2014. Weed management in conventional- and No-till soybean using flumioxazin/pyroxasulfone. *Weed Technology* **28**(2): 298–306.

Mani S, Malla ML, Gautam KC and Bhagwn Das. 1973. Weed killing chemicals in potato cultivation. *Indian Farming* VXXII: 17–18.

Odero D and Wright A. 2013. Response of Sweet Corn to pyroxasulfone in high-organic-matter soils. *Weed Technology* **27**(2): 341–346.

Soltani N, Brown RL and Sikkema HP. 2019. Weed Control in Corn and Soybean with Group 15 (VLCFA Inhibitor) Herbicides Applied Preemergence. *International Journal of Agronomy* Volume Article ID 8159671, 7 pages https://doi.org/10.1155/2019/8159671

Tanetani Y, Kaku K, Kawai K, Fujioka T and Shimizu T. 2009. action mechanism of novel herbicide, Pyroxasulfone. *Pesticide Biochemistry and Physiology* **95**: 47–55 DOI: 10.1016/j.pestbp.2009.06.003.

Indian Journal of Weed Science **53**(1): 104–106, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Performance of ready-mix herbicides for weed control in blackgram

N. Ram Mohan Reddy, D. Subramanyam*, V. Sumathi, V. Umamahesh and G. Karuna Sagar
Department of Agronomy, S. V. Agricultural College, Tirupati, Andhra Pradesh 517 502, India
**Email: subbuagro37@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00018.6

Type of article: Research note

Received : 12 July 2020
Revised : 17 November 2020
Accepted : 20 November 2020

Key words
Diclosulam, Economics, Ready-mix herbicides, Weed growth, Yield

ABSTRACT

A field experiment was conducted during *Kharif* (rainy season), 2019 at S.V. Agricultural College, Tirupati, Andhra Pradesh to find out the best chemical weed management practice for blackgram. Results revealed that pre-emergence application of diclosulam 20 g/ha supplemented with HW at 30 DAS resulted in lower density and dry weight of weeds with higher weed control efficiency, and it was closely followed by pre-emergence application of pendimethalin + imazethapyr 1000 g/ha supplemented with HW at 30 DAS. Heavy weed infestation of weeds in unweeded check reduced the seed yield by 58.4% compared to pre-emergence application of pendimethalin + imazethapyr 1000 g/ ha supplemented with HW. All the pre-and post-emergence herbicides did not show inhibitory effect on succeeding fodder sorghum.

Blackgram (*Vigna mungo* L.) is an important legume crop grown in tropical and sub-tropical regions of the world and it have high protein in its seeds. India is the largest producer and consumer of blackgram in the world. In Andhra Pradesh, blackgram is cultivated in an area of 4.03 lakh hectares with a total production of 3.70 lakh tonnes with an average productivity of 920 kg/ha during 2017-18. Rainy season blackgram is severely infested with diversified weed flora because of good amount of rainfall received during the crop period. The competition offered by weeds is severe in blackgram due to its slow initial growth and short statured growth habit particularly in recently released varieties of blackgram than greengram. The loss of seed yield in blackgram due to weeds range from 50-87% (Sukumar *et al*. 2018) and critical period for crop weed competition is around 15 to 45 DAS (Khot *et al.* 2016). Generally, pendimethalin 1000 g/ha is recommended to control the weeds, but it is not effective in controlling certain broad-leaved weeds and perennial sedges. Continuous use of pendimethalin resulted in weed shift towards broad-leaved weeds. The late coming weeds are controlled by post-emergence application of imazethapyr 75 g/ ha, but it has carryover effect on succeeding cereal crops due to its higher half-life period (Sondhia *et al.* 2015). Thus, there is need to have alternate herbicides with different modes of action and leaching behaviour for obtaining broad-spectrum weed control. Low-dose high-efficacy herbicide, diclosulam and ready-mix herbicide combinations are available in the market for control of mixed weed flora in pulse crops. Keeping these facts in view, the present investigation was undertaken to know the performance of ready-mix combination of pre-and post-emergence herbicides for broad-spectrum weed control in *Kharif* (rainy season) blackgram.

A field experiment was conducted during *Kharif,* 2019 at wetland farm of S.V. Agricultural College, Tirupati campus of Acharya N.G. Ranga Agricultural University, Andhra Pradesh. The soil of experimental site was sandy loam soils having 0.21% organic carbon, 244, 26 and 289 kg/ha available N, P and K, respectively. The total rainfall received during crop period was 79.24 mm with 29 rainy days. The experiment was laid out in a randomized block design with 10 weed management practices. The treatments consisted of pendimethalin + imazethapyr (ready-mix) 1000 g/ha, diclosulam 20 g/ha and pendimethalin 1000 g/ha as pre-emergence; and propiquizafop + imazethapyr (ready-mix) 127 g/ha, sodium acifluorfen + clodinafop-propargyl (ready-mix) 180 g/ha and imazethapyr 70 g/ha as post-emergence including standard checks (**Table 1**). Blackgram was sown at 30 x 10 cm spacing on 3rd July, 2019. Pre-emergence herbicides were applied at 1 DAS and post-emergence herbicides were applied at 15 DAS with the help of knap-sack sprayer fitted with flat-fan nozzle and spray volume of 500 L/ha. The crop was fertilized with 20 and 50 kg/ha of nitrogen and phosphorous, respectively. Weed density and dry weight was recorded at 45 DAS and at harvest by using standard procedures. The data on weed density and dry weight were subjected to square root transformation to normalize their distribution. Weed control efficiency was computed as per the method suggested by (Mani *et al.* 1973). Dry matter production and yield components were recorded at harvest. Seed and haulm yield were recorded based on the yield obtained from net plot. Net returns were calculated by subtracting the cost of cultivation from gross returns. Benefit-cost ratio was calculated after dividing gross returns with cost of cultivation. The crop was harvested on 18th September, 2019. A residual crop of fodder sorghum was raised in plastic pots after filling the soil collected from respective treatments where blackgram was grown to know the residual effect of herbicides applied to blackgram. Germination per cent and seedling vigour index of fodder sorghum was computed at 15 DAS as per the method suggested by Abdul Baki and Anderson (1973).

The predominant weed flora associated with blackgram was *Digitaria sanguinalis* (L.) Scop. (42%), *Cyperus rotundus* L. (22%), *Euphorbia thymifolia* L. (9%), *Boerhavia erecta* L. (6%), *Borreria hispida* (L.) K. Schum. (5%), *Cynodon dactylon* (L.) Pers. (5%), *Commelina benghalensis* L. (3%), *Cleome viscosa* L. (3%) and others (5%). Different weed management practices significantly influenced the density of all categories of weeds at 45 DAS. The lowest density of sedges, broad-leaved weeds and total weeds were registered with pre-emergence (PE) application of diclosulam 20 g/ha supplemented with HW at 30 DAS followed by PE application of pendimethalin + imazethapyr 1000 g/ha supplemented with HW at 30 DAS. However, the latter weed management practice recorded significantly lesser density of grasses than former weed management practice. Both the weed management practices were significantly superior in suppressing the total weed density compared to HW twice at 15 and 30 DAS **(Table 1)**. Total weed dry weight was reduced significantly at 45 DAS with HW twice at 15 and 30 DAS, which was comparable with PE application of diclosulam supplemented with HW at 30 DAS. However, latter treatment registered significantly lower weed dry weight at harvest. Similar results were also reported by Naveen *et al.* (2019) with diclosulam 20 g/ha supplemented with HW at 20 DAS in groundnut on sandy loam soils. Diclosulam might have readily available at lethal dose in the soil at weed seed zone due to its low absorption coefficient and better leaching potential, which in turn aided better distribution of diclosulam in soil solution compared to pendimethalin (Hornsby *et al.* 1996). Among the post-emergence herbicides, propiquizafop + imazethapyr 127 g/ha was effective in suppressing total density and dry weight at 45 DAS and at harvest compared to rest of the post-emergence herbicides due to its dual mode of action in controlling weeds. Hand weeding twice resulted in higher weed control efficiency at 45 DAS while PE application of diclosulam supplemented with HW obtained higher weed control efficiency at harvest. It clearly indicates that diclosulam 20 g/ha extended its activity for longer period due to higher half-life period (Lavorenti *et al.* 2003). Among the herbicidal treatments, lower weed control efficiency was calculated with imazethapyr 75 g/ha due to its poor control of weeds, at both the stages of observations.

Different weed management practices had significant and positive influence on yield components, yield and economics of blackgram **(Table 2)**. Significantly higher number of seeds/plant and test weight were recorded under PE application of pendimethalin + imazethapyr 1000 g/ha supplemented with HW at 30 DAS due to reduced competition for growth resources, which in turn increased the translocation of photosynthates to

Table 1. Weed density, weed dry weight and weed control efficiency as influenced by different weed management practices at 45 DAS and at harvest in blackgram

Treatment	Dose (g/ha)	Time of application (DAS)	Weed density at 45 DAS (no./m^2)				Total weed dry weight (g/m^2)		Weed control efficiency (%)	
			Grasses	Sedges	BLWs	Total	At 45 DAS	At harvest	At 45 DAS	At harvest
Diclosulam	20	1	4.39(18)	3.21(9)	2.58(6)	5.85(33)	3.51(11)	3.77(13)	74.76	54.66
Pendimethalin + imazethapyr	1000	1	4.54(20)	3.69(13)	3.21(9)	6.52(42)	4.28(17)	7.49(55)	61.55	38.84
Diclosulam *fb* HW	20	1 *fb** 30	2.82(7)	2.42(5)	1.70(2)	3.84(14)	2.36(5)	3.55(12)	89.79	66.92
Pendimethalin + imazethapyr *fb* HW	1000	1 *fb* 30	2.65(6)	2.89(7)	2.19(4)	4.27(17)	2.48(5)	5.31(27)	88.44	65.84
Propaquizafop + imazethapyr	127	15	4.64(21)	3.84(14)	3.55(12)	6.85(46)	4.65(21)	5.79(33)	54.27	34.76
Sodium acifluorfen + clodinafop-propargyl	180	15	5.22(26)	4.82(22)	3.91(14)	7.99(63)	5.40(28)	6.87(46)	37.70	26.28
Pendimethalin	1000	1	4.71(21)	4.54(20)	3.41(11)	7.24(52)	5.11(25)	7.77(60)	44.39	27.65
Imazethapyr	75	15	5.42(29)	5.12(25)	4.61(20)	8.66(74)	5.78(33)	7.08(49)	28.30	13.52
HW twice	-	15 *fb* 30	2.80(7)	2.46(5)	2.19(4)	4.10(16)	2.55(6)	5.20(26)	87.65	65.23
Unweeded check (control)			5.76(32)	6.13(37)	4.86(23)	9.62(92)	6.80(45)	7.90(62)	-	-
LSD (p=0.05)			0.13	0.25	0.11	0.22	0.09	0.16		

The figures in parentheses are original values; *fb*: followed by

Table 2. Yield and economics of blackgram as influenced by different weed management practices

Treatment	Dose (g/ha)	Time of application (DAS)	Dry matter production (t/ha)	No. of pods/ plant	Test weight (g)	Seed yield (kg/ha)	Haulm yield (t/ha)	Net returns (x10^3 `/ha)	B:C ratio	Fodder sorghum (succeeding crop)	
										Germination (%)	Seedling vigour index
Diclosulam	20	1	1.76	16.3	38.8	634	1.01	16.32	1.78	93.21	1647
Pendimethalin + imazethapyr	1000	1	1.94	17.2	41.1	715	1.13	19.57	1.88	95.10	1659
Diclosulam *fb* HW	20	1 *fb* 30	2.10	16.7	41.3	730	1.23	18.92	1.79	93.20	1748
Pendimethalin + imazethapyr *fb* HW	1000	1 *fb* 30	2.11	17.4	41.6	796	1.25	21.24	1.84	94.15	1676
Propaquizafop + imazethapyr	127	15	1.73	15.8	38.0	618	1.00	15.55	1.75	95.51	1612
Sodium acifluorfen + clodinafop-propargyl	180	15	1.68	15.5	37.9	586	0.99	14.09	1.69	97.12	1804
Pendimethalin	1000	1	1.77	16.1	38.2	628	1.03	15.38	1.72	95.32	1884
Imazethapyr	75	15	1.67	15.4	36.8	582	0.98	13.10	1.62	93.51	1547
HW twice	-	15 *fb* 30	2.10	17.3	41.3	789	1.24	16.95	1.58	97.35	1933
Unweeded check (control)			1.20	12.7	34.3	331	0.79	0.43	1.02	97.21	1924
LSD (p=0.05)			0.08	0.94	1.55	78	0.21	1.97	0.044	2.06	79.93

developing seeds. Pre-emergence application of pendimethalin + imazethapyr supplemented with HW produced significantly higher seed yield and haulm yield which was at par with HW twice at 15 and 30 DAS. The decrease in seed yield due to heavy weed infestation in unweeded check was 58.4 per cent compared to best treatment. Among all the weed management practices, the highest gross and net returns were obtained with PE application of pendimethalin + imazethapyr 1000 g/ha supplemented with HW at 30 DAS. However, higher benefit-cost ratio was realized with PE application of pendimethalin + imazethapyr 1000 g/ha. Hand weeding twice at 15 and 30 DAS lag behind compared to PE application of pendimethalin + imazethapyr 1000 g/ha, with respect to net returns and benefit-cost ratio of blackgram cultivation. Higher net returns and benefit-cost ratio were computed with post-emergence application of propiquizafop + imazethapyr 127 g/ha at 15 DAS than rest of the post-emergence herbicides.

Germination per cent and seedling vigour index of residual fodder sorghum was not affected by pre- and post-emergence herbicides applied to preceding blackgram. Kumar *et al.* (2015) reported that pre-emergence application of pendimethalin applied to blackgram did not affect the succeeding crops like wheat, mustard and gram. However, pre-emergence application of diclosulam 20 g/ha to blackgram showed marginal decrease in germination per cent of fodder sorghum. Among the herbicidal treatments, maximum seedling vigour was computed with PE application of pendimethalin 1000 g/ha. Significantly higher germination per cent and seedling vigour index of fodder sorghum was obtained with post-emergence application of sodium acifluorfen + clodinafop-propargyl 180 g/ha than propaquizafop + imazethapyr 127 g/ha, applied to preceding blackgram.

Thus, it can be concluded that pre-emergence application of pendimethalin + imazethapyr (ready-mix) 1000 g/ha supplemented with HW resulted in higher seed yield and monetary returns, apart from broad-spectrum weed control in *Kharif* blackgram on sandy loam soils.

REFERENCES

Abdul-Baki AA and Anderson ID. 1973. Relationship between decarboxylation of glutamic acid and vigour in soybean (*Glycine max* L.). *Crop Science* **13**: 227–232.

Hornsby AG, Don Wauchope R and Herner AE. 1996. Pesticide properties in the environment. *Springer-Verlag, Inc.*, New York.

Khot AB, Sagvekar VV, Muthal YC, Panchal VV and Dhonde MB. 2016. Effect on summer blackgram (*Phaseolus mungo* L.) to different sowing time and weed management practices with respect to yield, quality and nutrient uptake. *International Journal of Tropical Agriculture* **34**(7): 2155–2161.

Kumar S, Bhatto MS, Punia SS and Punia R. 2015. Bio-efficacy of herbicides in blackgram and their residual effect on succeeding mustard. *Indian Journal of Weed Science* **47**(2): 211–213.

Lavorenti A, Rocha AA, Prata F, Regitano JB, Torniselio VL and Pinto OB. 2003. Comportamento do diclosulam emamostras de um latossolovermelhodistroférrico sob plantiodireto e convencional. *RevistaBrasileira de Ciencia do Solo* **27**(1): 183–190.

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

Naveen KB, Subramanyam D, Nagavani AV and Umamahesh V. 2019. Weed management in groundnut with high efficiency herbicides.*Indian Journal of Weed Science* **51**(3): 306–307.

Sondhia S, Khankhane PJ, Singh PK and Sharma AR. 2015. Determination of imazethapyr residues in soil and grains after its application to soybeans. *Journal of Pesticide Sciences* **40**(3): 106–110.

Sukumar J, Pazhanivelan S and Kunjammal P. 2018. Effect of pre-emergence and post-emergence herbicides on weed control in irrigated blackgram. *Journal of Pharmacognosy and Phytochemistry* **1**: 3206–3209.

Indian Journal of Weed Science **53**(1): 107–110, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Bio-efficacy of new post-emergent herbicides on growth and yield of blackgram

S. Harisha*, C. Seenappa, B.S. Lalitha, Gurunath Raddy and U. Pandu

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

**Email: harishs27666@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00019.8

Type of article: Research note

Received : 12 September 2020
Revised : 24 January 2021
Accepted : 27 January 2021

Key words

Blackgram, Fomesafen + propaquizafop, phytotoxicity, nutrient uptake and economics, yield

ABSTRACT

A field experiment was conducted during *Kharif* 2018 Gandhi Krishi Vigyan Kendra, University of Agricultural Sciences, Bangalore, Karnataka. to evaluate the bio-efficacy of new herbicides with pre-mix formulations in blackgram. Major weeds were *Achyranthes aspera, Ageratum conyzoides, Alternanthra sessilis, Borreria articularis, Cynodon dactylon, Dactyloctenium aegyptium, Echinochloa colona, Eleusine indica* and *Cyperus rotundus*. Post-emergence application of fomesafen 18.8% SL + propaquizafop (5.83% EC) 252 + 78 g/ha recoded better crop growth seed yield (1.29 t/ha) along with higher net returns (₹ 50,106/ha) and benefit:cost ratio (3.27) without any phytotoxic effect on crop and was found comparable with two hand weeding at 15 and 30 days after sowing (seed yield 1.348 t/ha)

Blackgram [*Vigna mungo* (L.) Hepper] is one of the important nutritive pulse crops. In India, it is mostly grown in summer and rainy seasons, covering an area of 5.44 million hectares with total production of 3.56 million tones and average productivity of 655 kg/ha during 2017-18 (DPD 2018). Major production of blackgram comes from the states of Madhya Pradesh, Rajasthan, Andhra Pradesh, Uttar Pradesh, Tamil Nadu, Maharashtra, Jharkhand, Gujarat, Karnataka and West Bengal. Although India is the largest producer and consumer of blackgram in the world, its realizable productivity is comparatively lower than the potential level. Even blackgram productivity in the state of Karnataka is quite less than the national average (Anonymous 2018). Weeds are the principal biotic constraints in adversely influencing the productivity. They compete for different growth-limiting resources like nutrient, moisture and light during critical period of crop-weed competition (first 20-40 days after sowing). Season-long weed competition causes yield reduction to the extent of 27-84% depending on the kind and intensity of weed species (Bhowmick *et al.* 2015). Though hand weeding is usually preferred, it adds more to the cost of cultivation due to higher labour wages and does not ensure weed removal at the critical stages of crop-weed competition (Duary *et al.* 2015). Fomesafen at 250 g/ha is an effective post-emergence (PoE) herbicide for controlling non-grassy weeds (Singh *et al.* 2014), whereas propaquizafop at 50 g/ha takes care of grassy weeds in soybean (Tiwari and Mathew 2002). However, the efficacy of fomesafen + propaquizafop (pre-mix) has not been evaluated for weed management in blackgram under Eastern dry zone of Karnataka as well as other parts of the country. Hence, the present investigation was undertaken.

A field experiment was conducted during rainy season (*Kharif*), 2018 at the Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences, Bengaluru, Karnataka. The experimental site was situated in the Eastern dry zone (Zone-V) of Karnataka (12º51' N Latitude and 77º35' E Longitude with an altitude of 930 m above mean sea level). The soil of the experimental site was sandy loam in texture and slightly acidic in reaction (pH 5.8), medium in organic carbon content (0.50%), low available nitrogen (253.60 kg/ha), medium available phosphorus (32.24 kg/ha) and high available potassium (283.20 kg/ha) with electrical conductivity of 0.32 dS/m. The moisture content at field capacity was 18.63% with bulk density of 1.43 g/cc. Eleven treatments were assigned in a randomized complete block design with three replications. Treatments included fomesafen 25% SL 250 g/ha at 20 days after sowing (DAS), propaquizafop 10% EC 100 g/ha (20 DAS), imazethapyr 10% SL 100 g/ha (20 DAS), fomesafen 18.8% SL + propaquizafop 5.83% EC (pre-mix) 168 + 52, 210 + 65, 252 + 78 and 294 + 91 g/ha (20 DAS), propaquizafop 2.5% EC + imazethapyr 3.7% SL (pre-mix) 50 + 75 g/ha (20

DAS), two hand weeding (15 and 30 DAS), weed free and weedy check. Seeds of blackgram variety '*LBG-625*' (*Rashmi*) were sown in lines at the rate of 25 kg/ha and at a depth of 2-3 cm, maintaining 30 cm row spacing. The crop was fertilized with 25-50-25 kg N-P-K/ha through urea, single super phosphate and muriate of potash, respectively. The crop was sown during 13th July and harvested at 24th October 2018.

Monocot and dicot weeds were counted separately within a random quadrat of 0.5 x 0.5 m in each net plot at 25, 50 DAS and harvest, and expressed as number of weeds/m^2. Weed dry weight was recorded at 25, 50 DAS and at harvest. Weeds were cut close to the ground level within a quadrat in each net plot and dried at 70^{o}C to a constant weight. Dry weight of weeds was recorded, expressed in g/m^2 and subjected to square root transformation before statistical analyses to normalize their distribution. Observations were recorded on crop growth (plant height, number of branches), yield attributes, seed and stover yield at harvest. Uptake of nutrients (nitrogen, phosphorus and potassium) by crop plants as well as weeds was also recorded at harvest. Visual observations were recorded at 1, 3, 5, 7 and 10 days after spraying of herbicides to know the extent of their toxicity on crop by using phytotoxicity rating scale of 0-10 with 0 being no toxicity and 10 being 100% toxicity. The phytotoxicity rating was done on the basis of symptoms like epinasty, hyponasty, necrosis, wilting, vein clearing and stunted growth. Economics of different treatments were also worked out.

Weed control efficiency (WCE) and weed index (WI) were calculated as per standard formulae as:

$$\text{WCE (\%)} = \frac{\text{Dry matter of weeds in unweeded plot - Dry matter of weeds in treated plot}}{\text{Dry matter of weeds in unweeded plot}} \times 100$$

$$\text{WI (\%)} = \frac{\text{Yield of weed free plot – Yield of treated plot}}{\text{Yield of weed free plot}} \text{ x } 100$$

Weed flora

The major weed flora and their relative density at 50 days after sowing in the experimental plots were *Achyranthes aspera* (7.45%), *Ageratum conyzoides* (14.51%), *Alternanthera sessilis,* (13.72%), *Borreria articularis* (12.47%) and *Emilia sonchifolia* (5.44%) among broad-leavedweeds *Cynodon dactylon*, (7.13%) *Dactyloctenium aegyptium* (7.92%), *Digitaria marginata*, (6.31%) *Echinochloa colona*, (6.18%) *Eleusine indica* (14.29%) among the grassy weeds and *Cyperus rotundus* (5.24%) among sedges.

Effect on weed

Among different treatments, PoE application of fomesafen + propaquizafop at 252 + 78 g/ha caused significant reduction in density of all categories of weeds at harvest (**Table 1**). But it was at par with two rounds of hand weeding at 15 and 30 DAS. Lower weed density and weed dry weight in the plots of two hand weeding (15 and 30 DAS) was due to elimination of all categories of weeds through physical uprooting of both above and below ground parts of weeds. Two hand weeding was found comparable with fomesafen + propaquizafop (pre-mix) in registering lower weed density and weed dry weight due to its broader spectrum effect on weed flora. Similar results were reported by Goverdhan (2018). On the other hand, sole application of fomesafen at 250 g/ha (PoE) caused more reduction in density and dry weight of broad-leaved weeds only because of its contact activity. Fomesafen was reported to inhibit the key enzyme 'protoporphyrinogen oxidase' (PROTOX) with its involvement in chlorophyll synthesis and heme biosynthesis, leading to breaking chain of reactions, causing the cells and cell organelles to dry and disintegrate rapidly in case of broad-leaved weeds (Tiwari and Mathew 2002, Goverdhan 2018). Similarly, PoE application of propaquizafop 100 g/ha reduced both density and dry weight of grassy weeds for its selective nature, causing reduced cell division and growth through inhibition in 'acetyl CoA carboxylase' (ACCase) enzyme functioning (Tiwari and Mathew, 2002, Shiva Pratap *et al.* 2018). Weedy check plots recorded higher values of weed density and dry weight (**Table 1**).

Higher WCE (92.3%) and lower WI (6.19%) were recorded with two hand weeding (15 and 30 DAS), which was at par with PoE application of fomesafen + propaquizafop at 252 + 78 g/ha with WCE of 91.1% and WI of 10.23%. This was mainly due to effective control of weeds at critical stages of crop growth, enabling the crop to better utilize available resources like light, nutrients, moisture and space and resulting in higher yields with lower WI. Kewat *et al.* (2014) were of similar opinion.

Effect on crop

PoE application of pre-mix herbicides significantly recorded higher values of growth and yield attributes as compared to their sole application and remained at par with weed free plot. Weed free plot was significantly superior to all other treatments in respect of growth and yield attributes. Higher plant height (39.2 and 38.3 cm) along with more number of branches/plant (8.2 and 8.1), pods/plant (43.5 and

42.0) and pod length (5.3 and 5.2 cm) were recorded under fomesafen + propaquizafop at 252 + 78 and 210 + 65 g/ha, respectively. Minimum values were recorded under weedy check treatment. Higher seed yield (1.45 t/ha) and stover yield (4.21 t/ha) was recorded in weed free check (**Table 2**), which was significantly on par with two hand weeding at 15 and 30 DAS (1.35 and 4.13 t/ha) and fomesafen + propaquizafop 252 + 78 g/ha (1.29 and 3.95 t/ha). This was due to better control of both grassy as well as broad-leaved weeds during early crop growth period. It provided a congenial environment for better expression of growth stature and yield attributes, resulting in increased seed yield. These results corroborated with the findings of Sylvestre *et al.* (2013) and Khot *et al.* (2015).

There was a positive correlation between nutrient uptake by crop plants with seed and stover yields at harvest. Seed and stover yields were significantly higher with more uptake of nitrogen, phosphorus and potassium by crop plants as recorded in weed free check, two hand weeding and fomesafen + propaquizafop 252 + 78 g/ha due to better weed control and less crop-weed competition (**Table 3**). The lowest level of nutrient uptake by the crop was recorded in unweeded control due to intense crop-weed competition, causing lower dry matter production. Similar observation was also reported by Younesabadi *et al.* (2013) and Chhodavadia *et al.* (2013).

Crop yield and nutrient uptake by weeds were negatively correlated. More nutrient removal by weeds resulted in luxuriant weed growth that suppressed crop growth and development, causing poor crop yield as reflected in weedy check. Significantly the lowest removal of nutrients by the weeds was recorded under two hand weeding as a consequence of effective weed removal (**Table 3**). The results were in conformity with the findings of Komal *et al.* (2015) and Prachand *et al.* (2015).

Production economics

PoE application of fomesafen + propaquizafop 252 + 78 g/ha fetched higher net return (₹ 50,106/ha) with benefit/cost ratio (BCR) of 3.26, which was at par with fomesafen + propaquizafop 210 + 65 g/ha with net return of ₹ 48,030/ha and BCR of 3.20 as compared to two hand weeding (BCR of 2.60).

Table 1. Effect of treatments on weed growth, weed control efficiency and weed index in blackgram

Treatment	Weed density (no./m^2) at harvest			Weed dry weight (g/m^2) at harvest			WCE (%) at 30 DAS	WI (%)
	Sedge	Grasses	Broad-leaved	Sedge	Grasses	Broad-leaved		
Fomesafen 250 g/ha (20 DAS)	1.41(1.10)	1.36(19.80)	2.74(6.57)	1.51(1.32)	1.58(36.73)	1.43(24.97)	68.3	46.42
Propaquizafop 100 g/ha (20 DAS)	1.14(0.33)	1.10(6.60)	5.05(24.57)	1.36(0.87)	1.30(18.03)	1.56(34.97)	74.5	44.05
Imazethapyr 100 g/ha (20 DAS)	1.80(2.27)	1.38(23.03)	4.79(22.00)	2.02(3.10)	1.57(35.33)	1.59(37.40)	61.7	47.67
Fomesafen + propaquizafop 168 + 52 g/ha (20 DAS)	1.11(0.25)	1.20(18.97)	3.83(13.87)	1.66(1.78)	1.52(31.17)	1.49(28.93)	75.1	34.03
Fomesafen + propaquizafop 210 + 65 g/ha (20 DAS)	1.30(0.73)	1.06(14.73)	3.68(12.57)	1.46(1.17)	1.46(26.93)	1.51(30.97)	89.7	13.15
Fomesafen + propaquizafop 252 + 78 g/ha (20 DAS)	1.20(0.53)	0.87(7.03)	3.17(9.07)	1.26(0.60)	1.32(19.23)	1.46(27.47)	91.1	10.23
Fomesafen + propaquizafop 294 + 91 g/ha (20 DAS)	1.57(1.52)	1.17(11.07)	3.72(12.87)	1.61(1.67)	1.40(23.27)	1.52(31.27)	88.8	31.20
Propaquizafop + imazethapyr 50 + 75 g/ha (20 DAS)	2.11(3.47)	1.39(22.93)	4.22(16.87)	2.00(3.03)	1.64(42.03)	1.54(32.80)	78.0	30.06
Two hand weeding (15 and 30 DAS)	1.14(0.33)	0.67(6.63)	2.51(5.40)	1.33(0.77)	1.24(15.73)	1.31(18.80)	92.3	6.19
Weed free	1.00(0.00)	0.30(0.00)	1.00(0.00)	1.00(0.00)	0.30(0.00)	0.30(0.00)	100.0	0.00
Weedy check	1.99(3.07)	1.44(44.67)	5.28(27.07)	2.24(4.07)	1.83(66.20)	1.71(50.13)	0.0	68.27
LSD (p=0.05)	0.16	0.43	0.70	0.13	0.24	0.15	NA	NA

DAS: Days after sowing, WCE: Weed control efficiency, WI: Weed index. Original figures within parentheses were subjected to log ($\sqrt{x+2}$) transformation for grasses and square root ($\sqrt{x+1}$) transformation for sedge and broad-leaved

Table 2. Effect of treatments on crop growth, yield parameters and yield of blackgram

Treatment	Plant height (cm)	Branches /plant	Productive pods/plant	Pod length (cm)	Seed yield (t/ha)	Stover yield (t/ha)	Harvest index (%)	Net returns (x10^3₹/ha)	B:C ratio
Fomesafen 250 g/ha (20 DAS)	28.5	5.7	21.8	4.5	0.77	2.95	20.7	20.64	1.92
Propaquizafop 100 g/ha (20 DAS)	27.6	6.1	26.3	4.6	0.80	2.91	21.7	23.04	2.05
Imazethapyr 100 g/ha (20 DAS)	26.9	5.3	23.0	4.6	0.75	2.88	20.8	20.73	1.97
Fomesafen + propaquizafop 168 + 52 g/ha (20 DAS)	30.2	6.2	26.5	4.7	0.95	2.98	24.1	31.50	2.46
Fomesafen + propaquizafop 210 + 65 g/ha (20 DAS)	38.3	8.1	42.0	5.2	1.25	3.85	24.5	48.03	3.20
Fomesafen + propaquizafop 252 + 78 g/ha (20 DAS)	39.2	8.2	43.5	5.3	1.29	3.95	24.6	50.11	3.26
Fomesafen + propaquizafop 294 + 91 g/ha (20 DAS)	28.5	5.7	28.5	4.7	0.99	2.99	22.9	32.92	2.47
Propaquizafop + imazethapyr 50 + 75 g/ha (20 DAS)	30.0	5.8	32.3	4.6	1.00	3.65	21.4	34.30	2.56
Two hand weeding (15 and 30 DAS)	40.3	8.4	44.6	5.4	1.35	4.13	24.6	48.78	2.60
Weed free	42.1	9.2	45.1	5.7	1.44	4.21	25.4	47.99	2.48
Weedy check	23.9	3.9	13.4	4.3	0.46	2.71	14.4	3.05	1.15
LSD (p=0.05)	4.61	0.40	3.4	0.57	0.19	0.36	4.61	20.64	1.92

Table 3. Nutrient uptake (kg/ha) by crop and weeds at harvest as influenced by different post-emergent herbicides

Treatment	Crop			Weeds		
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
Fomesafen 250 g/ha (20 DAS)	49.4	11.9	21.4	9.40	3.83	5.60
Propaquizafop 100 g/ha (20 DAS)	50.6	12.4	23.1	6.93	3.47	5.33
Imazethapyr 100 g/ha (20 DAS)	49.1	11.5	22.5	8.87	3.83	6.87
Fomesafen + propaquizafop 168 + 52 g/ha (20 DAS)	58.2	12.4	26.3	6.67	3.17	5.03
Fomesafen + propaquizafop 210 + 65 g/ha (20 DAS)	77.5	15.3	34.6	5.83	3.20	4.87
Fomesafen + propaquizafop 252 + 78 g/ha (20 DAS)	78.9	15.4	35.2	4.83	2.90	4.13
Fomesafen + propaquizafop 294 + 91 g/ha (20 DAS)	62.9	13.4	24.8	6.93	3.43	5.47
Propaquizafop + imazethapyr 50 + 75 g/ha (20 DAS)	50.9	11.6	26.5	8.47	4.30	7.10
Two hand weeding (15 and 30 DAS)	79.0	15.9	35.4	4.57	2.83	4.03
Weed free	81.8	16.7	36.9	0.0	0.0	0.0
Weedy check	36.9	8.2	15.3	11.30	5.57	8.90
LSD (p=0.05)	5.10	1.46	2.87	1.17	0.47	0.96

Weedy check recorded the lowest net return (₹ 3,051/ha) with minimum BCR (1.15). Use of herbicides provided cost-effective control of weeds since beginning of crop establishment, compared with cost-prohibitive hand weeding (**Table 2**). These results were in harmony with the findings of Khot *et al.* (2015) and Sakthi *et al.* (2018).

Crop phytotoxicity

Application of fomesafen + propaquizafop at 294 + 91 g/ha caused epinasty and stunted growth of crop plants at 1, 3, 5, 7 and 10 days after spraying. Although the treatment initially displayed slight yellowing of leaves and epinasty symptoms at 3 days after application, the crop plants gradually recovered with progress of growth after 7 days of spraying with almost disappearance of symptoms after 15 days of application Similar findings were also reported by Singh *et al.* (2014) and Goverdhan (2018).

Application of fomesafen 18.8% SL + propaquizafop 5.83% EC 252 + 78 g/ha proved to be the most efficient weed management practice for obtaining higher yields with more profit. Combined application of herbicides was found to be more effective than single herbicide application in ensuring broad spectrum weed management in blackgram.

REFERENCES

Anonymous. 2018. *Annual Report on Pulses*. Ministry of Agriculture and Farmers Welfare (DAC&FW), Government of India, p.20.

Bhowmick MK, Duary B and Biswas PK. 2015. Integrated weed management in blackgram. *Indian Journal of Weed Science* **47**: 34–37.

Chhodavadia SK, Sagarka BK and Gohil BS. 2013. Integrated management for improved weed suppression in summer greengram (*Vigna radiata* L.). *An International Quarterly Journal of Life Sciences* **9**(2): 1577–1580.

DPD. 2018. *Annual Report (2017-18)*. Government of India, Ministry of Agriculture & Farmers Welfare (Department of Agriculture, Cooperation & Farmers Welfare), Directorate of Pulses Development (DPD), Vindhyachal Bhavan, Madhya Pradesh, India. 8. 177 pp.

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

Goverdhan, L. 2018. Evaluation of post-emergence herbicides against weeds in soybean. *M.Sc. (Agriculture) Thesis*, JNKVV, Jabalpur, Madhya Pradesh, India.

Kewat ML, Suryawanshi T and Sahu SL. 2014. Efficacy of propaquizafop and imazethapyr mixture against weeds in blackgram. p. 176. In: *Biennial Conference of Indian Society of Weed Science on "Emerging Challenges in Weed Management"*, Directorate of Weed Science Research. February 15-17, 2014. Jabalpur, M.P.

Khot DB, Pagar RD and Munde SD. 2015. Effect of different weed management practices on yield and economics of summer blackgram (*Vigna mungo* L.). *Agriculture for Sustainable Development* **3**(1): 21–22.

Komal, Singh SP and Yadav RS. 2015. Effect of weed management on growth, yield and nutrient uptake of greengram. *Indian Journal of Weed Science* **47**(2): 206–210.

Prachand S, Kalhapure A and Kubde KJ. 2015. Weed management in soybean with pre- and post-emergence herbicides. *Indian Journal of Weed Science* **47**: 163–165.

Sakthi J, Velayutham A, Hemalatha M and Vasanthi D. 2018. Economics of herbicides against weeds of blackgram. Under irrigated condition. *International Journal of Advances in Agriculture Science and Technology* **5**(7): 133–143.

Shiva Pratap S, Rawal VK, Dua S, Roy MJ, Sadaworti and Sharma. 2018.Evaluation of Propaquizafop: A new molecule as post emergence herbicide in potato. *International Journal of Chemical Studies* **5**(5): 1216–1220.

Singh G, Kaur H, Aggarwal N and Sharma P. 2014. Effect of herbicides on weed growth and yield of greengram. *Indian Journal of Weed Science* **47**(1): 38–42.

Sylvestre H, Kalyana Murthy KN, Shankaralingappa BC, Devendra R, Sanjay MT and Ramachandra C. 2013. Effect of pre- and post-emergence herbicides on weed dynamics, growth and yield of soybean (*Glycine max* L.). *Advances in Applied Science Research* **4**(4): 72–75.

Tiwari BK and Mathew R. 2002. Influence of post-emergence herbicides on growth and yield of soybean. *JNKVV Research Journal* **36**(2): 17–21.

Younesabadi M, Das TK and Sharma AR. 2013. Effect of tillage and tank-mix application on weed management in soybean. *Indian Journal of Agronomy* **58**(3): 372–378.

Indian Journal of Weed Science **53**(1): 111–113, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Weed management in groundnut

Satyanarayan Regar, S.P. Singh[1], Hansraj Shivran*[1], R.C. Bairwa[1], Vimal Khinchi
Department of Agronomy, College of Agriculture, Bikaner Rajasthan 334006, India
[1]Agriculture Research Station, SKRAU, Bikaner, Rajasthan 334006, India
**Email: spbhakar2010@gmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00020.4

Type of article: Research note

Received : 19 September 2020
Revised : 9 January 2021
Accepted : 14 January 2021

Key words
Groundnut

Pendimethalin

Weed management

ABSTRACT

A field experiment was conducted on groundnut (*Arachis hypogaea* L.) during *Kharif* (rainy season) 2016 at College of Agriculture, SKRAU, Bikaner (Rajasthan). The soil was loamy sand, low in organic carbon (0.08%) and available N (78 kg/ha) and medium in available P (22 kg/ha) and available K (210 kg/ha) with pH 8.3. Significantly the lowest density and dry matter of weeds and the highest haulm and pod yield were recorded with application of pendimethalin + imazethapyr (30+2) 800 g/ha(PE) followed by pendimethalin 1.0 kg/ha as PE, imazethapyr + imazamox (35:35) 70 g/ha at 20 DAS as PoE (at 3-4 leaf stage), pendimethalin + imazethapyr (30 + 2) premix 800 g/ha(PPI), imazethapyr + imazamox (35:35) 50 g/ha at 20 DAS as PoE (at 3-4 leaf stage), imazethapyr 70 g/ha at 20 DAS as PoE and pendimethalin + imazethapyr (30 + 2) 800 g/ha (Dry). Maximum net returns of ₹ 223016 /ha was realized under the weed free treatment and it was closely followed by pendimethalin + imazethapyr (30+2) 800 g/ha (PE), pendimethalin 1.0 kg/ha (PE) and pendimethalin 1.0 kg/ha (PPI) as ₹ 185045, ₹ 9177813 and ₹ 175462 /ha, respectively.

In India out of total production of edible oil, 67 per cent is contributed by groundnut. The demand for edible oil in the country is rising by 6 per cent per annum. Therefore, concerted efforts are now being made for increasing and stabilizing oilseed production (Narayan 2017). Groundnut (*Arachis hypogaea* L.) is one of the most important food as well as cash crop of the country. It is gaining importance due to its contents namely, 48-50 per cent of oil and 26-28 per cent of protein. Groundnuts also contain vitamin 'E' and small amounts of vitamin 'B' complex and good source of calories, 5.6 calories /nut. Weeds are one of the important factors responsible for low yield of groundnut. They play an important role in the dietary requirements of resource poor women and children and haulms are used as livestock feed. The main problems limiting production of groundnut are poor cultural practices as well as inadequate weed management (EL Naim *et al.* 2010). Weeds reduce yield by competing with the groundnut plant for resources, such as moisture, nutrients, space, and sunlight *etc*. (Upadhyay 1984). Heavy weed infestation appears to be the most serious menace in groundnut production causing extensive losses. Because of its short stature and initial slow growth in comparison to fast growing weeds, weeds smother this crop at every stage by sharing water, nutrients, space, solar radiation and other resources. Pendimethalin as pre-emergence has performed well in leguminous crops. Pendimethalin is a selective and pre-emergence herbicide absorbed by roots and leaves. Affected plants die shortly after germination or following emergence from the soil. If the farmers skipped to apply this herbicide due to one or other reasons, application of post-emergence herbicide is the option left with them.

The field experiment was conducted at College of Agriculture, S.K. Rajasthan Agricultural University, Bikaner during *Kharif* 2016. Bikaner (28.01°N latitude and 73.22°E longitude at an altitude of 234.70 meters above mean sea level). The experimental soil was deep, sandy and coarse loamy, desert soils with low water holding capacity, hot and arid climate, having pH 8.0, organic carbon 0.08%,78.20 N kg/ha, 22.0 P kg/ha, 116.82 potassium kg/ha and bulk density 1.65, respectively. The variety used in this experiment was *'HNG-10'*. The treatments consisted of pendimethalin 1.0 kg/ha as dry, pendimethalin 1.0 kg/ha as pre-plant incorporation (PPI), pendimethalin 1.0 kg/ha as PE, pendimethalin + imazethapyr (30+2) 800 g/ha (dry), pendimethalin imazethapyr (30+2) 800 g/ha(PPI), pendimethalin imazethapyr (30+2) 800 g/

ha(PE), imazethapyr 50 g/ha at 20 DAS as PoE, imazethapyr 70 g/ha at 20 DAS as PoE, imazethapyr + imazamox (35:35) 50 g/ha at 20 DAS as PoE (at 3-4 leaf stage), imazethapyr + imazamox (35:35) 70 g/ha at 20 DAS as PoE (at 3-4 leaf stage), weed free and weedy check. These herbicides were sprayed with knap-sack sprayer using 500 liters of water per hectare. The analysis of data was done using the Fisher's method of analysis of variance technique as described by Gomez and Gomez (1984). The differences of means were identified by Duncan's univariate test at p ≥0.05.

Effect on weeds

Major weeds of the experimental field were *Amaranthus spinosus* L., *Digera arvensis* Forsk, *Physalis minima, Tribulus terrestris* L., *Portulaca oleracea* L., *Trianthima portulacastrum*, *Cyperus rotundus* L., *Cenchrus biflorus* L., *Eleusine indica* L., and *Dactyloctenium aegypticum*. Weed control treatments brought about significant variation in the count and dry weights of weeds (**Table 1**). All the weed control treatments had significantly lower total weed count and dry matter as compared to untreated plot. At the 30, 60 DAS and at harvest, the significantly lower count and dry matter of weed with application of pendimethalin + imazethapyr (30 + 2) premix 800 g/ha (PE) followed by pendimethalin 1.0 kg/ha as PE, imazethapyr + imazamox (35:35) 70 g/ha at 20 DAS as PoE (at 3-4 leaf stage), pendimethalin + imazethapyr (30 + 2) premix 800 g/ha (PPI), imazethapyr + imazamox (35:35) 50 g/ha at 20 DAS as PoE (at 3-4 leaf stage), imazethapyr 70 g/ha at 20 DAS as PoE and pendimethalin + imazethapyr (30 + 2) premix 800 g/ha (Dry), respectively. These treatments were statistically at par with each other. Similar result also collaborated with Rana *et al.* (2019), Singh *et al.* (2019) and Komal *et al.* (2015).

Pendimethalin + imazethapyr (30 + 2) pre-mix 800 g/ha (PE), pendimethalin 1.0 kg/ha (PE) and imazethapyr + imazamox (35:35) 70 g/ha at 20 DAS as PoE (at 3-4 leaf stage) pendimethalin + imazethapyr (30 + 2) premix 800 g/ha (PPI) recorded higher weed control efficiency 99.23, 98.68, 86.75 and 82.55% (**Table 2**). Data further indicate that the lowest weed index was recorded under pendimethalin + imazethapyr (30 + 2) premix 800 g/ha (PE) (3.99%) followed by pendimethalin 1.0 kg/ha (PE) (7.35%) and imazethapyr + imazamox (35:35) 70 g/ha at 20 DAS as PoE (at 3-4 leaf stage) (9.70%). These findings are akin to report of Gupta *et al.* (2015) and Singh *et al.* (2019).

Effect on groundnut

Pod and haulm yield were also significantly increased under various treatments of weed management during the experimentation over weedy check. Increase in straw yield might be due to the direct influence of various weed management treatments on the suppression of weeds. Thus, crop weed competition resulted into increased plant height, dry matter accumulation (**Table 2**) and nutrient uptake. The results so obtained for straw corroborate with the findings of Kumar *et al.* (2003), Mishra and Chandrabhanu (2006) and Tiwari *et al.* (2014).

Table 1. Effect of weed control measures on total density and dry weight of weeds in groundnut

Treatment	Total weeds density (no./m^2)			Total weeds dry weight (g/m^2)			Weed control efficiency (%)	Weed index (%)
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest		
Pendimethalin 1.0 kg/ha as dry	6.0(35.6)	6.5(42.0)	6.5(42.0)	5.2(27.0)	5.9(34.3)	4.51(19.9)	75.38	17.00
Pendimethalin 1.0 kg/ha as PPI	5.4(28.8)	6.0(33.6)	6.0(33.6)	4.5(19.5)	5.2(26.2)	3.93(15.0)	80.58	12.87
Pendimethalin 1.0 kg/ha as PE	3.4(11.2)	3.5(11.7)	3.5(11.7)	1.4(1.5)	1.5(1.8)	1.35(1.3)	98.68	7.35
Pendimethalin + imazethapyr (30+2) premix 800 g/ha(dry)	4.9(23.7)	5.6(31.1)	5.6(31.1)	5.1(25.2)	5.7(32.1)	4.37(18.6)	76.03	16.28
Pendimethalin + imazethapyr (30+2) premix 800 g/ha (PPI)	4.3(18.2)	4.8(22.9)	4.8(22.9)	4.2(17.1)	5.0(24.3)	3.84(14.3)	82.55	9.70
Pendimethalin + imazethapyr (30+2) premix 800 g/ha (PE)	1.0(0.5)	1.2(1.0)	1.2(1.0)	1.1(0.7)	1.3(1.1)	1.11(0.7)	99.23	3.99
Imazethapyr 50 g/ha at 20 DAS as PoE	6.2(37.8)	6.8(45.4)	6.8(45.4)	5.9(33.9)	6.8(45.6)	5.48(29.6)	64.54	28.57
Imazethapyr 70 g/ha at 20 DAS as PoE	4.9(26.4)	5.1(26.0)	5.1(26.0)	5.1(26.0)	5.4(29.0)	4.46(19.4)	79.29	21.71
Imazethapyr + imazamox (35:35) 50 g/ha at 20 DAS as PoE	4.5(19.4)	5.6(30.9)	5.6(30.9)	4.5(20.1)	5.6(30.4)	4.21(17.2)	75.16	23.68
Imazethapyr + imazamox (35:35) 70 g/ha at 20 DAS as PoE	3.9(15.0)	4.1(16.3)	4.1(16.3)	3.7(12.9)	4.4(18.8)	3.42(11.2)	86.75	20.84
Weed free	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.71(0.0)	100.00	0.00
Weedy check	10.7(114.3)	11.5(132.1)	11.5(132.1)	10.1(102.3)	11.6(134.8)	9.19(83.9)	0.00	90.54
LSD (p=0.05)	0.12	0.14	0.14	0.12	0.13	0.11		

Figures in parentheses are original, weed density transformed to $\sqrt{x+0.5}$

Table 2. Effect of weed control measures on yield, net return and B:C ratio in groundnut

Treatment	Pod yield (t/ha)	Haulm yield (t/ha)	Net return (x10^3 ₹/ha)	B C ratio
Pendimethalin 1.0 kg/ha as dry	3.89	7.71	169.20	2.34
Pendimethalin 1.0 kg/ha as PPI	4.06	8.26	178.40	2.47
Pendimethalin 1.0 kg/ha as PE	4.35	8.89	180.80	2.50
Pendimethalin + imazethapyr (30+2) premix 800 g/ha (Dry)	3.90	7.97	170.60	2.36
Pendimethalin + imazethapyr (30+2) premix 800 g/ha (PPI)	4.20	8.83	172.70	2.39
Pendimethalin + imazethapyr (30+2) premix 800 g/ha (PE)	4.48	8.92	188.00	2.60
Imazethapyr 50 g/ha at 20 DAS as PoE	3.34	6.73	136.40	1.89
Imazethapyr 70 g/ha at 20 DAS as PoE	3.64	7.62	148.30	2.06
Imazethapyr + imazamox (35:35) 50 g/ha at 20 DAS as PoE	3.58	6.99	152.60	2.10
Imazethapyr + imazamox (35:35) 70 g/ha at 20 DAS as PoE	3.71	7.60	153.40	2.10
Weed free	4.69	10.27	223.00	3.01
Weedy check	2.49	5.02	93.20	1.31
LSD (p=0.05)	0.49	1.55	27.46	0.38

The extents of increase in pod, haulm and biological yield of groundnut were followed by 93.48, 104.5 and 99.04% under weed free treatment However, the increases pod yield under pendimethalin + imazethapyr (30 + 2) premix 800 g/ha (PE) and pendimethalin 1.0 kg/ha (PE) were 79.83 and 74.21%, respectively compared to weedy check. The results so obtained for straw corroborate with the findings of Singh *et al.* (2019).

Maximum net returns of ₹223016 /ha was realized under the weed free treatment and it was closely followed by pendimethalin + imazethapyr (30 + 2) premix 800 g/ha (PE), pendimethalin 1.0 kg/ha (PE) and pendimethalin 1.0 kg/ha (PPI) 185045, 9177813 and 175462/ha, respectively (**Table 2**). The higher pod yield recorded with this treatment might be responsible for higher net returns. The maximum B:C ratio (2.5) was accrued under treatment pendimethalin + imazethapyr (30 + 2) pre-mix 800 g/ha (PE) followed by pendimethalin 1.0 kg/ha (PE) and pendimethalin 1.0 kg/ha (PPI) values 2.4 and 2.3. These findings were in close vicinity with those reported by Gupta *et al.* (2015), Singh *et al.* (2016).

It was concluded that pre-emergence application of pendimethalin and imazethapyr 800 g/ha could be adopted for effective management of weeds and higher productivity of groundnut in hyper arid region of Rajasthan.

REFERENCS

Duncan DB. 1955. Multiple range and multiple F tests. *Biometrics* **11**: 1–42.

El Naim AM, Eldouma MA and Abdalla AE. 2010. Effect of weeding frequencies and plant density on the vegetative growth characteristic in groundnut (*Arachis hypogaea* L.) in north Kordofan of Sudan. *International Journal of Applied Biology and Pharmaceutical Technology* **1**(3). 1188–1193.

Gomez KA and Gomez AA. 1984. *Statistical for Agricultural Research*. John. Wiley and Sons. New York, 704 p.

Gupta Versa, Singh SP, Yadav RS. 2015. Yield performance and nutrient uptake as influenced by integrated weed management in cluster bean. *Indian Journal of Weed Science* **47**(1): 82–84.

Komal, Singh SP and Yadav RS. 2015. Effect of weed management on growth, yield and nutrient uptake of greengram. *Indian Journal of Weed Science* **47**(2): 206–210.

Kumar V, Singh S and Gill OP. 2003. Integrated weed management in irrigated groundnut *(Arachis hypogaea* L.) *Indian Journal of Agronomy* **48**: 117–119.

Mishra JS and Chandrabhanu 2006. Effect of herbicides on weeds, nodulation and growth of rhizobium in summer black gram (*Vigna mungo* L.). *Indian Journal of Weed Science* **38**(1&2): 150–153.

Narayan P. 2017. Recent demand-supply and growth of oilseeds and edible oil in India: an analytical approach. *International Journal of Advanced Engineering Research and Science* **4**(1): 2349–6495.

Rana SS, Sharma N and Badiyala D. 2019. A preliminary study on the time of application of imazethapyr and its ready-mix combination with pendimethalin and imazamox against weed in black gram. *Journal of Research in Weed Science* **2**(4): 282–291.

Singh SP, Yadav RS, and Sharma Vikas 2016. Weed control in cluster bean through post-emergence herbicides. *Indian Journal of Weed Science* **48**(2): 202–205.

Singh SP, Yadav RS, Godara SL, Kumawat A and Birba. 2019. Herbicidal weed management in groundnut (*Arachis hypogaea*). *Legume Research* **42**(6): 829–833.

Tiwari VK, Nagre SK, Chandrakar DK and Sharma MK. 2014. Effect of weed management practices on yield attribution of urdbean under late sown condition. pp. 218. In: *Biennial Conference of Indian Society of Weed Science on "Emerging challenges in weed management"*, February 15-17, 2014. DWSR, Jabalpur.

Upadhyay UC. 1984. Weed management in oilseed crops. pp. 491–99. In: *Proceedings of Symposium*. Oilseed Production, Utilization, Constraints and Opportunities.

Indian Journal of Weed Science **53**(1): 114–116, 2021

Print ISSN 0253-8040 Online ISSN 0974-8164

Effect of weed management treatments on growth and yield of tomato

M.P. Kavitha*, M. Uma Maheswari, K. Krishna, G. Balaji, R. Yuavaraj, R. Sachin and S. Kissan Kumar

Horticultural College and Research Institute, Periyakulam, Tamil Nadu 625 604, India

**Email: kavimaruthu@rediffmail.com*

Article information

DOI: 10.5958/0974-8164.2021.00021.6

Type of article: Research note

Received : 16 August 2020

Revised : 19 January 2021

Accepted : 21 January 2021

Key words

Black polythene mulch, Herbicides, Rice straw mulch, Tomato

ABSTRACT

A field experiment was conducted to study the effect of weed management treatments on growth and yield of tomato (*Lycopersicon esculentum L*) at Western block, Horticultural College and Research Institute, Periyakulam during summer season of the year 2019. The experiment was carried out in randomized block design with eight treatments and replicated thrice. Application of black polythene mulch (60% 6000 m^2/ha) gave maximum control of weed by lowering the weed density, weed biomass and higher weed control efficiency (98.9%). This was followed by rice straw mulch 5 t/ha which recorded weed control efficiency of 98.5 %. Black polythene mulch recorded significantly higher fruit yield (28.1 t/ha) and recorded higher net returns (₹ 1, 90,630/-) and the BC ratio (3.11).

Tomato (*Lycopersicon esculentum* L) is the second most important vegetable crop next to potato in the world. In India, tomato is the vital vegetable featuring prominently in the diet of the people. In the traditional cropping system, tomato is intercropped with food crops such as cassava, yam, maize and other vegetable crops like pepper, okra, onion (Anonymous 2017). Tomato crop severely surfers with many weed species. Therefore, in order to control weed growth and obtain maximum yield in tomato, this study was done.

Field experiment was conducted during summer season, 2019 at Western block, Horticultural College and Research Institute, Periyakulam, Tamil Nadu located at 10^0.13' N, 77^0.59' E and at an altitude of 289 m above mean sea level with average rainfall 791.1 mm. The soil was sandy loam having pH 7.1, organic carbon (0.26%), medium in available nitrogen (298 kg/ha), low in available P (10.4 kg/ha) and medium in available potash (220 kg/ha). The field experiment was carried out in randomized block design with three replications. The experiment consisted of eight treatments, *viz*. pre-emergence application (PE) of pendimethalin 1.0 kg/ha, pendimethalin 1.0 kg/ha (PE) + one hand weeding on 30 days after transplanting (DAT), oxyfluorfen 0.25 kg/ha (PE), oxyfluorfen 0.25 kg/ha (PE) + one hand weeding on 30 DAT, rice straw mulch (5 t/ ha), black polythene mulch (50-micron thickness), two hand weeding (on 30 DAT and 60 DAT) and unweeded control. Tomato variety *PKM 1* was used for this study. The seedlings were tranplanted at a spacing of 60 x 45 cm. The crop was fertilized with N, P, K 60, 80, 60 kg/ha, respectively. The nitrogen was applied in the form of urea, P in the form of single super phosphate, K in the form of muriate of potash. The half of nitrogen was applied at the time of transplanting. The remaining nitrogen was applied in two split of 1/4 nitrogen at the time of flowering and fruit formation respectively. The number of irrigation was 2-3 per week depending up on the demand of the crop. Required quantity of herbicides pendimethalin and oxyfluorfen was calculated and were applied with manually operated knap sack sprayer delivering a spray volume of 500 litres of water per hectare on 3 DAS.

Rice straw mulch was applied 5 t/ ha immediately after transplanting. Black polythene mulch (50-micron thickness) was used for this study. Tomato seedlings were transplanted immediately after laying black polythene mulch sheets. Hand weeding was done on 30 DAT and 60 DAT in the respective treatments. Data on density and biomass of weeds were recorded at 15, 30, 45 and 60 DAT with the help of 0.25 m^2 quadrate selected randomly in each plot. After identifying, the weed species were grouped into monocotyledons and dicotyledons separately. Weed density was calculated on the basis of the total number of an individual weed species/m^2. On the basis of weed data, weed indice like weed control efficiency was computed. Observations on growth, yield attributes and yield of tomato were recorded and the data were statistically analysed for interpretation.

Economics were calculated based on the prevailing market price of the tomato and labour wages/man day. The data recorded on various parameters during the course of investigation and the summed-up data were statistically analyzed following the analysis of variance for randomized block design as suggested by Gomez and Gomez (1984).

Weed flora

The weed flora observed in the experimental field during the course of study consisted of grasses, sedges and broad-leaved weeds. *Cynodon dactylon* and *Dactyloctenium aegyptium* in grasses, *Cyperus rotundus* in sedges, *Cleome viscosa, Euphorbia hirta, Trianthema portulacastrum, Sida acuta, Amaranthus viridis, Boerhavia diffusa, Eclipta alba, Phyllanthus niruri and Parthenium hysterophorus* in broad leaved weeds were observed in the experimental field. The predominant weeds were sedges followed by broad-leaved weeds and grasses. *Cyperus rotundus, Trianthema portulacastrum* and *Cynodon dactylon* were the dominant weed species in their sedges (24.7%), broad-leaved (35.8%) and grassy (39.5%) at 60 DAT, respectively.

Weed density, biomass and weed control efficiency

Weed management practices significantly influenced the weed density at all stages of observations, *viz.* 15, 30, 45 and 60 DAT (**Table 1**). Among different weed management practices, at 15 DAT, application of rice straw mulch 5 t/ha and black polythene mulch recorded significantly lowest weed density followed by pre-emergence application of pendimethalin 1.0 kg/ha and pre-emergence application of pendimethalin 1.0 kg/ha + one hand weeding at 30 DAT. The highest weed population was observed in unweeded control as also observed by Chaudhari and Patel (2018). Lower total weed density and biomass on 30 DAT was observed with the application of rice straw mulch 5 t/ha, black polythene mulch, two hand weeding at 30 and 60 DAT, pre-emergence application of pendimethalin 1.0 kg/ha + one hand weeding at 30 DAT and pre-emergence application of oxyfluorfen 0.25 kg/ha + one hand weeding at 30 DAT. Rice straw mulch and black polythene mulch did not allow the weeds to grow as recorded by Monks *et al.* (1997). Similarly, the treatments receiving pre-emergence application of herbicide (pendimethalin or oxyfluorfen) followed by one hand weeding recorded lower weed density due to better control of early emerging weeds by PE herbicides. (**Table 1**).

Similarly, observation at 45 and 60 DAT showed that significantly lower total weed density, biomass and weed control efficiency was recorded with black polythene mulch. It was followed by rice straw

Table 1. Effect of weed management treatments on weed density in tomato at 15, 30, 45 and 60 DAT

Treatment	Total weed density (no./m^2)			
	15 DAT	30 DAT	45 DAT	60 DAT
Pendimethalin 1.0 kg/ha (PE)	5.09(26.0)	8.08(65.3)	8.80(77.6)	9.09(82.7)
Pendimethalin 1.0 kg/ha (PE) + one hand weeding at 30 DAT	5.29(28.0)	1.22(1.5)	3.64(13.3)	4.89(24.0)
Oxyfluorfen 0.25 kg/ha (PE)	5.70(32.6)	8.36(70)	9.25(85.6)	9.87(96.7)
Oxyfluorfen 0.25 kg/ha (PE) + one hand weeding at 30 DAT	5.91(35.0)	1.22(1.5)	4.27(18.3)	5.19(26.9)
Rice straw mulch 5 t/ha	1.22(1.5)	1.22(1.5)	1.73(3.0)	3.16(10.0)
Black polythene mulch	1.22(1.5)	1.22(1.5)	1.22(1.5)	2.77(7.7)
Two hand weeding at 30 and 45 DAT	10.93(119.6)	1.22(1.5)	4.42(19.6)	3.10(9.66)
Unweeded control	13.32(177.6)	13.96(195.0)	15.21(231.6)	15.87(252.0)
LSD (p=0.05)	0.137	0.241	0.135	0.148

*Data in parentheses are original values. Data are subjected to ($\sqrt{x+0.5}$) transformation.

Table 2. Effect of weed management treatments on weed biomass and weed control efficiency in tomato

Treatment	Weed biomass (g/m^2)				Weed control efficiency (%)			
	15 DAT	30 DAT	45 DAT	60 DAT	15 DAT	30 DAT	45 DAT	60 DAT
Pendimethalin 1.0 kg/ha (PE)	3.4(11.7)	5.9(35.3)	6.8(46.6)	8.0(64.5)	85.3	66.5	66.4	65.8
Pendimethalin 1.0 kg/ha (PE) + one HW at 30 DAT	3.5(12.06)	1.22(1.5)	2.8(8.0)	4.2(18.0)	84.2	100	94.2	90.4
Oxyfluorfen 0.25 kg/ha (PE)	3.8(14.7)	6.1(37.8)	7.2(51.4)	6.1(37.0)	81.6	64.1	63.3	80.4
Oxyfluorfen 0.25 kg/ha (PE) + one HW at 30 DAT	4.0(15.75)	1.22(1.5)	3.3(11)	4.5(20.2)	80.2	100	92.1	89.2
Rice straw mulch 5 t/ha	1.22(1.5)	1.22(1.5)	1.18(1.4)	2.2(5.0)	99.5	99.4	99.5	97.3
Black polythene mulch	1.22(1.5)	1.22(1.5)	0.7(0.5)	2.4(5.75)	99.5	99.4	98.4	96.9
Two hand weeding at 30 and 45 DAT	7.3(53.25)	1.22(1.5)	3.4(11.8)	2.7(7.25)	32.6	99.4	91.5	96.1
Unweeded control	8.9(79.75)	10.3(105.3)	11.8(139.0)	13.7(189.0)	0	0	0	0
LSD (p=0.05)	0.098	0.139	0.199	0.205				

*Data in parentheses are original values. Data are subjected to ($\sqrt{x+0.5}$) transformation

Table 3. Effect of weed management treatments on growth and yield parameters of tomato

Treatment	Plant height (cm)	No. of fruits/plant	No. of branches	Fruit yield/ plant (kg)	Fruit yield/ Plot (kg)	Fruit yield (t/ha)
Pendimethalin 1.0 kg/ha (PE)	88.7	13.9	26.4	0.648	23.32	20.3
Pendimethalin 1.0 kg/ha (PE) + one HW at 30 DAT	90.1	16.8	27.5	0.661	23.81	22.7
Oxyfluorfen 0.25 kg/ha (PE)	87.1	14.3	24.8	0.634	22.84	20.1
Oxyfluorfen 0.25 kg/ha (PE) + one HW at 30 DAT	89.3	16.2	26.1	0.658	23.71	22.5
Rice straw mulch 5 t/ha	91.3	18.3	29.6	0.707	25.46	23.2
Black polythene mulch	95.8	28.2	32.2	0.800	27.31	28.1
Two hand weeding at 30 and 45 DAT	90.4	17.2	28.3	0.675	24.30	22.8
Unweeded control	65.3	6.8	16.2	0.590	21.38	7.5
LSD (p=0.05)	2.80	1.2	1.10	0.15	1.30	2.80

Table 4. Effect of weed management treatments on yield and economics of tomato

Treatment	Fruit yield (t/ha)	Cost of cultivation (x10^{3} `/ha)	Gross return (x10^{3} `/ha)	Net return (x10^{3} `/ha)	BC ratio
Pendimethalin 1.0 kg/ha PE	20.3	75.24	203.00	127.76	2.70
Pendimethalin 1.0 kg/ha + one hand weeding at 30 DAT	22.7	80.94	227.00	146.06	2.80
Oxyfluorfen 0.25 kg/ha PE	20.1	74.55	201.00	126.45	2.70
Oxyfluorfen 0.25 kg/ha PE + one hand weeding at 30 DAT	22.5	80.51	225.00	144.49	2.79
Rice straw mulch 5 t/ha	23.2	78.09	232.00	153.91	2.97
Black polythene mulch	28.1	90.37	281.00	190.63	3.11
Two hand weeding at 30 and 45 DAT	22.8	83.17	228.00	144.83	2.74
Unweeded control	7.5	72.37	75.00	2.63	1.04

mulch 5 t/ha. Among the herbicide treatments, pre-emergence application of pendimethalin 1.0 kg/ha + one hand weeding at 30 DAT recorded lower total weed density and biomass during 45 and 60 DAT. (**Table 1 and 2**). These results are in accordance with Rajan *et al*. (2017). Highest weed density and biomass was recorded in unweeded control at all stages of observation (**Table 1** and **2**). Similar observations were made by Aman and Rab (2013).

Effect on yield and economics

Significantly higher plant height and number of branches was recorded with application of black polythene mulch and was followed by rice straw mulch 5 t/ha and lowest was with unweeded control. These results are in conformity with the findings of Ranjan *et al*. 2017. Black polythene mulch recorded significantly higher fruit yield per plant and fruit yield per hectare. This treatment recorded higher fruit yield of 28.1 t/ha (**Table 3**). This was due to better control of weeds and lower weed dry matter production and higher weed control efficiency and there by higher plant growth and yield parameters. This was followed by rice straw mulch 5 t/ha. Pre-emergence application of Pendimethalin or oxyfluorfen followed by one hand weeding on 30 DAT and two hand weeding on 30 and 45 DAT also recorded higher plant growth and yield attributes.

The treatment on black polythene mulch recorded significantly higher fruit yield per ha and thereby this treatment recorded higher economic returns. This treatment recorded higher net returns (₹ 190630/-) and BC ratio (3.11) (**Table 4**). Though the cost of cultivation was higher under black polythene mulch, the economics returns realised were found to more due to better control of weeds and there by higher fruit yield. This was followed by rice straw mulch 5 t/ha and this treatment recorded higher net return of ₹ 153911 and B:C ratio of 2.97 (Srinivasa Reddy 2015).

REFERENCES

Aman S and Rab A. 2013. Response of tomato to nitrogen levels with or without humic acid. *Sarhad Journal of Agriculture* **29**(2): 181–186.

Anonymous. 2017. Indian Horticultural database. www.nhb.gov.in

Behera B and Singh GS. 1999. Studies on weed management in monsoon season crop of tomato. *Indian Journal of Weed Science* 31(1&2): 67–70.

Chaudhari HC and Patel SY. 2018. Effect of different weed management practices on growth and yield of tomato. *Environment and Ecology* **37**(1): 139–142.

Gomez KA and Gomez AA. 1984. Statistical Procedures for Agricultural Research. 2nd Edn. John Wiley and Sons. New York. U.S.A.

Monks CD, Monks DW, Basden T Selders A, Poland S and Rayburn E. 1997. Soil temperature, soil moisture, weed control, and tomato (*Lycopersicon esculentum*) response to mulching. *Weed Technology* **11**(3): 561–566.

Ranjan P, Patle GT, Prem M, Solanke KR. 2017. Organic Mulching- A Water Saving Technique to Increase the Production of Fruits and Vegetables. *Current Agricultural Research* **7**: 5(3).

Srinivasa Reddy. 2015. Weed management in Tomato (*Solanum lycopersicum* L.) - Radish (*Raphanus sativus* L.) Cropping System. Thesis.Department of Horticulture. University of Horticulture. Bangalore.