Indian Journal of Weed Science

Print ISSN 0253-8040
Online ISSN 0974-8164

Volume – 51 | Number – 2
April – June, 2019

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 51 | Number 2 | April – June, 2019

Review article

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.

Indian Journal of Weed Science **51**(2): 101–105, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Potentials of water hyacinth as livestock feed in Sri Lanka

H.D.A. Wimalarathne[2] and P.C.D. Perera[1*]

[1]*Department of Agricultural Biology, Faculty of Agriculture, University of Ruhuna, Kamburupitiya, Sri Lanka*

[2]*Department of Food Technology, Sri Lanka German Training Institute, Kilinochchi, Sri Lanka*

**Email: chathuradineth2@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00024.8

Type of article: Review article

Received : 1 February 2019
Revised : 2 June 2019
Accepted : 4 June 2019

Key words
Eichhornia crassipes
Invasive weed
Livestock feeds
Weeds

ABSTRACT

Eichhornia crassipes or universally known as Water hyacinth (WH) is considered as one of the noxious and invasive plants with a high growth rate and vigorous reproductive capacity. Due to these characteristics, this plant causes severe ecological, economic and social problems in many tropical and subtropical countries. Currently, many countries like India, China, Vietnam *etc*., convert this aquatic invasive plant into a beneficial plant to solve serious environmental problems. WH is an excellent source in absorbing nutrients and pollutants from eutrophic/polluted waters. Moreover, WH biomass is used to produce bio-energy, feed and fertilizers. This review discusses the potential of using WH as a livestock feed in Sri Lanka. Sri Lanka is an agricultural country and livestock plays a major role in the society. The non-availability of quality pasture/fodder and shortage of improved pasture/fodder have been identified as one of the major causes for the poor production of milk and meat. But WH has been successfully utilized over the decades as a livestock feed by other countries for ruminants, swine, ducks, geese and fish due to its high crude protein content and progressive growth. Along with the relevant treatments and proper inclusion level to the main ration, this plant is a feasible alternative to rice straw and other low-quality roughages. WH shows an island-wide distribution in Sri Lanka inhabiting freshwater bodies such as tanks, canals, marshes, ponds *etc*. There is a greater opportunity of utilizing this plant to reduce the feed shortage in Sri Lanka ton livestock. Apart from biological, chemical and mechanical control methods, utilizing water hyacinth as a livestock feed is one of the better approaches out of many productive ways of controlling the growth of this plant.

INTRODUCTION

Over the centuries, water hyacinth (*Eichhornia crassipes*) has altered from a beautiful ornamental plant to an invasive alien species that negatively impacted natural aquatic systems (Yan and Guo 2017). Currently WH causes severe complications in at least 62 countries in the regions between 40° N and 45° S (Yan and Guo 2017) and already naturalized in Central America, Africa, Asia, Australia and New Zealand (Ramey 2001). Moreover, this plant has made severe complications such as obstructing the water transportation, providing habitat for disease vectors, reducing biodiversity and obstructing the fishing activities (Ndimele *et al.* 2011). Tham (2016) revealed that all tropical and sub-tropical countries have been infested with *Eichhornia crassipes* and is considered as one of the world's most invasive aquatic plants. Water hyacinth (WH) shows an island-wide distribution in Sri Lanka inhabiting freshwater bodies such as tanks, canals, marshes, ponds, *etc*. (Bambaradeniya 2002).

WH belongs to Family Pontederiaceae is a free floating aquatic plant. It forms two distinct canopies such as leaf canopies above the water and root canopies below the water surface (Downing-Kunz and Stacey 2012). Roots, rhizomes, leaves, inflorescences, stolons and first clusters are the main constituents of a mature WH plant (Penfound and Earle 1948). WH petioles may grow up to 60 cm long and bear flowers while stolons grow horizontally (about 10 cm) and produce new plants from the terminal buds (Parsons and Cuthbertson 2001). To enable the floating of the plant in water is facilitated by the leaf stalks with bladder-like swellings consisting of large air cells (Parsons and Cuthbertson 2001). WH have mauve coloured six petals flowers (Tham 2012) with massive fibrous root system (Tham 2012) which are able to absorb the nutrient even in a low nutrient water body (Xie and Yu 2003).

Livestock plays an immense role in Sri Lankan agriculture. The agriculture sector's contribution to the National Gross Domestic Production (GDP) had been reduced to 7.9% in 2015 (Central Bank of Sri Lanka 2015) and the contribution of the livestock sector is recorded as 0.6% to the National GDP (Livestock Statistical Bulletin 2015). According to the Department of Census and Statistics (2017), Sri Lanka had 21.2 million chicken, 1.0 million cattle, and 0.3 million buffaloes followed by swine (0.1 million), goats/sheeps (0.23 million), and ducks (0.01 million) as the main livestock species in 2017.

In a global context, the current status of the livestock sector in Sri Lanka is performing underneath the desired expectations due to many reasons. The non-availability of quality pasture/ fodder and shortage of improved grass (pasture seeds) and lands for grass cultivation has been considered to be one of the major bottlenecks in livestock production in Sri Lanka (Houwers *et al.*2015). Perera and Jayasooriya (2008) revealed that seasonal scarcities of green fodder and unbearable cost of concentrates are the main reasons for hindering the growth of the dairy sector in Sri Lanka. Further, they found that the quality and quantity of available forage also fluctuates due to highly seasonal rainfall in many parts of the country affecting the milk yield and lactation length of both cattle and buffalo. Therefore, it is vital to adopt a system where we can obtain fodder and other feed sources for an annual cycle rather than dry and wet season feeding.

Water hyacinth invasion in Sri Lanka

In 1904, the WH was introduced in Sri Lanka as an ornamental aquatic plant, however the plant was distributed in water bodies profusely and threatening the natural aquatic ecosystems in Sri Lanka (Room and Fernando 1992). WH was considered as a prohibited weed in 1909, which was incorporated under the Plant Protection Act in 1924 (FAO 2018). Perera and Dahanayake (2015) revealed that WH and Salvinia *(Salvinia molesta*) profusely dominating in rural and urban eutrophic waterways in Sri Lanka. Sri Lanka is an agricultural country, therefore, irrigation in the dry period is strictly relying on the small tanks and reservoirs. Due to its excessive growth, vigorous reproductive capacity it considerably reduce the productivity of inland water bodies and increase the cost for regular maintenance of reservoirs, irrigation networks, lakes and rivers as well. Moreover, decaying the biomass of WH leads to deteriorate the water quality and aquatic life. The excessive surface covering by water hyacinth of water reservoirs limit the sunlight penetration and decrease the contact with air which leads to decrease the dissolved oxygen concentration which badly affect inland fisheries and aquatic biodiversity. Bambaradeniya (2002) reported that dense mats of WH and *Salvinia* directly inclined by the sedimentation on a greater scale. This cause reduction of water through evapotranspiration also from the reservoirs and converted the wetlands into terrestrial habitats. Bambaradeniya (2002) was of the opinion that letting these aquatic invasive plants established in water ecosystem will reduce and narrow down the native biological diversity.

Chemical composition of water hyacinth

Fresh WH contains about 90% water and 15-20% solid materials (Ndimele *et al.* 2011). Further Ndimele *et al.* (2011) reported that on a dry weight basis, the weed contains about 23-25% protein-related matter. Men *et al.* (2006) revealed that higher the proportion of protein can be found in immature leaves and petioles of the WH than in mature plants. Essential amino acids like glutamine, asparagine and leucine are rich in leaves of WH (Virabalin *et al.*1993) as well. Several studies revealed that the chemical composition of WH varies with season, habitat and fraction of the weed (Poddar *et al.* 1981, Tucker *et al.*1981; Abdelhamid 1991). According to Men *et al.* (2006) percentages of dry matter, crude protein, crude fibre and ash content of water hyacinth were 6.8±0.76,18.6±0.71, 21.4±0.85 and 16.7±1.95, respectively. He reported that the metabolic energy of fresh WH was 2000 kcal/kg. WH is also considered as a carrier of heavy metals such as iron, magnesium and zinc, due to which this weed is used for phytoremediation (Ndimele 2003).

Feed for ruminants

Countries like China, India and Vietnam were able to convert WH as a resource with various kinds of applications. Usage as a source of biogas, animal feed and bio fertilizers are commonly found applications of WH (Bagnal *et al.* 1974, Shiralipour and Smith 1984). Many scientists had conducted experiments to utilize WH as animal feed for cattle, sheep, geese, pigs, *etc*. either in silage form or fresh form. This plant can be utilized to overcome the feed shortage in Sri Lankan livestock due to its high crude protein content and progressive growth along with the relevant treatments. Not only as a livestock feed, but in some countries WH is also used as a vegetable for humans as well. Nguyen (1996) reported that WH flowers are used as a food source in Vietnam.

Due to its high levels of cellulose and hemicellulose, Mukherjee and Nandi (2004) suggested the possibility of using it as a feed for ruminants. Eldin (1992) mentioned that the minimum amount of crude protein content in fodder for ruminants should be 9%. Aboud *et al.* (2005) found that leaves and shoots of WH contained 18% of crude protein which can be utilized for the young or lactating ruminants, feeding as fresh and as a sole diet can cause severe digestive problems to ruminants. Bolenz *et al.* (1990) revealed that due to the presence of intercellular spaces filled with air in WH and soaking up rumen juices inside their intercellular spaces while digesting, leads to excessive water consumption by the ruminants. Moreover, the tissues of the digestive tract can be damaged by the microscopic sharp needles present in the WH. Further, these needles are formed of calcium oxalate,which discourages the feed intake and causes mouth irritation in livestock. Abdelhamid and Gabr (1991) reported that if WH is offered as a sole diet to the ruminants, the death can be occurred by tetany due to the changes in blood profile in severe cases. But these problems can be eliminated by several treatments. Chopping the WH into fine pieces to remove the air in the tissues to eliminate the growth of aerobic moulds during the fermentation and washing the bagasse with acid to eliminate acid-soluble calcium oxalate after separating the soluble tissue components (juice) by pressing and centrifuging one of the methods to make it utilizable (Bolenz *et al.* 1990). But the acids wash process replaced by the fermentation (Yan and Guo 2017).

According to the Paddy statistic (2014/2015) by the Department of Census and Statistics in Sri Lanka, only 3% of total rice straw production is used as a livestock feed. But, under currently practiced feeding systems at small farms in Sri Lanka rice straw is not pre-treated for improving the feeding value of straw. Tham and Uden (2013) revealed that ensiled WH had >3 times higher protein content and 24% lower neutral detergent fibre than rice straw and suggested that ensiled WH is more favourable than rice straw to animals due to this reason. Further, they reported that formulated WH can be a good feed for cattle with the highest digestibility of 72% for organic matter, 75% for crude protein, 62% for neutral detergent fibre and 49% for acid detergent fibre as well. Baldwin *et al.* (1974) found that cattle immediately accepted the ensiled WH after gradual adaptation. This suggests that with the proper ensiling of WH it can be replaced as feed material to ruminants. Sunday (2002) recommended the utilization of sun-dried WH biomass at 40% of goat feed. Abdelhamid and Gabr (1991) suggested that using WH biomass as roughage for ruminants, crude protein content of 200 g/kg dry matter can be obtained. Sunday (2002) reported that 40% sun-dried WH inclusion was greater than the efficiencies of goats fed with 30% sun-dried WH inclusion. Moreover, the mean final weights of the goats fed with 40% sun-dried WH were significantly higher (P>0.05) than the similar (P>0.05) weights of goats which fed 30% sundried WH inclusion. Hence utilization of sun-dried WH by growing goats up to 40% dietary level of inclusion is beneficial. Tag EI-Din (1992) revealed that average daily weight gain of sheep can be greatly reduced by providing WH as a sole diet, however substituting the bean straw up to 30% with WH didn't affect the growth rate of sheep. WH also had been utilized as an ensiled product for ruminants. Tham and Uden (2013) tested different additives (molasses, rice bran, inoculants of fermented vegetable juice and their combinations) with WH biomass for silage production. Agarwala (1988) reported that incorporation of molasses, rice straw and urea with WH silage, forms a palatable cattle feed fulfilling the adequate amount of protein need to calves. Byron *et al.* (1975) suggested to add acids adequately to obtain the quality silage. WH silage diet produced an average daily weight gain of 104–145 g/d (Bai *et al.* 2010, 2011). Chakraborty *et al.* (1991) found that feeding dairy cattle with an ensiled mixture of WH, rice straw and molasses had shown an increase in milk yield. Bagnall *et al.* (1974) suggested to preserve the silage of water hyacinth for future use.

Feed for non-ruminants

For pig: The high cost of concentrated feed and non-availability of feed ingredients has also been identified as major constraints for pig producers in Sri Lanka (Wickramaratne 2002). Pig has a well-developed large intestine; hence a wide range of materials including some fibre can be digested (Gunaratne *et al.* 2009). Exploiting this advantage, the farmers use many low quality materials in pig feeding. Several studies had been conducted to find the potential of non-conventional feed materials in pig feeding including *Colocasia* yams (Ravindran 1987), kapok seed meal (Ganegoda and Siriwardena 1978), arrack distillery spent wash (Ganegoda 1983) and Eppawala rock phosphate (Ganegoda *et al.* 1986). However, inadequate studies have been done to evaluate WH as a feeding material for pig in Sri Lanka. Feeding boiled and chopped WH with rice bran, vegetables, copra cake and salt has been practiced for years as a feeding material for swine by Chinese pig farmers (Ndimele *et al.* 2011). Further he reported that WH can become a worthy feeding material for pigs, ducks and pond fish after cooking fresh WH with rice bran, fishmeal and mixing with copra meal. A study conducted by Men *et al.* (2006) revealed that pig had shown good acceptance for WH and the pigs fed on WH based diets had better carcass appearance than the common diet-fed pigs in Vietnam, because, pork exhibited low back-fat and body fat with excellent meat productivity (Choi 2004, Kim 2012). Inclusion of 5-15% of WH biomass in the pig feed did not affect daily gain in feed intake, fat thickness and loin eye area compared to control (Cui *et al.* 2004). Broiler diets with 3–7% dry WH did not have negative effects on the average daily gain, feed efficiency and carcass performance (Xie *et al.* 1999).

Poultry feed: Poultry production is the rapidly growing sector in the globe as well as in Sri Lanka (Prabakaran 2003). Chicken are considered mostly consumed animal protein source among Sri Lankans (Silva *et al.* 2010). Most of the farmers rely on commercial poultry feed and self-mixed feed to feed chicken. Ducks and geese are the least types of poultry in Sri Lanka. Several studies have been conducted to utilize WH. Lu *et al.* (2008) reported that when ducks were fed 50 g fresh WH per day for a month, they showed better daily feed intake and higher egg-laying capacity in the treatment group compared to the control group. Further, he found that not only the feed intake was enhanced, but also the egg production performance, eggshell thickness, level of feed digestion and utilization were increased after feeding freshwater hyacinth. This emphasized that adding WH roughage in diet can reduce production costs without decreasing the productivity and economic return. However, Men and Yamasaki (2005) found that a replacement of 5 to 25% of a commercial diet by fresh WH to growing ducks decreased performance, but was economically profitable due to the lower feed cost.

Animal feed: Even WH is a good potential for animal feed based on the nutrient value, however this plant may contain toxic materials from the source of biomass. The heavy metals like cadmium (Cd), chromium (Cr), lead (Pb) and mercury (Hg), and metalloids such as arsenic (As) and fluorine (F) can be absorbed by WH because of having greater capacity in adsorbing, absorbing and accumulating heavy metals (Zhou *et al.* 2005, Shi and Zhao 2007). Roots have three times high capacity to hold and transport the toxic elements than the other parts and tissues of WH (Yan and Guo 2017). They suggested that WH growing in industrial waste water and in waters surrounding mining areas may be unsafe to utilize as feed.

It can be concluded that utilizing WH as a livestock feed is one of the better approaches out of many other ways of controlling the growth of this plant. Unlike Sri Lanka, countries like China, India, Vietnam have already identified the tremendous potential of WH using as a livestock feed after proper treatment and inclusion levels.

REFERENCES

Abdelhamid AM and Gabr AA. 1991. Evaluation of water hyacinth as a feed for ruminants. *Archiv für Tierernaehrung* **41**(7-8): 745–756.

Aboud AAO, Kidunda RS and Osarya J. 2005: Potential of water hyacinth (*Eicchornia crassipes*) in ruminant nutrition in Tanzania. *Livestock Research for Rural Development. Vol. 17, Art. #96*. Retrieved July 28, 2019, from http://www.lrrd.org/lrrd17/8/abou17096.htm Agarwala ON. 1988. Water hyacinth (*Eichhornia crassipes*) silage as cattle feed. *Biological wastes* **24**: 71–73.

Bagnall LO, Baldwin JA and Hentges JF. 1974. Processing and storage of water hyacinth silage. *Hyacinth Control Journal* **12**(12): 73–79.

Bai YF, Zhou WX, Yan SH, Liu J, Zhang H and Jiang L. 2010. Effects of feeding water hyacinth silage on lambs fattening. *Jiangsu Journal of Agricultural Sciences* **26**(5): 1108–1110.

Bai YF. 2011. Ensilaging water hyacinth: effects of water hyacinth compound silage on the performance of goat. *Chinese Journal of Animal Nutrition* **23**(2): 330–335.

Baldwin JA, Hentges JF, Bagnall LO. 1974. Preservation and cattle acceptability of water hyacinth silage. *Hyacinth Control Journal* **12**: 79–81.

Bambaradeniya CN. 2002. The status and implications of alien invasive species in Sri Lanka. *Zoos' Print Journal* **17**(11): 930–935.

Bolenz S, Omran H and Gierschner K. 1990. Treatments of water hyacinth tissue to obtain useful products. *Biological Wastes* **33**(4): 263–274.

Byron HT, Hentges JF, O'Connell JD and Bagnall LO. 1975. Organic acid preservation of water hyacinth silage. *Journal of Aquatic Plant Management* **13**: 64.

Chakraborty B, Biswas P, Mandal L and Banerjee GC. 1991. Effect of feeding fresh water hyacinth (*Eichhorinia crassipes*) or its silage on the milk production in crossbred cows. *Indian Journal of Animal Nutrition* **8**(2):115–118.

Central Bank of Sri Lanka.2015 *Annual Report*. Central Bank of Sri Lanka, Colombo.

Choi YS.2004. *Studies On The Pork Quality Of Korean Native Black Pigs And Its Improvement Through Dietary Manipulation*. Ph.D. thesis. Kangwon National Univ.; Chuncheon, Korea.169 p.

Cui L, Xiao H, Chen L, Xu Y, Huang Y and Chu J. 2004. Feeding effects of water hyacinth from Lake Dinshan on swine fattening. *Feed Industry* **25**(3) 39–40.

Department of Census and Statistics.2014/2015. *Paddy statistic*. Department of Census and Statistics, Colombo.

Downing-Kunz MA and Stacey MT. 2012. Observations of mean and turbulent flow structure in a free-floating macrophyte root canopy. *Limnology and Oceanography: Fluids and Environments* **2**: 67–79.

Eldin AT. 1992. Utilization of water-hyacinth hay in feeding of growing sheep. *Indian Journal of Animal Sciences* **62**(10): 989–992.

FAO. 2018. Plant Production and Protection Division: Sri Lanka - Water weeds. Available from URL at: http://www.fao.org/agriculture/crops/thematicsitemap/theme/biodiversity/weeds/issues/sri-ww/en/. Accessed 24 August 2018.

Ganegoda GAP and Siriwardena JADS. 1978. Effect of feeding kapok seed meal to growing pigs and broiler chickens.*Ceylon Veterinary Journal* **26**: 53.

Ganegoda GAP. 1983. Feeding value of arrack distillery spent wash for pigs. *The Sri Lanka Veterinary Journal* **31**(1/2): 43–45.

Ganegoda GAP, Gunaratne SP, Gunatilake AAP.1986. Evaluation of Eppawala Rock Phosphate as phosphorus supplement in diets for growing chickens and pigs. *Journal of the National Science Council of Sri Lanka* **14**: 251–260.

Houwers W, Wouters B andVernooij A. 2015. Sri Lanka fodder study; An overview of potential, bottlenecks and improvements to meet the rising demand for quality fodder in Sri Lanka. Lelystad, Wageningen UR (University and Research Centre) Livestock Research, *Livestock Research Report* 924.

Jianbo LU, Zhihui FU and Zhaozheng YIN. 2008. Performance of a water hyacinth (*Eichhornia crassipes*) system in the treatment of wastewater from a duck farm and the effects of using water hyacinth as duck feed. *Journal of Environmental Sciences* **20**(5): 513–519.

Kim GW. 2012. Analysis of carcass quality grades according to gender, back fat thickness and carcass weight in pigs. *Korean Journal Animal Science Technology***54**:29–33.

Livestock and Poultry Statistics. 2017. Department of Census and Statistics. Ministry of Finance and Planning; Colombo Sri Lanka Available from URL: http://www.statistics.gov.lk/agriculture/Livestock/LivestockStatistics.html. Accessed 20 July 2018.

Gunarathne SP, Chandrasiri ADN and Gajanayake S. 2009. Small holder pig production. pp. 189–212. In: *Livestock for Rural Development and Poverty Reduction: Sri Lankan Experience*. Hector Kobbekaduwa Agrarian Research and Training Institute.

Men BX and Yamasaki S. 2005. Use of water hyacinth as partial supplements in diets of growing crossbred common ducks. Pp. 83–90. In: *Proceedings of the Workshop on the Technology Development for Livestock Production*, JIRCAS - CTU; Can Tho University, Vietnam..

Men LT, Yamasaki S, Caldwell JS, Yamada R, Takada R and Taniguchi T. 2006. Effect of farm household income levels and rice-based diet or water hyacinth (*Eichhornia crassipes*) supplementation on growth/cost performances and meat indexes of growing and finishing pigs in the Mekong Delta of Vietnam. *Animal Science Journal* **77**(3): 320–329.

Mukherjee R and Nandi B. 2004. Improvement of in vitro digestibility through biological treatment of water hyacinth biomass by two Pleurotus species. *International Biodeterioration and Biodegradation* **53**: 7–12.

Ndimele PE, Kumolu-Johnson CA and Anetekhai MA. 2011. The invasive aquatic macrophyte, water hyacinth {*Eichhornia crassipes* (Mart.) Solm-Laubach: Pontedericeae}: problems and prospects. *Research Journal of Environmental Sciences* **5**(6): 509–520.

Ndimele PE. 2003. *The Prospect Of Phytoremediation Of Polluted Natural Wetlands By Inhabiting Aquatic Macrophytes (Water Hyacinth).* M.Sc. Thesis, University of Ibdan, Nigeria.

Nguyen NXD. 1996. *Identification And Evaluation Of Non-Cultivated Plants Used For Livestock Feed In The Mekong Delta Of Vietnam*. M.Sc.Thesis.

Parsons WT and Cuthbertson EG. 2001. Noxious Weeds of Australia (2nd edition)., CSIRO Publishing, Collingwood, Victoria, Australia, 139–144.

Penfound WT and Earle TT. 1948. The biology of the water hyacinth. *Ecological Monographs* **18**(4): 447–472.

Prabakaran R. 2003. *Good practices in planning and management of integrated commercial poultry production in South Asia (No. 159).* Food and Agriculture Organisation.

Perera BMAO and Jayasuriya M. 2008. The dairy industry in Sri Lanka: current status and future directions for a greater role in national development. *Journal of the National Science Foundation of Sri Lanka* **36:** 115–126.

Perera PCD and Dahanayake N. 2015. Review of major abundant weeds of cultivation in Sri Lanka. *International Journal of Scientific and Research Publications* **5**(5): 1–9.

Poddar K, Mandal L and Banerjee GC. 1991. Studies on water hyacinth (*Eichhornia crassipes*) – Chemical composition of the plant and water from different habitats. *Indian Veterinary Journal* **68***:* 833–837.

Ravindran V. 1987. Evaluation of wild colocasia corn meal in diets for growing pigs. *Sri Lanka Veterinary Journal* **35**(1-2): 25–31.

Ramey V. 2001. *Water-hyacinth*. Florida Department of Environmental Protection. Florida: Florida Department of Environment Protection. http://plants.ifas.ufl.edu/node/141.

Room PM and Fernando IVS. 1992. Weed invasions countered by biological control: *Salvinia molesta* and *Eichhornia crassipes* in Sri Lanka. *Aquatic Botany* **42**(2): 99-107.

Shi Z and Zhao R. 2007. Accumulation of Cd^{2+}, Zn^{2+} by water hyacinth. *Fisheries and Water Conservation* **27**(4): 66–68.

Sunday AD. 2002. The utilization of water hyacinth (*Eichhornia crassipes*) by West African dwarf (Wad) growing goats. *African Journal of Biomedical Research* **4**: 147–149.

Shiralipour A and Smith PH. 1984. Conversion of biomass to methane gas. *Biomass* **6**: 85–94.

Tham HT. 2016. Utilisation of water hyacinth as animal feed. *Nova Journal of Engineering and Applied Sciences* **4**(1):1-16.-methyl against broadleaf weeds of wheat. *Indian Journal of Weed Science* **43**(1): 12–22.

Tham H.T.2012. *Water Hyacinth (Eichhornia Crassipes) – Biomass Production, Ensilability And Feeding Value To Growing Cattle*. Doctoral Thesis. Swedish University of Agricultural Sciences Uppsala.

Tham HT and Udén P. 2013. Effect of water hyacinth (*Eichhornia crassipes*) silage on intake and nutrient digestibility in cattle fed rice straw and cottonseed cake. *Asian-Australasian Journal of Animal Sciences* **26**(5): 646.

Tucker CS and Debusk TA.1981. Seasonal growth of *Eichhornia crassipes* (Mart.) solms: Relationship to protein, fiber, and available carbohydrate content. *Aquatic Botany* **11**: 137–41.

Virabalin R, Kositsup B and Punnapayak H.1993. Leaf protein concentrate from water hyacinth. *Journal of Aquatic Plant Management* **31**: 207–209.

Wickramaratne SHG. 2002. Present status of the pig industry in Sri Lanka. *Proceedings of the Seminar on "Path for the Development of Pig Industry" 2nd July 2002*, Swine Development Office, Department of Animal Production and Health (Western Province) Welisara, Ragama, Sri Lanka.

Xie Y and Yu D. 2003. The significance of lateral roots in phosphorus (P) acquisition of water hyacinth (*Eichhornia crassipes*). *Aquatic Botany* **75**(4): 311–321.

Xie P, Zhou X, Yang J, Zhu X, Zhang Y and Zhang J. 1999. Feeding effects of water hyacinth from Lake Dianchi on production of broiler. *Feed Industry* **20**(4):26–28.

Yan S and Guo JY. 2017. *Water Hyacinth: Environmental Challenges, Management and Utilization*. CRC Press.

Zhou W, Tan L, Liu D, Yan H, Zhao M and Zhu D. 2005. Research advances of *Eichhornia crassipes* and its utilization. *Journal of Huazhong Agricultural University* **24**(4): 423–428.

Indian Journal of Weed Science **51**(2): 106–110, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Effectiveness of triafamone + ethoxysulfuron (pre-mix) against complex weed flora in transplanted rice and its residual effects on wheat

Dharam Bir Yadav*, Ashok Yadav and S.S. Punia

CCS Haryana Agricultural University, Hisar, Haryana 125 004, India

**Email: dbyadav@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00025.X

Type of article: Research article

Received : 28 February 2019
Revised : 7 May 2019
Accepted : 9 May 2019

Key words

Complex weed flora

Ethoxysulfuron

Residual effects

Triafamone

Transplanted rice

ABSTRACT

Bio-efficacy of triafamone (20%) + ethoxysulfuron (10%) (ready-mix, 30% WG) was evaluated as early post-emergence (1-2 leaf stage of weeds, 15 days after transplanting) against complex weed flora in transplanted rice at CCS Haryana Agricultural University Regional Research Station, Karnal during *Kharif* 2011 and 2012, phyto-toxicity on transplanted rice during *Kharif* 2012 and 2013 and its residual phyto-toxicity on wheat during *Rabi* 2012-13 and 2013-14. Triafamone + ethoxysulfuron 60-67.5 g/ha proved superior or at par with other herbicidal treatments in reducing the dry weight of grassy and broad-leaf weeds to the extent of >99% and 85-94%, respectively, and provided almost complete control of sedges (*Cyperus difformis* and *Fimbristylis miliaceae*) during both the years. There was no significant effect of different treatments on the plant height and panicle length of the rice during both the years. Application of triafamone + ethoxysulfuron 60 g/ha resulted in number of effective tillers (58.7/mrl in 2011 and 78.2/mrl in 2012) at par with triafamone 45 g/ha, butachlor 1250 and 1500 g/ha, and also weed free check during both the years. The grain yield of rice (6.08 t/ha in 2011 and 7.06 t/ha in 2012) due to triafamone + ethoxysulfuron 60 g/ha was higher than its lower dose (52.5 g/ha) but at par with the higher dose (67.5 g/ha), triafamone 45 g/ha, butachlor 1500 g/ha and weed free check during 2011 and 2012; butachlor 1250 g/ha and pretilachlor 1000 g/ha during 2012; but superior to all other herbicidal treatments during both the years. There were no visual phyto-toxicity symptoms of triafamone + ethoxysulfuron on rice crop and also no residual phyto-toxicity on succeeding wheat crop even up to 120 g/ha.

INTRODUCTION

Weed infestation in transplanted rice has been reported to cause yield reductions of 27-68% in India (Singh *et al*. 2003, Yadav *et al*. 2009, Manhas *et al*. 2012, Duary *et al*. 2015, Hossain and Malik 2017). Most of the herbicides recommended for transplanted rice (butaclor, pretilachlor, anilofos and oxadiargyl) are applied as pre-emergence. But, dry spell or lack of irrigation particularly during initial growth stage after transplanting reduces the efficacy of pre-emergence herbicides and the crop suffers from serious infestation of complex weed flora. There is thus a need of some post-emergence herbicide with broad spectrum weed control. Bispyribac-sodium is currently the most commonly used herbicide for post-emergence (20-25 days after transplanting) control of weeds in transplanted rice (Yadav *et al*. 2009). Penoxsulam is another option as an early post-emergence (10-12 days after transplanting) herbicide in transplanted rice (Mishra *et al*. 2007, Yadav *et al*. 2008). However, it has been observed that single application of either pre-emergence or post-emergence herbicide does not provide effective control of complex weed flora throughout the crop season. Some of broad-leaf weeds and sedges are not controlled effectively by alone application of these herbicides. Farmers often use 2,4-D, metsulfuron + chlorimuron, ethoxysulfuron or pyrazosulfuron as sequential post-emergence herbicides, which add to the cost of weed management. Bispyribac-sodium and penoxsulam based combinations were found less effective against *Leptochloa chinensis* and *Ludwigia parviflora* as compared to premix of triafamone + ethoxysulfuron (Menon *et al*. 2016). Farmers desire to achieve satisfactory weed control through single shot application of ready-mix or tank-mix combination of compatible herbicides at reduced cost and energy. Therefore, information on bio-efficacy of herbicide combinations particularly new herbicides is essential to achieve more efficient weed management. The objective of the present investigation was to evaluate the bio-efficacy of triafamone + ethoxysulfuron (ready-mix) as post-emergence herbicide against complex weed flora in transplanted rice and also its residual effects in succeeding wheat crop.

MATERIALS AND METHODS

A field experiment was conducted to evaluate the performance of triafamone (20%) + ethoxysulfuron (10%) 30% WG against complex weed flora in transplanted rice at CCS HAU Regional Research Station, Karnal during *Kharif* 2011 and 2012. The treatments included triafamone + ethoxysulfuron at 52.5, 60, 67.5 g/ha, triafamone 20% SC 45 g/ha, ethoxysulfuron 15%WG 22.5 g/ha at 1-2 leaf stage *i.e.* 15 days after transplanting (DAT), butachlor 50% EC 1250 or 1500 g/ha, pretilachlor 50%EC 625 or 1000 g/ha at 0-3 DAT, pyrazosulfuron ethyl 10% WP 15 g/ha at 15 DAT, along with weed free (two hand weedings at 25 and 45 DAT) and untreated checks. The experiment was laid out in randomized block design with three replications. Transplanting of rice cultivar *HKR 47* was done on 22 July, 2011 and 11 July 2012. The transplanting was done at a spacing of 20 x 15 cm in a plot size of 6.1 x 2.4 m. The post-emergence herbicides were applied as spray using knap-sack sprayer fitted with flat fan nozzle in a spray volume of 300 litres/ha, and the pre-emergence herbicides as sand mix broadcast using 150 kg sand/ha. Water was drained out at the time of application of the post-emergence herbicides and re-irrigated 24 hours after spray. Crop was raised as per the recommendations of the state University and harvested on 27 October, 2011 and 23 October, 2012. Density and dry weight of weeds were recorded at 60 DAT and yield and yield attributes at maturity. Visual pyto-toxicity (yellowing, chlorosis, stunting or scorching) (on 0-10 point scale) under different treatments in rice was also recorded at 15 days after herbicide application (DAA).

Another experiment was conducted to assess the phyto-toxicity of triafamone + ethoxysulfuron on transplanted rice during *Kharif* 2012 and 2013 and residual phyto-toxicty on succeeding wheat during *Rabi* 2012-13 and 2013-14. Three treatments, *viz.* triafamone + ethoxysulfuron at 60 and 120 g/ha and untreated check were also kept with three replications with plot size of 6.1 x 2.4 m. The herbicide was applied at 15 DAT in rice (Var. *HKR 47*) transplanted on 11 July 2012 and 7 July 2013 at spacing of 20 x 15 cm. After harvest of rice in October, wheat was sown on 20 November, 2012 (*DPW 621-50*) and 17 November 2013 (*WH 711*) using the seed rate of 100-112.5 kg/ha (row spacing 20 cm). Visual pyto-toxicity (yellowing, chlorosis, stunting or scorching) (on 0-10 point scale) under different treatments in rice was also recorded at 3, 7, 15 and 30 days after herbicide application (DAA), and in wheat at 15 and 30 days after sowing (DAS).

Before statistical analysis, the data on density of weeds was subjected to square root $(\sqrt{x+1})$ transformation to improve the homogeneity of the variance. The data were subjected to the analysis of variance (ANOVA) separately for each year. The significant treatment effect was judged with the help of 'F' test at the 5% level of significance. The 'OPSTAT' software of CCS Haryana Agricultural University, Hisar, India was used for statistical analysis (Sheoran *et al.* 1998).

RESULTS AND DISCUSSION

Major weed flora of the experimental field consisted of *Echinochloa crus-galli, Ammannia baccifera, Cyperus difformis* and *Fimbristylis miliaceae.*

Effect on weeds

Grassy weeds: Density of grassy weed *Echinochloa crus-galli* decreased with increase in dose of triafamone + ethoxysulfuron from 52.5 g/ha to 67.5 g/ha during both the years, however, the differences between successive doses were not significant (**Table 1**). Traifamone + ethoxysulfuron 67.5 g/ha was significantly superior to its lower dose 52.5 g/ha during 2012. Triafamone + ethoxysulfuron 60 g/ha resulted decrease in density of grassy weeds (1.3/m^2 in 2011 and 0.7/m^2 in 2012) at par with weed free check/ two hand weedings (2 HW) and the check herbicides butachlor 1250-1500 g/ha and pretilachlor 1000 g/ha, but significantly lower than pyrazosulfuron 15 g/ha, ethoxysulfuron 22.5 g/ha and pretilachlor 650 g/ha. Similarly triafamone 20%SC 45 g/ha was also at par with weed free check and the check herbicides butachlor 1250-1500 g/ha and pretilachlor 1000 g/ha, but superior to pretilachlor 625 g/ha in respect of density of *E. crus-galli.*

Dry weight of grassy weeds decreased with increase in dose of triafamone + ethoxysulfuron, however, the differences between 52.5 g/ha and its higher doses were significant only during 2011 (**Table 2**). Triafamone + ethoxysulfuron 60-67.5 g/ha (0.0-0.6 g/m^2 in 2011 and 0.0-0.2 g/m^2 in 2012) was at par

Table 1. Effect of different herbicides on density of weeds (no./m²) in transplanted rice (*Kharif* 2011 and 2012)

Treatment	Dose (g/ha)	*Echinochloa crus-galli*		*Ammannia baccifera*		*Cyperus difformis*		*Fimbristylis miliaceae*
		2011	2012	2011	2012	2011	2012	2011
Triafamone+ethoxysulfuron-30%WG	35+17.5	2.20(4.0)	2.10(4.0)	6.36(40.0)	5.66(31.3)	1.0(0)	1.0(0)	1.0(0)
Triafamone+ethoxysulfuron-30%WG	40+20	1.41(1.3)	1.24(0.7)	5.82(34.0)	3.48(11.3)	1.0(0)	1.0(0)	1.0(0)
Triafamone+ethoxysulfuron-30%WG	45+22.5	1.0(0)	1.0(0)	5.60(30.7)	3.95(14.7)	1.0(0)	1.0(0)	1.0(0)
Triafamone 20%SC	45	1.41(1.3)	1.41(1.3)	7.71(58.7)	6.88(46.7)	1.0(0)	1.0(0)	1.0(0)
Ethoxysulfuron 15%WG	22.5	5.46(29.3)	6.12(36.7)	5.80(33.3)	4.67(21.3)	1.0(0)	1.0(0)	1.0(0)
Pyrazosulfuron ethyl 10%WP	15	4.18(16.7)	5.62(30.7)	4.51(20.0)	5.95(34.7)	1.0(0)	1.0(0)	1.0(0)
Butachlor 50%EC	1250	2.32(4.7)	1.96(3.3)	5.59(30.7)	2.10(4.0)	2.8(8.7)	1.0(0)	1.0(0)
Butachlor 50%EC	1500	1.24(0.7)	1.0(0)	6.02(35.3)	1.90(2.7)	1.0(0)	1.0(0)	1.0(0)
Pretilachlor 50%EC	625	2.71(8.0)	3.05(8.7)	5.80(32.7)	4.31(18.0)	2.5(6.7)	1.0(0)	1.0(0)
Pretilachlor 50%EC	1000	-	1.0(0)	-	2.08(4.0)	-	1.0(0)	-
Two hand weedings		1.0(0)	1.0(0)	1.00(0.0)	1.00(0.0)	1.0(0)	1.0(0)	1.0(0)
Weedy check		5.90(34.0)	6.43(40.7)	10.68(113.3)	8.36(69.3)	3.6(12.7)	2.2(4.0)	2.1(4.0)
LSD p=0.05		1.29	0.95	1.11	1.10	1.07	0.22	0.52

*Original figures in parentheses were subjected to square root ($\sqrt{x+1}$) transformation before statistical analysis

Table 2. Effect of different herbicides on dry weight of weeds (g/m²) in transplanted rice (*Kharif* 2011 and 2012)

Treatment	Dose (g/ha)	Grassy weeds		Broad-leaf weeds		Sedges	
		2011	2012	2011	2012	2011	2012
Triafamone+ethoxysulfuron-30%WG	35+17.5	25.4	11.8	1.6	1.0	0	0
Triafamone+ethoxysulfuron-30%WG	40+20	0.6	0.2	0.4	0.6	0	0
Triafamone+ethoxysulfuron-30%WG	45+22.5	0	0	0.4	0.6	0	0
Triafamone 20%SC	45.0	5.6	3.3	2.9	1.7	0	0
Ethoxysulfuron 15%WG	22.5	193.1	203.2	0.5	0.6	0	0
Pyrazosulfuron ethyl 10%WP	15.0	115.0	195.4	1.1	0.7	0	0
Butachlor 50%EC	1250	35.5	0	1.0	0.9	0.5	0
Butachlor 50%EC	1500	6.3	0	1.1	0.3	0	0
Pretilachlor 50%EC	625	23.0	42.0	0.8	1.2	0.4	0
Pretilachlor 50%EC	1000	-	0	-	0.8	-	0
Two hand weedings		0.0	0	0	0	0	0
Weedy check		231.5	236.5	6.2	4.0	2.9	2.1
LSD p=0.05		20.9	50.6	1.3	0.7	0.7	0.4

with triafamone 45 g/ha, butachlor 1500 g/ha and two hand weeding, and was better than all other herbicidal treatments in respect of dry weight of grassy weeds during 2011, but better than ethoxysulfuron 22.5 g/ha and pyrazosulfuron 15 g/ha and at par with all other herbicidal treatments during 2012.

Broad-leaf weeds: The different treatments of triafamone + ethoxysulfuron were at par with each other in respect of density of *Ammannia baccifera,* except that at 52.5 g/ha, it was inferior to the higher doses during 2012 (**Table 1**). All the treatments of triafamone + ethoxysulfuron were better than triafamone 45 g/ha alone in respect of density of *Ammannia baccifera* during both the years. During 2011, triafamone + ethoxysulfuron 60 g/ha reduced the density of broad-leaf weeds statistically similar to ethoxysulfuron 22.5 g/ha and inferior to pyrazosulfuron 15 g/ha, but it was superior to these herbicides during 2012. During 2011, triafamone + ethoxysulfuron 60 g/ha was also similar to butachlor and pretilachlor treatments; while during 2012, it had more density of *Ammannia baccifera* than butachlor 1250-1500 g/ha and pretilachlor 1000 g/ha but at par with pretilachlor 625 g/ha.

Different doses of triafamone + ethoxysulfuron were at par with each other in respect of dry weight of broad-leaf weeds during both the years (**Table 2**). Triafamone + ethoxysulfuron 60 g/ha was at par while 52.5 g/ha was inferior to 2-HW. Triafamone + ethoxysulfuron 60 g/ha (0.4 g/m² in 2011 and 0.6 g/m² in 2012) was at par with all other herbicidal treatments in respect of dry weight of broad-leaf weeds during both the years.

Sedges: There was almost complete control of sedges *Cyperus difformis* and *Fimbristylis miliaceae* with triafamone + ethoxysulfuron at all the doses and was similar to all other herbicidal treatments and better than the untreated check, in respect of density (**Table 1**) and dry weight (**Table 2**) of sedges during both the years.

Compared to combination of bispyribac-sodium with chlorimuron + metsulfuron, premix of triafamone + ethoxysulfuron 60 g/ha was more effective against *Leptochloa chinensis* and it recorded lowest weed dry matter production in transplanted rice (Menon *et al.* 2016), however, it was relatively less effective against *E. crusgalli*. Abeysekhara and Wickrama (2004) have also reported that bispyribac-sodium does not control *L. chinensis*. Therefore, such information would be useful for farmers to make appropriate choice depending on weed flora in their fields.

Effect on crop

There was no significant effect of different treatments on the plant height and panicle length of the crop during both the years (**Table 3**). Number of effective tillers/mrl increased with increase in dose of triafamone + ethoxysulfuron but the differences were not always significant. Triafamone + ethoxysulfuron 60 g/ha produced effective tillers (58.7 mrl in 2011 and 78.2 mrl in 2012) at par with triafamone 45 g/ha, butachlor 1250, 1500 g/ha and weed free check during both the years. It was at par with pretilachlor 625 g/ha during 2011 and with pretilachlor 1000 g/ha during 2012.

The grain yield of rice under triafamone + ethoxysulfuron 60 g/ha (6.08 t/ha in 2011 and 7.06 t/ha in 2012) was higher than its lower dose (52.5 g/ha) and at par with the higher dose (67.5 g/ha) during both the years (**Table 3**), indicating it to be the optimum dose. Triafamone + ethoxysulfuron 60-67.5 g/ha was at par with triafamone 45 g/ha, butachlor 1500 g/ha and weed free check during both the years; butachlor 1250 g/ha and pretilachlor 1000 g/ha during 2012 and it was superior to all other herbicidal treatments in respect of grain yield of rice during both the years. Menon *et al.* (2016) have also reported that among different herbicidal treatments, the grain yield of rice was maximum in plots treated with triafamone + ethoxysulfuron 60 g/ha as it controlled complex weed flora very effectively. Hossain and Malik (2017) also reported that triafamone + ethoxysulfuron 60 g/ha produced grain yield of transplanted rice similar to other herbicidal combinations. Contrarily, Kailkhura *et al.* (2015) found that penoxsulam + cyhalofop-butyl (ready-mix) 135 g/ha and pre-emergence application of pendimethalin 1000 g/ha *fb* post-emergence application of bispyribac-sodium 25 g/ha due to better weed control produced more grain yield of transplanted rice than triafamone + ethoxysulfuron 60 g/ha.

Weeds allowed to grow throughout the crop season reduced the grain yield of transplanted rice to the extent of 31.2% and 39.4% during 2011 and 2012, respectively. This is in agreement with earlier reports elsewhere (Singh *et al.* 2003, Yadav *et al.* 2009, Manhas *et al.* 2012, Duary *et al.* 2015, Hossain and Malik 2017)

Crop injury

There was no visual crop injury of any of the herbicidal treatments in the bio-efficacy trial in respect of phyto-toxicity symptoms (yellowing, chlorosis, stunting or scorching), indicating that all the herbicides were safe to the transplanted rice crop during *Kharif* 2011 and 2012 (**Table 3**). Triafamone + ethoxysulfuron did not cause any phyto-toxicity on rice crop even up to 120 g/ha, indicating its safety up to 2X dose. Also, there was no residual phyto-toxicity of triafamone + ethoxysulfuron up to 120 g/ha on succeeding wheat crop during *Rabi* seasons of 2012-13 and 2013-14 (**Table 4**).

Based on the present investigation, it was concluded that triafamone + ethoxysulfuron 30%WG

Table 3. Effect of different herbicides on phyto-toxicity, plant height, yield attributes and yield of transplanted rice (*Kharif* 2011 and 2012)

Treatment	Dose (g/ha)	Visual phy-toxicity (%)		Plant height (cm)		No. of effective tillers/ mrl		Panicle length (cm)		Grain yield (t/ha)	
		2011	2012	2011	2012	2011	2012	2011	2012	2011	2012
Triafamone+ethoxysulfuron-30%WG	35+17.5	0	0	95.8	121.8	55.0	73.3	20.3	21.7	5.70	6.58
Triafamone+ethoxysulfuron-30%WG	40+20	0	0	96.1	121.7	58.7	78.2	20.3	22.0	6.08	7.06
Triafamone+ethoxysulfuron-30%WG	45+22.5	0	0	94.9	122.0	59.0	77.2	20.3	21.7	6.01	7.07
Triafamone 20%SC	45	0	0	96.2	121.9	57.8	75.8	20.3	21.9	5.88	6.75
Ethoxysulfuron 15%WG	22.5	0	0	94.9	121.2	46.8	53.3	20.3	21.7	4.66	5.20
Pyrazosulfuron ethyl 10%WP	15.0	0	0	96.6	121.7	49.8	59.8	20.1	21.7	5.13	5.55
Butachlor 50%EC	1250	0	0	96.1	121.4	55.3	76.3	20.3	21.9	5.69	6.76
Butachlor 50%EC	1500	0	0	95.3	121.5	58.2	78.3	20.5	21.9	6.0	7.02
Pretilachlor 50%EC	625	0	0	95.5	122.1	55.7	72.5	20.5	21.5	5.71	6.56
Pretilachlor 50%EC	1000	0	0	-	121.1	-	78.2	-	22.1	-	7.14
Two hand weeding		0	0	96.3	121.7	59.7	79.7	20.6	22.1	6.18	7.23
Weedy check		0	0	94.7	121.6	41.8	47.2	19.6	21.4	4.25	4.38
LSD p=0.05				NS	NS	3.9	5.4	NS	NS	0.36	0.48

Table 4. Phyto-toxicity (0-10 scale) of triafamone + ethoxysulfuron 30% WG on transplanted rice (*Kharif* 2012 and 2013) and succeeding wheat crop (*Rabi* 2012-13 to 2013-14)

Treatment	Dose (g/ha)	3 DAA*		7 DAA		15 DAA		30 DAA	
		2012	2013	2012	2013	2012	2013	2012	2013
Rice									
Triafamone+ethoxysulfuron-30%WG	60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Triafamone+ethoxysulfuron-30%WG	120	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Untreated check	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wheat						2012-13	2013-14	2012-13	2013-14
						15 DAS		30 DAS	
Triafamone+ethoxysulfuron-30%WG	60					0.0	0.0	0.0	0.0
Triafamone+ethoxysulfuron-30%WG	120					0.0	0.0	0.0	0.0
Untreated check	-					0.0	0.0	0.0	0.0

*DAA, days after herbicide application

60-67.5 g/ha applied at 1-2 leaf stage of weeds (15 DAT) in a spray volume of 300 liter water/ha provided effective control of complex weed flora with significant improvement in grain yield of transplanted rice. There was no phyto-toxicity of this herbicide up to 120 g/ha on transplanted rice and also no residual toxicity on succeeding wheat crop.

REFERENCES

Abeysekhara ASK and Wickrama UB. 2004. Control of *Leptochloa chinensis* (L.) Nees. in wet seeded rice fields in Sri Lanka. pp. 215–217. In: *Proceedings of the World Rice Research Conference*, Japan, 4-7 November.

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

Hossain A and Malik GC. 2017. Herbicide combinations for control of complex weed flora in transplanted rice in Lateritic belt of West Bengal. *Indian Journal of Weed Science* **49**(3): 276–278.

Kailkhura S, Pratap T, Singh VP, Guru SK and Singh SP. 2015. Herbicide combinations for control of complex weed flora in transplanted rice. *Indian Journal of Weed science* **47**(4): 414–416.

Manhas SS, Singh G, Singh D and Khajuria V. 2012. Effect of tank-mixed herbicides on weeds and transplanted rice (*Oryza sativa* L.). *Annals of Agricultural Research New Series* **33**(1&2): 25–31.

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

Mishra JS, Dixit A and Varshney JG. 2007. Efficacy of penoxsulam on weeds and transplanted rice (*Oryza sativa*). *Indian Journal of Weed Science* **39**(1&2): 24–27.

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 & Computer Applications* (Eds. Hooda DS and Hasija RC). CCS HAU, Hisar.

Singh G, Singh VP, Singh M and Singh SP. 2003. Effect of anilofos and triclopyr on grassy and non-grassy weeds in transplanted rice. *Indian Journal of Weed Science* **35**(1): 30–32.

Yadav DB, Yadav A and Punia SS. 2008. Efficacy of penoxsulam against weeds in transplanted rice. *Indian Journal of Weed Science* **40**(3&4): 142–146.

Yadav DB, Yadav A and Punia SS. 2009. Evaluation of bispyribac-sodium for weed control in transplanted rice. *Indian Journal of Weed Science* **41**(1&2): 23–27.

Indian Journal of Weed Science **51**(2): 111–115, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Sequential application of pre- and post-emergence herbicides for control of complex weed flora in dry direct-seeded rice under Cauvery command area of Karnataka

S.B. Yogananda*, P. Thimmegowda and G. K. Shruthi

Zonal Agricultural Research Station, V.C. Farm, Mandya, Karnataka 571 405, India

University of Agricultural Sciences, Bangalore, Karnataka 560 065, India

**Email: sbyogananda@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00026.1

Type of article: Research article

Received : 29 March 2019
Revised : 18 May 2019
Accepted : 22 May 2019

Key words

Bispyribac-sodium
Dry direct-seeded rice
Economics
Sequential application
Weeds

ABSTRACT

A field experiment was conducted during rainy *(Kharif)* season of 2014 and 2015 at Zonal Agricultural Research Station, V. C. Farm, Mandya, Karnataka to study the efficacy of sequential application of herbicides on weed density, weed dry weight, yield and economics of dry direct-seeded rice. The results revealed that pre-emergence application of bensulfuron-methyl 0.6% + pretilachlor 6% GR at 10 kg/ha *fb* post-emergence application of bispyribac-sodium at 25 g/ha at 20 days after sowing (DAS) recorded significantly lower total weed population (39.4 and 43.1/m^2) and weed dry weight (8.2 and 9.0 g/m^2) with weed control efficiency of 77.8 and 77.2% during 2014 and 2015, respectively. As a consequence of effective weed control the same treatment recorded significantly higher grain yield (4.60 and 4.42 t/ha), net monetary returns (` 39,340 and 36,710/ha) and B: C ratio (2.32 and 2.23) during 2014 and 2015, respectively. This treatment was statistically comparable to hand weeding thrice at 20, 40 and 60 DAS. Uncontrolled weed growth caused 56% reduction in grain yield of dry direct-seeded rice.

INTRODUCTION

Rice (*Oryza sativa* L.) is a major cereal crop and staple food for more than half of the world's population. About 90% of the world's rice is produced and consumed in Asia (FAO 2014). India is the second largest rice producing country in the world with an area of 43.7 mha and produced 112.7 Mt of rice with a productivity of 2576 kg/ha (Anonoymus 2017). In Karnataka paddy is mainly grown in command areas under transplanted submerged condition. Recent years, transplanted rice with submerged condition as become economical due to escalating labor cost, non-availability of timely labor and shortage of irrigation water due to recurrent droughts. Dry Direct-seeded rice is one of the viable options for rice production under shrinking water resources and scarcity of labors. Direct-seeded rice (DSR) is a cost effective rice establishment method where dry seed is drilled into the non-puddled soil. This provides opportunities of saving irrigation water by 12-35%, labor up to 60% and provides higher net returns (US$ 30-50/ha) with similar or slightly lower yield of rice (Kumar and Ladha 2011). However, the good harvest of crop yield under direct-seeded rice is mainly depends on effective weed management practices.

An effective early weed management tactic is imperative for any DSR production technology aiming at achieving higher productivity and profitability (Jaya Suria *et al.* 2011). Aerobic edaphic conditions under non-flooded conditions in DSR stimulate germination of diverse weed species. Weeds in DSR compete for moisture, nutrients, light and space and reduce the grain yield by 75 to 85% (Rao *et al.* 2007 and Dhanapal *et al.* 2018a). Weed problem in DSR can be managed by implementing integrated weed management. Chemical weed control by using pre-emergence herbicides being cost effective and less labour dependent is recommended to overcome weed menace in DSR. Broad-spectrum of weed flora, however, may not be controlled by spraying pre-emergence herbicides alone, as several flushes of weeds come up at different growth stages. Hence, use of sequential application of pre- *fb* post-emergence herbicides or pre-emergence herbicides *fb* manual weeding could be more convenient in containing the weed menace. The present investigation was carried out to study the efficacy of sequential application of herbicides to control complex weed flora observed in dry direct-seeded rice in Cauvery Command Area of Karnataka.

MATERIAL AND METHODS

A field experiment was conducted during *Kharif* season of 2014 and 2015 at the Zonal Agricultural Research Station, Mandya to know the influence of sequential application of herbicides on weed flora and their effect on growth and yield of dry direct-seeded rice under Cauvery Command Area of Karnataka. The farm is geo graphically situated between 11^0 30' to 13^0 05' N latitude and 76^0 05 to 77^0 45' East longitude with an altitude of 697 meters above MSL. The soil of experimental site was red sandy loams with bulk density and particle density of 1.15 g/cc and 2.65 g/cc, respectively with soil pH of 6.5. It was low in available nitrogen (225 kg/ha) and phosphorus (28 kg/ha) and potassium (126 kg/ha). Eight treatments, *viz.* bensulfuron-methyl 0.6% + pretilachlor 6% GR (Londax Power) at 10 kg/ha (PE) + one HW, pendimethalin (30 EC) at 1.0 kg/ha (PE) + one HW, bensulfuron-methyl 0.6% + pretilachlor 6% GR at 10 kg/ha (PE) *fb* bispyribac-sodium at 25 g/ha (PoE), pendimethalin at 1.0 kg/ha (PE) *fb* bispyribac-sodium at 25 g/ha (PoE), bispyribac-sodium at 25 g/ha (early PoE), hand weeding thrice at 20, 40 and 60 DAS, weedy and weed free check. These treatments were replicated thrice in a complete randomized block design.

Pre-germinated seeds of medium duration rice variety '*IR-30864*' were sown on well puddled and leveled field in June 2014 and 2015 with a seed rate of 62.5 kg/ha with a spacing of 20 x 10 cm. The crop was fertilized with 100:50:50 kg N:P_2O_5: K_2O/ha. The 50% of recommended nitrogen, entire dose of phosphorous and potassium was applied as basal in addition to zinc sulphate at 25 kg/ha. The remaining 50% of the nitrogen was top dressed at two equal splits at tillering and panicle initiation stage. The gross plot size was 5.0 x 3.0 m. Pre-emergence herbicides were mixed with sand at 100 kg/ha and applied uniformly in the field on 5 DAS. A thin film of water was maintained at the time of pre-emergence herbicide application. The post-emergence herbicides were sprayed at 3-4 leaf stage of weeds by using knap-sack sprayer fitted with deflector nozzle mixed with water 750 liter/ha. Hand weeding was carried out as per the treatment schedule.

The data on weed density and weed dry weight at 60 DAS were recorded with the help of quadrate (0.5 x 0.5 m). The normality of distribution was not seen in case of observation on weeds hence, the values were subjected to square root transformation ($\sqrt{x+0.5}$) prior to statistical analysis to normalize their distribution. Data on plant height and number of tillers at harvest and yield attributes, *viz.* grain weight/panicle, 100-seed weight and percent choppiness and grain and straw yield were recorded. The per cent choppiness was worked out by using the following formula.

$$\text{Per cent choppiness} = \frac{\text{No. of unfilled grains per panicle}}{\text{Total no. of grains per panicle}} \times 100$$

The weed control efficiency was worked out on the basis of weed dry matter production using the formula suggested by Mani *et al.* (1973) and weed index was calculated by using the formula suggested by Gill and Vijayakumar (1966). All the data obtained in the study were statistically analyzed using F-test, the procedure given by Gomez and Gomez (1984), Critical difference values at P=0.05 were used to determine the significance of differences between means.

RESULTS AND DISCUSSION

Weed flora

The predominant weed flora associated with dry direct-seeded rice in experimental field were in association with the direct-seeded dry sown rice, *viz. Cynodon dactylon* L. (Bermuda grass), *Dinebra retroflexa* (Vahl) Panz. (Viper grass), *Echinochloa colonum* L. (barnyard grass), *Panicum repens* L. (quack grass) and *Digiteria sanguinalis* L. (large crab grass) among grasses; *Ageratum conyzoides* L. (Billygoat weed), *Digera arvensis* L. (false amaranth), *Physalis minima* L. (native gooseberry), *Commelina Benghalensis* L. (benghal dayflower), *Abutilon indicum* L. (Indian mallow), *Portulaca oleracea* L. (common purslane), *Parthenium hysterophorus* L. (congress grasss) and *Trianthema portulacastrum* L. (desert horse purslane) among broad-leaved weeds (BLW); and *Cyperus rotundus* L. (purple nut sedge) and *Cyperus iria* L. (rice flat sedge) among sedges**.**

Weed density and dry weight

All the weed control treatments found effective in reducing the density and dry weight of grasses, BLW, sedges and total weeds as compared to unweeded check **(Table 1** and **2)**. At 60 DAS among the weed control treatments, hand weeding thrice at 20, 40 and 60 DAS recorded significantly lower density and dry matter of grasses, Sedges, BLW and Total weeds. However, it was at par with pre-emergence application of bensulfuron-methyl 0.6% +

pretilachlor 6% GR 10 kg/ha *fb* post-emergence application of bispyribac-sodium 25 g/ha. The pre-emergence application of bensulfuron-methyl 0.6% + pretilachlor 6% GR at 10 kg/ha found to control the all the three categories of weeds effectively upto 20-25 days after its application. While, later emerging weeds were effectively controlled by post-emergence application of bispyribac-sodium at 25 g/ha. Among the three categories of weeds BLW were dominant and post-emergence application of bispyribac sodium at 25 g/ha found effective in control of BLW. Hence the statement recorded significantly lower density of weeds and its dry matter production. These results are in conformity with (Pratik and Manoj 2017). While, the lowest weed density and dry weight of weeds were observed in weed free check due to season long weed removal and the highest was recorded in weedy check due to uncontrolled weed growth. The crop yield is directly proportional to weed control efficiency. The weed control efficiency at 60 DAS was maximum in hand weeding thrice at 20, 40 and 60 DAS (83.70% and 82.60% in 2014 and 2015, respectively) and this was closely followed by pre-emergence application of bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha *fb* post-emergence application of bispyribac-sodium 25 g/ha (77.80% and 77.20% in 2014 and 2015, respectively) and this was the best treatment among the herbicides in terms of higher WCE. The similar results are reported by Dhanapal *et al.* 2018b and Ramesha *et al.* 2019. The pre-emergence application of herbicides followed by one hand weeding at 40 DAS were failed to control the all types of weeds due to weed growth during critical period.

Table 1. Density of weeds (no./m^2) as influenced by weed management practices in dry direct-seeded rice at 60 DAS

Treatment	2014				2015			
	Grasses	BLW	Sedges	Total	Grasses	BLW	Sedges	Total
Bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha (PE) + one HW	4.30 (18.0)	4.74 (22.0)	1.94 (3.3)	6.62 (43.3)	4.57 (20.6)	4.87 (23.2)	2.14 (4.1)	6.95 (48.0)
Pendimethalin (30 EC) 1.0 kg/ha (PE) + one HW	4.34 (18.3)	4.77 (22.2)	2.30 (4.8)	6.77 (45.4)	4.53 (20.1)	4.91 (23.7)	2.42 (5.4)	7.04 (49.1)
Bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha (PE) *fb* bispyribac-sodium 25 g/ha (PoE)	4.10 (16.3)	4.51 (19.9)	1.92 (3.2)	6.31 (39.4)	4.36 (18.6)	4.64 (21.0)	1.99 (3.5)	6.60 (43.1)
Pendimethalin 1.0 kg/ha(PE) *fb* bispyribac-sodium 25 g/ha (PoE)	4.89 (23.4)	4.90 (23.6)	2.14 (4.1)	7.18 (51.1)	5.05 (25.1)	5.06 (25.2)	2.28 (4.7)	7.44 (55.0)
Bispyribac-sodium 25 g/ha (early PoE)	5.41 (28.8)	6.57 (42.8)	2.56 (6.1)	8.84 (77.8)	5.54 (30.4)	6.39 (40.4)	2.66 (6.7)	8.82 (77.4)
Hand weeding thrice at 20, 40 and 60 DAS	3.07 (8.9)	3.83 (14.2)	1.45 (1.6)	5.02 (24.8)	3.25 (10.1)	3.97 (15.3)	1.53 (1.9)	5.26 (27.2)
Weed free check	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
Weedy check	6.93 (47.8)	8.91 (78.9)	3.07 (9.0)	11.66 (135.6)	7.07 (49.6)	9.02 (80.8)	3.14 (9.4)	11.84 (139.8)
LSD (p=0.05)	0.50	0.38	0.29	0.53	0.66	0.33	0.32	0.59

Square root $\sqrt{x+0.5}$ transformed values. Values in the parentheses are original values

Table 2. Dry weight of weeds (g/m^2) and weed control efficiency as influenced by weed management practices in dry direct-seeded rice at 60 DAS

Treatment	2014				2015				WCE (%)	
	Grasses	BLW	Sedges	Total	Grasses	BLW	Sedges	Total	2014	2015
Bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha (PE) + one HW	2.06 (3.75)	2.07 (3.77)	1.79 (2.70)	3.27 (10.2)	2.12 (4.02)	2.08 (3.82)	1.91 (3.20)	3.39 (11.0)	72.4	72.0
Pendimethalin (30 EC) 1.0 kg/ha (PE) + one HW	2.26 (4.63)	2.35 (5.03)	1.87 (3.00)	3.63 (12.7)	2.36 (5.09)	2.41 (5.31)	1.94 (3.27)	3.76 (13.7)	65.9	65.4
Bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha (PE) *fb* bispyribac-sodium 25 g/ha (PoE)	2.05 (3.70)	1.86 (2.95)	1.44 (1.58)	2.95 (8.2)	2.16 (4.18)	1.91 (3.15)	1.46 (1.62)	3.07 (9.0)	77.8	77.2
Pendimethalin 1.0 kg/ha(PE) *fb* bispyribac-sodium 25 g/ha (PoE)	2.12 (3.99)	2.22 (4.43)	1.51 (1.79)	3.27 (10.2)	2.21 (4.40)	2.29 (4.77)	1.56 (1.93)	3.40 (11.1)	72.5	71.9
Bispyribac-sodium 25 g/ha (early PoE)	2.52 (5.86)	3.30 (10.62)	2.33 (4.96)	4.67 (21.4)	2.59 (6.21)	3.33 (10.86)	2.40 (5.28)	4.76 (22.4)	42.3	43.4
Hand weeding thrice at 20, 40 and 60 DAS	1.64 (2.19)	1.48 (1.68)	1.63 (2.16)	2.56 (6.0)	1.69 (2.37)	1.58 (2.00)	1.73 (2.54)	2.71 (6.9)	83.7	82.6
Weed free check	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	100.0	100.0
Weedy check	3.54 (12.06)	3.95 (15.14)	3.24 (10.00)	6.14 (37.2)	3.66 (12.96)	4.03 (15.84)	3.35 (10.83)	6.32 (39.6)	0.0	0.0
LSD (p=0.05)	0.18	0.44	0.19	0.30	0.21	0.45	0.26	0.36	-	-

Square root $\sqrt{x+0.5}$ transformed values. Values in the parentheses are original values

Phytotoxicity

Among the herbicides tested, pendimethalin was found toxic with phytotoxic value of 5 and hindered the germination of rice seeds leading to reduced plant population. A similar phytotoxic effect caused by pendimethalin on rice crop was observed by Rana *et al.* (2016).

Growth, yield and yield attributing characters

The rice growth attributes, *viz.* plant height (cm) and no. of tillers at harvest and yield attributes, *viz.* grain weight/panicle (g), 100-seed weight (g), percent choppiness were influenced significantly due to weed control treatments. Among the weed control treatments, hand weeding thrice at 20, 40 and 60 DAS found excellent in recording significantly higher growth and yield attributes as compared to others. However, it was at par with herbicide treatment pre-emergence application of bensulfuron-methyl 0.6% + pretilachlor 6% GR at 10 kg/ha *fb* post-emergence application of bispyribac-sodium at 25 g/ha. This increases yield in herbicide treatment is mainly due to considerable reduction in weed emergence at the initial crop growth stage lead to establishment of rice seedlings vigorously and resulted in higher number of tillers per hill and consequently significantly yield attributing characters, *viz.* number of panicles/m^2 and 100-seed weight (g). The accurance of choffy grains is one of the main yield limiting factors in dry direct-seeded rice and the percent choffyness was significantly influenced by weed control practices. Among them, pre-emergence application of bensulfuron-methyl 0.6% + pretilachlor 6% GR at 10 kg/ha *fb* post-emergence application of bispyribac-sodium at 25 g/ha recorded significantly lower percentage of choffyness (15%) and was statistically comparable with hand weeding thrice at 20, 40 and 60 DAS (12%). This lower percent choffyness is mainly due to increased number of filled grains per panicle due to uptake of more nutrients by the crop and more photosynthetic activity especially during grain filling period due to season long control of weeds in these treatments.

As a consequence of significantly higher growth and yield attributes the pre-emergence application of bensulfuron-methyl 0.6% + pretilachlor 6% GR at 10 kg/ha *fb* post-emergence application of bispyribac-sodium at 25 g/ha recorded significantly higher grain yield (4.60 t/ha and 4.42 t/ha) as compared to others and was statistically comparable with hand weeding thrice at 20, 40 and 60 DAS (4.98 t/ha and 4.65 t/ha) and weed free check (5.04 t/ha and 4.82 t/ha) during both the years of experimentation, respectively. This increased yield in the above treatment is mainly attributed to reduced competition for moisture, space, light and nutrients between crop and weeds along with effective suppression of weeds by combination of herbicides. The same results also reported by Dhanapal *et al.* 2018b and Ramesha *et al.* 2019. Unweeded control gave the lowest paddy grain yield (2.21 and 2.12 t/ha) due to severe competition from all types of weeds. The season long uncontrolled weed growth reduced the dry direct seeded rice to an extent of 56%.

Economics

Among different weed management practice, the higher net returns (` 36705-39,337/ha) and B:C ratio (2.32-2.23) were recorded with pre-emergence application of bensulfuron-methyl 0.6% + pretilachlor 6% GR at 10 kg/ha *fb* post-emergence application of bispyribac-sodium at 25 g/ha during 2014 and 2015, respectively. While, the lowest net returns (` 8200/ha and ` 6935/ha) and B:C ratio (1.33 and 1.28) were

Table 3. Growth and yield attributes in dry DSR as influenced by weed management practices

Treatment	Plant height at harvest (cm)		No. of tillers at harvest		Grain weight/panicle (g)		100-seed weight (g)		Percent choppiness	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha (PE) + one HW	54.59	53.56	14.00	13.55	2.49	2.25	1.44	1.33	17.85	18.78
Pendimethalin (30 EC) 1.0 kg/ha (PE) + one HW	49.97	49.11	11.81	12.91	1.54	2.18	1.14	1.31	25.23	19.37
Bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha (PE) *fb* bispyribac-sodium 25 g/ha (PoE)	58.91	58.24	14.83	14.07	2.56	2.26	1.48	1.44	14.95	16.23
Pendimethalin 1.0 kg/ha(PE) *fb* bispyribac-sodium 25 g/ha (PoE)	49.64	48.83	14.12	11.66	2.47	1.52	1.45	1.09	17.25	26.30
Bispyribac-sodium 25 g/ha (early PoE)	46.57	45.94	10.82	10.38	1.43	1.4	1.06	1.08	28.12	19.08
Hand weeding thrice at 20, 40 and 60 DAS	60.76	60.07	14.89	14.95	2.57	2.45	1.69	1.64	11.64	12.39
Weed free check	61.09	60.26	15.49	14-98	2.64	2.52	1.71	1.67	10.54	11.83
Weedy check	43.94	43.94	8.66	7.94	1.4	1.35	1.04	1.02	57.18	60.53
LSD (p=0.05)	5.25	5.25	1.80	2.05	0.19	0.29	0.13	0.17	4.97	5.02

Table 4. Grain yield, weed index and economics of dry DSR as influenced by weed management practices

Treatment	Grain yield (t/ha)		Weed index (%)		Net returns (x 10^3 `/ha)		B:C ratio	
	2014	2015	2014	2015	2014	2015	2014	2015
Bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha (PE) + one HW	4.57	4.37	9.2	9.3	37.80	34.81	2.23	2.13
Pendimethalin (30 EC) 1.0 kg/ha (PE) + one HW	2.86	4.39	43.3	8.9	13.28	36.32	1.45	2.23
Bensulfuron-methyl 0.6% + pretilachlor 6% GR 10 kg/ha (PE) *fb* bispyribac-sodium 25 g/ha (PoE)	4.60	4.42	8.6	8.2	39.34	36.71	2.32	2.23
Pendimethalin 1.0 kg/ha(PE) *fb* bispyribac-sodium 25 g/ha (PoE)	4.57	2.80	9.2	42.0	38.87	12.20	2.30	1.41
Bispyribac-sodium 25 g/ha (early PoE)	2.56	2.42	49.2	49.8	11.53	9.43	1.43	1.35
Hand weeding thrice at 20, 40 and 60 DAS	4.98	4.65	1.0	3.5	37.83	32.84	2.02	1.89
Weed free check	5.04	4.82	0.0	0.0	32.60	29.41	1.76	1.68
Weedy check	2.21	2.12	56.1	55.9	8.20	6.94	1.33	1.28
LSD (p=0.05)	0.436	0.498	8.9	10.4	-	-	-	-

observed in un weeded check **(Table 4)**. The increased monetary benefits in this treatment was mainly attributed to higher grain yield and reduced labour cost due to effective control of all types of weeds. Similar findings have been also reported by Prameela *et al.* 2015, Dhanapal *et al.* 2018b and Nagarjun *et al.* 2019.

It was concluded that pre-emergence application of bensulfuron-methyl 0.6% + pretilachlor 6% GR at 10 kg/ha *fb* post-emergence application of bispyribac-sodium at 25 g/ha found most effective and economical in controlling the weeds in direct-seeded dry sown rice in Cauvery command area of Karnataka.

REFERENCES

Anonoymus. 2017. Area, production and productivity of major cereals in India. *www.indiastat.com.*

Dhanapal GN, Sanjay MT, Nagarjun P and Sandeep A. 2018a. Integrated weed management for control of complex weed flora in direct seeded upland rice under Southern transition zone of Karnataka. *Indian Journal of Weed Science* **50**(1): 33–36.

Dhanapal GN, Kamala Bai S, Sanjay MT, Nagarjun P and Sandeep A. 2018b. Efficacy of weed management practices in transplanted rice under southern dry zone of Karnataka. *Indian Journal of Weed Science* **50**(3): 294–297.

FAO. 2014. *FAOSTAT Database*. Food and Agriculture Organization. FAO; Rome. (www.faostat.fao.org)

Gill HS and Vijayakumar. 1969. Weed index- a new method for reporting weed control trials. *Indian Journal of Agronomy* **14**(1): 96–98.

Gomez KA and Gomez AA. 1984. *Statistical Procedures for Agricultural Research*. (2nd Edition) *Chichesler,* UK: John Wiley and Sons.

Jaya Suria ASM, Juraimi AS, Rahman Md M, Man AB and Selamat A. 2011. Efficacy and economics of different herbicides in aerobic rice system. *African Journal of Biotechnology* **10**(41): 8007–8022.

Kumar V and Ladha JK. 2011. Direct seeded of rice. Recent developments and future research needs. *Advances in Agronomy* **111**: 299–413.

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

Nagarjun P, Dhanapal GN, Sanjay MT, Yogananda SB and Muthuraju R. 2019. Energy budgeting and economics of weed management in dry direct-seeded rice. *Indian Journal of Weed Science* **51**(1): 1–5.

Prameela P, Syama Menon S and Meera Menon V. 2014. Effect of post emergence herbicides on weed dynamics in wet seeded rice. *Journal of Tropical Agriculture* **52**(1): 94–100.

Pratik Sanodiya and Manoj Kumar Singh. 2017. Integrated weed management in direct-seeded rice. *Indian Journal of Weed Science* **49**(1): 10–14.

Rao AN, Johnson DE, Sivaprasad B, Ladha JK and Mortimer AM. 2007. Weed management in direct seeded rice. *Advances in Agronomy* **93**: 153–255.

Ramesha YM, Anand SR, Krishnamurthy D and Manjunatha Bhanuvally. 2019. Weed management effect to increase grain yield in dry direct-seeded rice. *Indian Journal of Weed Science* **51**(1): 6–9.

Rana SS, Dinesh Badiyala, Neelam Sharma, Rajinder Kumar, Rajesh Thakur, Suresh Kumar and Pawan Pathania. 2016. Herbicide combinations for weed management in direct-seeded rice. *Indian Journal of Weed Science* **48**(3): 266–271.

Indian Journal of Weed Science **51**(2): 116–122, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Indian Journal of Weed Science

Weed density and species composition in rice-based cropping systems as affected by tillage and crop rotation

J.S. Mishra*, Rakesh Kumar, Ravikant Kumar, K. Koteswara Rao and B.P. Bhatt

Division of Crop Research, ICAR Research Complex for Eastern Region Patna, Bihar 800 014, India

**Email: jsmishra31@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00027.3

Type of article: Research article

Received : 9 May 2019
Revised : 24 June 2019
Accepted : 25 June 2019

Key words

Cropping system

Rice

Tillage

Weeds

ABSTRACT

Weeds in crop fields are largely influenced by crop rotations and management practices. A better understanding of response of various weed species to changing management practices is required to develop improved weed management systems. A study was conducted to assess the effect of different tillage intensities and crop rotations on the weed population dynamics in rice-based cropping systems. In this study, three tillage practices *viz*. conventional tillage (CT), reduced tillage (RT) and RT with 30% crop residues (RTR30) were evaluated in three different crop rotations, *viz*. rice-wheat, rice-lentil and rice-winter maize for their effect on weeds. Results show that weed density and species composition differed with tillage and crop rotation. Interaction between various tillage intensities and cropping systems had significant effect on density and dry weight of total, broadleaved, grasses and sedges. Irrespective of the tillage systems rice-wheat crop rotation favoured the prevalence of weeds (a total weed population of 1670/m^2 and weed dry biomass of 241.1 g/m^2), whereas rice-winter maize rotation suppressed the weed growth (a total weed population of 403/m^2 and weed dry biomass of 213.4 g/m^2) in summer (pre-*Kharif*) season. Reduced tillage with 30% residues retention (RTR30) favoured the infestation of horse purslane (*Trianthema portulacastrum* L.) in rice-wheat cropping system, but suppressed the weed growth in rice-lentil system. Contrary to this, RTR30 favoured the infestation of black nightshade (*Solanum nigrum* L.) in rice-winter maize cropping system, but suppressed the weed growth in rice-lentil and rice-wheat systems during winter season.

INTRODUCTION

Rice (*Oryza sativa* L.) is an important cereal crop in Asia, where about 90% of the global rice is produced and consumed. It is grown over a range of agro-ecosystems and management practices (Rao *et al.* 2007). The rice-wheat cropping system occupying nearly 14 million ha (10.5 m ha in India, 2.2 mha in Pakistan, 0.8 mha in Bangladesh and 0.5 m ha in Nepal) in Indo-Gangetic Plains (IGP) is the largest agricultural production system in South Asia. However, the productivity of this system is plateauing and total factor productivity is declining due to exhausted natural resource base (Ladha *et al.* 2003). Rice-rice (4.70 mha), rice-pulses (3.50 mha), rice-vegetables (1.40 mha) and rice-maize (0.53 mha) (Timsina *et al.* 2010) are the other rice-based cropping systems in different agro-ecological regions of India that help to produce food and feed, improve the soil health and livelihood. Presently, the conservation tillage practices, particularly no-tillage and reduced tillage are being promoted in IGP to address the issues of shortage of man power, water and energy, soil health and climate change in rice-wheat cropping system (Kumar *et al.* 2013).

Weeds are one of the key threats to crop productivity, input-use efficiency and profitability in rice-based cropping systems. Continuous cultivation of rice-wheat cropping sequence favoured the intensification of grassy weeds (Bhatt *et al.* 2016). Tillage systems, crop rotations, choice of crop and management practices affect weed infestation by altering weed seed banks and species composition. Cultivation of crops having similar management practices favours certain weed species to become dominant in the system (Chauhan *et al.* 2012). For instance, conventional tillage (repeated soil tilling) in continuous cereal cropping of rice-wheat in IGP, favoured grassy weed littleseed canarygrass (*Phalaris minor* Retz.) in wheat and awn less barnyard grass [*Echinochloa colona* (L.) Link] in rice

(Malik *et al.* 2014). Therefore, it is necessary to rotate cereals with crops having different management requirements and crop duration. Crop diversification also changes weed spectrum (Singh *et al.* 2008) and makes soil conditions unfavourable for emergence and growth of certain weed species. Some weeds like *T. portulacastrum* and red sprangeltop [*Leptochloa chinensis* (L.) Nees] in rice and *Solanum nigrum*, common vetch (*Vicia sativa* L.) and burclover (*Medicago denticulata* Willd.) in winter crops are becoming difficult to control by commonly used herbicides.

In India, conservation tillage practices such as no-tillage and reduced tillage are being promoted in rice-based cropping systems. Change in tillage system affects weed communities by direct killing of weeds or by redistributing weed seeds in varying soil depths, and by changing the soil environment and there by affecting weed seed germination and emergence (Nichols *et al.* 2015). Many weeds are crop specific. Therefore, diversification of the prevalent cropping system may helps to reduce the infestation of a particular weed. Crop residues can affect weed seed germination by altering weed seed environment (light interception, physical barrier, soil moisture conservation and allelopathy) (Nichols *et al.* 2015). Much emphasis has been given on studying the effect of herbicides on weed control and crop yields in rice-wheat system, but very less effort has been made at managing weed populations by imposing diverse tillage sequences in cropping systems. The aim of the present study was to evaluate the density and composition of the weed population established after 4 years of crop rotations in 3 tillage systems.

MATERIALS AND METHODS

The present study was carried out during summer (pre-*Kharif*) and winter seasons of 2016 after completion of 4th year of a fixed field experiment from 2012-2016 at the Research farm, ICAR Research Complex for Eastern Region, Patna (25^{0}30‘N latitude 85^{0}15‘E longitude, and 52 m above mean sea level), Bihar, India. The soil of the experimental field was sandy clay loam soil (sand:55.5% silt:15.6% and clay 28.9%), low in available N (219 kg/N ha), medium in available P (19.3 kg P/ha) and K (190 kg K/ha) with pH 6.83 and EC 0.11 dS/m. The climate of the region is sub-tropical. Mean annual rainfall received during 2012 to 2016 at experimental site was 895.82 mm indicating a shortfall of 231.47 mm than the long-term normal rainfall (1127.29 mm). On an average, the highest precipitation was received in the month of August and September in all the 4 years of experimentation. Mean monthly maximum temperature varied from 18.7^{o}C (January) to 38.1^{o}C (May) whereas, mean monthly minimum temperature ranged from 6.5^{o}C (January) to 29.6 (August).

The treatments included three tillage practices *viz.* conventional tillage (CT), reduced tillage (RT) and RT with 30% crop residues (RTR30); and three different cropping systems *viz.* rice-wheat, rice-lentil and rice-winter maize. Tillage practices were assigned to the main plot and cropping systems to the sub-plot. Each sub-plot measured 4.5 x 10 m. Treatments were replicated thrice in a split-plot design. Rice was grown as puddled transplanted during rainy season, and treatments were imposed in following winter season. In CT and RT, rice was harvested manually from ground level leaving 5$\pm$2 cm anchored crop residue in the field, where as in RTR 30, about 30% anchored crop residues were left in the field by harvesting the crop 30$\pm$5 cm from the soil surface, and incorporated in the soil. After the harvesting the preceding rice crop, the field was prepared by two cultivations with tractor mounted cultivator followed by rotovator in CT. In RT/RTR30, the fields were prepared through reduced tillage practices involving one harrowing and one field levelling (using a wooden plank).

Data on weed count, for estimating weed density and their composition, and weed biomass were recorded (at 4-5 leaf stage) after completion of 4th year of field experiment during fallow period in early June (prior to planting rice crop) and 30 days after sowing of the succeeding crops, *viz.* wheat, maize and lentil (prior to application of post-emergence herbicide/manual weeding) with the help of quadrate (0.5 x 0.5 m) placed randomly at four spots in each plot. All the data on weed density and weed dry matter values were analyzed with ‘Statistix 8.1’ for analysis of variance (ANOVA). Data were square-root transformed before analysis to reduce heterogeneity of variance.

RESULTS AND DISCUSSION

Sixteen weed species including broad-leaved (BLW), grasses and sedges were identified from the weed density assessment during 1st week of June (pre-*Kharif*) and twelve weed species were observed during winter (*Rabi*) crop season. The field was dominated by broad-leaved weeds-BLWS (90%) followed by grasses (9%) and sedges (1%). Among BLWs, *T. portulacastrum* (72%), common purslane (*Portulaca oleracea* L.) 7% and prostrate knotweed

(*Polygonum aviculare* L.) 6% were major weeds during summer. In winter, *S. nigrum* (84%) was the dominant weed.

Density and dry matter of weeds during summer (pre-*Kharif*) season

Mean specific weed density (**Table 1**) and weed dry matter (**Table 2**) recorded during pre-*Kharif* season are presented to give an overview of weed densities and their dry matter in present study, and overall effect of the various tillage systems, crop rotations. The interaction of densities and dry weight of major weeds to various treatments is subsequently presented in **Table 3**. Conventional tillage in rice-maize crop rotation had the minimum total weed density (352/m^2) whereas reduced tillage with 30% anchored crop residue in rice-wheat rotation had the maximum total density (2049/m^2) and dry matter of weeds (270.6 g/m^2). The minimum total weed dry matter (187.6 g/m^2) was recorded with RT +30% anchored crop residue in rice-maize rotation. Irrespective of the tillage systems, minimum total weed density (403/m^2) and weed dry biomass (213.4 g/m^2) was recorded in the rice-maize system followed by rice-lentil and rice-wheat systems. As compared to RT and RT30, CT system had reduced the total weed density and weed biomass in rice-wheat system, but promoted the weed infestation in rice-lentil rotation (**Table 5**). Tillage changes vertical distribution of weed seeds in soil profile and soil physical properties, and affects emergence and seed survival of weeds through changes in soil conditions (Chauhan *et al.* 2006) and determines weed seedling emergence and species composition (Sosnoskie *et al.* 2006, Murphy *et al.* 2006).

Maximum density and dry weight of broadleaved weed *T. portulacastrum* were recorded under CT than the other tillage practices. Among the crop rotations, maximum density and dry biomass of this weed were recorded in rice-wheat system followed by rice-lentil and rice-maize systems. Regarding interactive effects, density of *T. portulacastrum* was the highest in rice-wheat rotation under RT30 than other rotations and tillage systems (**Table 3**). However, rice-lentil rotation under RT30 and rice-maize rotation under RT helped to reduce the weed density than the other systems. In spite of the highest density of *T. portulacastrum* in rice-wheat system under RT30, its dry biomass was the lowest. Similarly, other crop rotations in combination with RT30 recorded the lowest dry biomass of this weed. The lowest weed dry biomass of *T. portulacastrum* was recorded in rice maize rotation under RT30. Crop residues have an impact on weed ecology (Chauhan *et al.* 2012). Presence of crop residues can influence weed emergence by altering soil moisture, light transmission or through allelopathic effects (Chauhan *et al.* 2012). Rice-wheat rotation probably created favourable conditions for germination and seedling emergence of the dominant broad-leaved weed *T. portulacastrum* as compared to rice-lentil and rice-maize rotations. In present study, compared to CT, reduced tillage with 30% crop residues (RT30) stimulated the emergence of *T. portulacastrum* in rice-wheat system, but suppressed its emergence in rice-lentil system.

Table 1. Weed density (no./m^2) in summer (pre-*Kharif*) season as influenced by tillage practices and cropping systems

Treatment	Broad-leaved weeds								Sedge	Grasses				Others
	TP	PA	PO	EA	AV	AP	SN	CA	CR	BR	CD	EC	DS	
Tillage practice														
CT	26.50	8.80	8.28	1.87	1.87	3.34	3.25	1.22	3.53	6.67	2.12	3.39	1.22	3.25
	(702)	(77)	(68)	(3)	(3)	(10)	(5)	(1)	(12)	(44)	(4)	(11)	(1)	(5)
RT	25.11	8.03	8.09	2.92	2.78	4.85	2.91	1.58	2.35	8.03	4.53	2.91	1.22	1.58
	(630)	(64)	(65)	(8)	(7)	(23)	(8)	(2)	(5)	(64)	(20)	(8)	(1)	(2)
RT30	26.33	6.36	8.22	2.35	2.12	3.08	5.05	1.58	2.74	7.65	4.42	2.74	3.39	2.55
	(693)	(40)	(67)	(5)	(4)	(9)	(25)	(2)	(7)	(58)	(19)	(7)	(11)	(6)
LSD (p=0.05)	1.16	0.35	NS	0.23	0.16	0.14	0.23	0.07	0.26	0.40	0.15	0.18	0.09	0.10
Cropping system														
Rice-Wheat	39.52	3.24	2.74	2.12	0.71	1.22	3.67	1.22	1.58	7.91	1.87	0.71	0.71	2.74
	(1561)	(10)	(7)	(4)	(0)	(1)	(13)	(1)	(2)	(62)	(3)	(0)	(0)	(7)
Rice-Lentil	20.06	11.89	4.85	2.35	1.22	0.71	3.39	1.58	4.53	8.63	5.96	2.35	3.39	1.87
	(402)	(141)	(23)	(5)	(1)	(0)	(11)	(2)	(20)	(74)	(35)	(5)	(11)	(3)
Rice-Maize	7.84	5.52	13.09	2.55	3.81	6.52	3.54	1.58	1.87	5.52	2.12	4.74	1.22	1.87
	(61)	(30)	(171)	(6)	(14)	(42)	(12)	(2)	(3)	(30)	(4)	(22)	(1)	(3)
LSD (p=0.05)	1.55	0.34	0.42	0.14	0.11	0.12	0.NS	0.05	0.14	0.37	0.09	0.10	0.08	0.07

Data subjected to square root transformation $\sqrt{x+0.5}$, Values in parentheses are original, CT=Conventional tillage, RT=Reduced tillage, RT30= RT + 30% crop residues

TP- *T. portulacatrum;* PA- *P. aviculare;* PO- *P. oleracea;* EA- *E. alba;* AV- *A. viridis;* AP- *A. pungens;* SN- *S. nigrum;* CA- *C. album;* CR- *C. rotundus;* BR- *B. ramose;* CD- *C. dactylon;* EC- *E. colona;* DS- *D. sangualis*

Density of *P. aviculare* was the highest under CT (**Table 1**), but the dry biomass was higher under RT than the other tillage systems (**Table 2**). Among crop rotations, maximum density and dry biomass of this weed were recorded in rice-lentil rotation than the other rice-based cropping systems (**Table 3** and **4**). *P. aviculare* was the most prevalent in rice-lentil rotation with CT and rice-maize rotation with RT compared with the other systems (**Table 3**). In contrast to these, rice-wheat rotation had minimum density and dry weight of this weed (**Table 3**).

Tillage systems did not show significant influence the density of *P. oleracea* (**Table 1**). The dry biomass of *P. oleracea* was, however significantly higher in CT than the other tillage systems (**Table 2**). Among crop rotations, maximum density and dry weight were recorded in rice-maize rotation followed by rice-lentil and rice-wheat rotations. *P. oleracea* was more prevalent in rice-maize system with RT and RT30 than the CT system. However in rice-lentil rotation, CT system favoured this weed compared to other tillage systems.

Table 2. Weed dry matter (g/m^2) in summer (pre-*Kharif)* season as influenced by tillage practices and cropping systems

Treatment	Broad-leaved weeds								Sedge	Grasses				Others
	TP	PA	PO	EA	AV	AP	SN	CA	CR	BR	CD	EC	DS	
Tillage practice														
CT	10.24	3.87	7.09	2.00	1.58	2.72	3.06	0.95	3.37	3.91	1.91	2.57	1.14	2.43
	(104.4)	(14.5)	(49.8)	(3.5)	(2.0)	(6.9)	(8.9)	(0.4)	(10.9)	(14.8)	(3.15)	(6.1)	(0.8)	(5.4)
RT	9.65	5.41	4.63	3.00	2.12	3.18	4.12	1.52	2.26	4.65	3.56	1.87	1.18	1.63
	(92.6)	(28.8)	(20.9)	(8.5)	(4.0)	(9.6)	(16.5)	(1.7)	(4.6)	(21.1)	(12.2)	(3.0)	(0.9)	(2.16)
RT30	8.18	3.42	5.54	2.26	1.79	2.70	6.65	1.30	2.51	4.12	3.48	1.81	4.00	2.33
	(66.5)	(11.2)	(30.2)	(4.6)	(2.7)	(6.8)	(43.7)	(1.19)	(5.8)	(16.5)	(11.6)	(2.8)	(15.5)	(4.92)
LSD (p=0.05)	0.52	0.25	0.37	0.23	0.12	0.12	0.31	0.07	0.12	0.29	0.16	0.14	0.18	0.11
Cropping system														
Rice-Wheat	13.11	3.15	2.81	2.21	0.71	1.09	4.86	1.00	1.31	4.32	1.67	0.71	0.71	2.57
	(171.5)	(9.4)	(7.4)	(4.4)	(0)	(0.7)	(23.1)	(0.5)	(1.21)	(18.2)	(2.3)	(0)	(0)	(6.1)
Rice-Lentil	7.76	5.48	5.12	2.43	0.89	0.71	4.58	1.41	4.28	5.13	4.66	1.52	4.00	1.89
	(59.7)	(29.5)	(25.7)	(5.4)	(0.3)	(0)	(20.0)	(1.5)	(17.8)	(25.7)	(21.2)	(1.7)	(15.5)	(3.1)
Rice-Maize	5.72	3.99	8.26	2.68	2.98	4.81	5.15	1.38	1.67	2.98	2.00	3.29	1.52	1.95
	(32.2)	(15.4)	(67.8)	(6.7)	(8.4)	(22.6)	(26.0)	(1.4)	(2.3)	(8.4)	(3.5)	(10.3)	(1.7)	(3.3)
LSD (p=0.05)	0.55	0.20	0.27	0.14	0.09	0.09	0.23	0.04	0.11	0.22	0.14	0.10	0.18	0.10

Data subjected to square root transformation $\sqrt{x+0.5}$, Values in parentheses are original, CT=Conventional tillage, RT=Reduced tillage, RT30= RT + 30% crop residues

TP- *T. portulacatrum;* PA- *P. aviculare;* PO- *P. oleracea;* EA- *E. alba;* AV- *A. viridis;* AP- *A. pungens;* SN- *S. nigrum;* CA- *C. album;* CR- *C. rotundus;* BR- *B. ramosa;* CD- *C. dactylon;* EC- *E. colona;* DS- *D. sanguinalis*

Table 3. Interaction effect of tillage and cropping systems on density and dry weight of major weeds in pre-*Kharif* season

Treatments	*T. portulacastrum*			*P. aviculare*			*P. oleracea*			Total		
	Rice-Wheat	Rice-Lentil	Rice-Maize	Rice-Wheat	Rice-Lentil	Rice-Maize	Rice-Wheat	Rice-Lentil	Rice-Maize	Rice-Wheat	Rice-Lentil	Rice-Maize
Weed density (no./m^2)												
CT	37.14	25.40	9.03	3.58	14.67	1.87	2.12	7.15	12.24	38.07	32.18	18.77
	(1379)	(645)	(81)	(12)	(215)	(3)	(4)	(51)	(149)	(1449)	(1035)	(352)
RT	37.48	21.36	5.47	3.98	9.80	9.04	1.08	3.72	13.50	38.88	27.43	21.47
	(1404)	(456)	(30)	(15)	(96)	(82)	(1)	(13)	(182)	(1511)	(752)	(461)
RT + 30% crop	43.58	10.33	8.63	1.22	10.63	2.55	4.06	2.41	13.48	45.27	20.33	19.91
residues	(1899)	(106)	(74)	(1)	(113)	(6)	(16)	(5)	(181)	(2049)	(413)	(396)
	T x CS		CS x T	T x CS		CS x T	T x CS		CS x T	T x CS		CS x T
LSD (p=0.05)	2.47		2.80	0.59		0.63	0.80		0.80	2.86		3.13
Weed dry weight (g/m^2)												
CT	13.54	9.27	6.72	2.86	5.86	1.61	2.75	6.34	10.16	15.03	15.20	15.56
	(183.1)	(85.5)	(44.70)	(7.7)	(33.9)	(2.1)	(7.1)	(39.8)	(102.7)	(225.7)	(230.7)	(241.8)
RT	13.55	8.17	5.38	3.02	6.18	6.39	0.74	5.72	5.56	15.47	15.42	14.42
	(183.1)	(66.2)	(28.5)	(8.6)	(37.7)	(40.3)	(0.1)	(32.2)	(30.5)	(239.0)	(237.3)	(207.7)
RT + 30% crop	12.2	5.30	4.90	3.53	4.19	2.26	3.97	2.40	8.40	16.46	14.66	13.71
residues	(148.3)	(27.6)	(23.5)	(12.0)	(17.10)	(4.6)	(15.2)	(5.3)	(70.20)	(270.6)	(214.5)	(187.6)
	T x CS		CS x T	T x CS		CS x T	T x CS		CS x T	T x CS		CS x T
LSD (p=0.05)	0.93		1.01	0.38		0.38	0.53		0.52	1.10		1.05

Data subjected to square root transformation $\sqrt{x+0.5}$, Values in parentheses are original, CT=Conventional tillage, RT=Reduced tillage, RT30= RT + 30% crop residues

Maximum dry matter of this weed was recorded with rice-maize rotation under CT system. Rice-wheat system with RT almost completely suppressed this weed (**Table 3**). Similarly, rice-lentil system with RT30 and rice-maize system with RT recorded the lowest dry weight of *P. oleracea*.

Rice-maize rotation and RT favoured the density of false daisy [*Eclipta alba* (L.) Hassk.], slender amaranth (*Amaranthus viridis* L.) and khaki weed (*Alternanthera pungens* Kunth.) compared to other rotations and tillage systems (**Table 1**). Density of *S. nigrum* was significantly higher with RT30 compared to CT and RT. Purple nutsedge (*Cyperus rotundus* L.) was the only sedge recorded during summer season. Its density was maximum in CT compared to RT and RT30 (**Table 1**). Among crop rotations, maximum density of this weed was recorded in rice-lentil rotation. Rice-wheat and rice-maize rotations suppressed the density of *C. rotundus* to a great extent. Browntop millet [*Brachiaria ramosa* (L.) Stapf.], bermudagrass [*Cynodon dactylon* (L.) Pers.], Awnless barnyard grass [*Echinochloa colona* (L.) Link.] and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] were the major grassy weeds in the experimental field. Density and dry weight of *B. ramosa* and *C. dactylon* were significantly higher under RT and RT30 as compared to CT system (**Table 1** and **2**). Higher emergence of *C. dactylon* in RT and RT30 was probably due to lower soil disturbance compared to CT, resulting in an increase in its density (Gruber and Claupein 2009). Among crop rotations, rice-lentil system favoured these two weeds as compared to other rotations. Density and dry weight of *E. colona* were in the order of CT>RT>RT30, and maximum density and dry biomass were recorded with rice-maize rotation (**Table 3** and **4**). Similarly, the density and dry biomass of *D. sanguinalis* were higher in RT30 and rice-lentil rotation compared to other tillage systems and crop rotations.

Density and dry matter of weeds during winter season

Mean specific weed density and weed dry biomass recorded during winter season are presented in **Tables 4** and **5** to give an overall effect of the various tillage systems, crop rotations and their interactions on densities and dry weight of major weeds. *S. nigrum*, common lambsquarters (*Chenopodium album* L.), beach launea (*Launaea pinnatifida* Cass.), strawbery clover (*Trifolium fragiferum*L.) (among broad-leaved weeds), *C. rotundus* (among sedges) and *B. ramosa* (among grasses) were the dominant weed species in the experimental plot (**Table 4**). Irrespective of the tillage systems, minimum total weed density and dry biomass was recorded with rice-wheat crop rotation followed by rice-lentil and rice-maize rotations. The lowest total weed density and dry weight was recorded with CT followed by RT and RT30 systems (**Table 6**). The minimum total weed density (118/m^2) was recorded with RT30 in rice-wheat rotation, whereas the minimum total weed dry matter (6.32 g/m^2) was recorded with CT system in rice-maize rotation. As compared to RT and RT30, CT system had reduced the total weed density and weed dry biomass in rice-maize system, but promoted the weed infestation in rice-wheat rotation.

Maximum density (**Table 4**) and dry weight (**Table 5**) of broadleaved weed *S. nigrum* were recorded under RT30 followed by RT and CT systems. Increase in density of *S. nigrum* under RTR30 was 471 and 119 per cent higher over CT and RT, respectively. Among the crop rotations, maximum density and dry biomass of this weed were recorded in rice-maize rotation followed by rice-wheat and rice-lentil systems. Regarding interactive effects, density and dry weight of *S. nigrum* were the highest in rice-maize rotation under RT30 than other rotations and tillage systems (**Table 6**). However, RT in rice-lentil and rice-wheat rotations helped to reduce

Table 4. Weed density (no./m^2) as influenced by different tillage and cropping systems in winter (*Rabi*) season

Treatments	*S. nigrum*	*C. album*	*L. pinnatifida*	*T. fragiferum*	*C. rotundus*	*B.ramosa*	Others
Tillage practice							
CT	11.73(137)	4.18(17)	1.87(3)	1.22(1)	1.58(2)	2.74(7)	5.43(29)
RT	18.88(356)	3.81(14)	0.71(0)	0.71(0)	1.22(1)	5.61(31)	6.67(44)
RT30	27.97(782)	3.24(10)	4.85(23)	0.71(0)	1.58(2)	3.67(13)	6.74(45)
LSD (p=0.05)	1.08	0.16	0.10	0.07	0.04	0.32	0.65
Cropping system							
Rice-wheat	11.64(135)	1.87(3)	2.00(4)	1.22(1)	0.71(0)	4.43(19)	2.74(7)
Rice-lentil	7.71(59)	5.79(33)	4.64(21)	0.71(0)	2.34(5)	1.58(2)	10.51(110)
Rice-maize	32.90(1082)	2.55(6)	0.71(0)	0.71(0)	0.71(0)	5.52(30)	2.12(4)
LSD (p=0.05)	0.84	0.18	0.08	0.06	0.06	0.17	0.38

Data subjected to square root transformation $\sqrt{x+0.5}$, Values in parentheses are original, CT=Conventional tillage, RT=Reduced tillage, RT30= RT + 30% crop residues the weed density than the other systems. Higher weed density and dry weight of *S. nigrum* in rice-maize rotation under RT30 and RT system compared to CT system is probably attributed to greater soil moisture that promoted germination and reduced the resistance of soil to seedling emergence (Morton and Buchele 1960).

Density and dry biomass of *C. album* were the highest under CT (**Table 4** and **5**). This may be due to the effect of CT on the vertical distribution of weed seed bank in a silt loam soil. Association of *C. album* with CT in many crops has also been reported (Swanton *et al.* 1999, Shrestha *et al.* 2002). *C. album* was the most prevalent in rice-lentil rotation with RT and rice-maize rotation with CT compared with the other systems (**Table 6**). The *C. album* seeds may have been brought up to the surface under CT, but the lesser competitiveness of lentil compared to wheat and winter maize might have increased its population in rice-lentil system. In contrast to these, rice-wheat rotation had minimum density and dry weight of *C. album* (**Table 4** and **5**). Density and dry biomass of *L. pinnatifida* were the highest in rice-lentil rotation under RT30 than the other rotations and tillage systems (**Table 6**). Population of *C. rotundus* was very less and observed only in rice-lentil system. Rice-maize rotation and RT favoured the density of *B. ramosa* compared to other rotations and tillage systems. Rice-lentil rotation and CT suppressed the growth of *B. Ramosa.* Population density of perennial weed *C. rotundus* increased in CT compared to other tillage systems. *C. rotundus* multiplies rapidly through tubers which can be greatly accelerated by conventional tillage.

Tillage systems and crop rotations had significant influence on weed infestation and species

Table 5. Weed dry weight (g/m^2) as influenced by different tillage and cropping systems in winter (*Rabi)* season

Treatments	*S. nigrum*	*C. album*	*L. pinnatifida*	*T.fragiferum*	*C. rotundus*	*B.ramosa*	Others
Tillage practice							
CT	2.22(4.43)	1.20(0.97)	1.14(0.80)	0.82(0.20)	0.79(0.13)	1.06(0.63)	0.95(0.41)
RT	4.02(15.70)	1.15(0.97)	0.71(0)	0.71(0)	0.88(0.27)	1.56(1.93)	1.57(1.97)
RT30	4.79(23.03)	1.01(0.53)	2.25(4.58)	0.83(0.20)	0.82(0.20)	1.03(0.57)	1.39(1.43)
LSD (p=0.05)	0.20	0.05	0.11	0.06	0.04	0.32	0.13
Cropping system							
Rice-wheat	2.72(6.90)	0.84(0.20)	1.19(0.93)	0.83(0.20)	0.71(0)	1.37(1.37)	0.93(0.37)
Rice-lentil	1.69(2.37)	1.45(1.60)	2.22(4.43)	0.83(0.20)	1.02(0.53)	0.92(0.37)	1.86(2.97)
Rice-maize	5.87(33.90)	1.08(0.67)	0.71(0)	0.71(0)	0.71(0)	1.37(1.40)	0.98(0.47)
LSD (p=0.05)	0.16	0.05	0.04	0.04	0.03	0.05	0.07

Data subjected to square root transformation $\sqrt{x+0.5}$, Values in parentheses are original, CT=Conventional tillage, RT=Reduced tillage, RT30= RT + 30% crop residues

Table 6. Interaction effect of tillage and cropping systems on density and dry weight of major weeds in winter (*Rabi)* season

Treatment	*S. nigrum*			*C. album*			*L. pinnatifolia*			Total		
	Rice-Wheat	Rice-Lentil	Rice-Maize	Rice-Wheat	Rice-Lentil	Rice-Maize	Rice-Wheat	Rice-Lentil	Rice-Maize	Rice-Wheat	Rice-Lentil	Rice-Maize
Weed density (no./m^2)												
CT	13.70 (187)	9.30 (86)	11.80 (139)	2.93 (8)	5.87 (34)	3.23 (10)	2.97 (8)	0.71 (0)	0.71 (0)	14.53 (211)	14.73 (217)	12.78 (162)
RT	10.20 (104)	5.07 (25)	30.67 (939)	0.70 (0)	6.37 (40)	1.57 (2)	0.71 (0)	0.71 (0)	1.58 (2)	13.07 (170)	13.53 (183)	31.40 (987)
RT 30	10.67 (113)	8.10 (65)	46.57 (2167)	0.70 (0)	4.97 (24)	2.73 (7)	2.37 (5)	7.97 (63)	0.71 (0)	10.90 (118)	16.93 (286)	47.10 (2219)
	T x CS	CS x T		T x CS	CS x T		T x CS	CS x T		T x CS	CS x T	
LSD (p=0.05)	1.59	1.60		0.29	0.32		0.15	0.15		2.01	1.99	
Weed dry matter (g/m^2)												
CT	2.53 (5.90)	1.82 (2.80)	2.66 (4.60)	1.05 (0.60)	1.41 (1.50)	1.14 (0.80)	1.70 (2.40)	0.71 (0)	0.70 (0)	3.22 (9.90)	2.64 (6.50)	2.61 (6.32)
RT	2.81 (7.40)	1.41 (1.50)	6.22 (38.20)	0.71 (0)	1.63 (2.10)	1.14 (0.80)	0.71 (0)	0.71 (0)	0.82 (0.60)	3.56 (12.20)	2.95 (8.20)	6.57 (42.70)
RT 30	2.81 (7.40)	1.82 (2.80)	7.71 (58.90)	0.71 (0)	1.30 (1.20)	0.95 (0.40)	0.95 (0.40)	3.71 (13.30)	0.71 (0)	2.88 (7.80)	4.81 (22.70)	7.85 (61.10)
	T x CS	CS x T		T x CS	CS x T		T x CS	CS x T		T x CS	CS x T	
LSD (p=0.05)	0.31	0.30		0.09	0.08		0.08	0.08		2.07	2.01	

Data subjected to square root transformation $\sqrt{x+0.5}$, Values in parentheses are original, CT=Conventional tillage, RT=Reduced tillage, RT30= RT + 30% crop residues, T=Tillage, CS=Cropping system composition in rice-based cropping systems. The effect of crop rotation was more pronounced than the tillage system. The present study revealed that rice-wheat cropping system encourages the weed problems whereas rice-winter maize rotation reduces the weed growth. Reduced tillage with 30% residues retention (RTR30) favoured the infestation of dominant broadleaved weed *T. portulacastrum* in rice-wheat cropping system, whereas rice-winter maize system had strong suppressive effect against this weed in different tillage systems. But rice-maize rotation favoured the infestation of *P. oleracea* and *S. nigrum*. These findings suggest that both tillage system and crop rotation strategies are significant considerations while developing sustainable and eco-friendly weed management strategies.

REFERENCES

Bhatt R, Kukal SS, Busari MA, Arora S and Yadav M. 2016. Sustainability issues on rice-wheat cropping system. *International Soil and Water Conservation Research* **4**: 64–74.

Chauhan BS, Gill G and Preston C. 2006. Influence of tillage system on vertical distribution, seedling recruitment and persistence of rigid rye grass (*Lolium rigidorum*) seedbank. *Weed Science* **54**: 669–676.

Chauhan BS, Singh RG and Mahajan G. 2012. Ecology and management of weeds under conservation agriculture: A review. *Crop Protection* **38**: 57–65.

Gruber S and Claupein W. 2009. Effect of tillage intensity on weed infestation in organic farming. *Soil and Tillage Research* **105**: 104–111.

Kumar V, Singh S, Chhokar RS, Malik RK, Brainard DC and Ladha JK. 2013. Weed management strategies to reduce herbicide use in zero-till rice-wheat cropping systems of the Indo-Gangetic plains. *Weed Technology* **27**: 241–254.

Ladha JK, Pathak H, Padre AT, Dave D and Gupta RK. 2003. Productivity trends in intensive rice–wheat cropping systems in Asia, pp. 45–76. In: *Improving the Productivity and Sustainability of Rice–Wheat Systems: Issues and Impacts.* (Ed. Ladha, JK) ASA Special Publication No. 65, ASA, CSSA, and SSSA, Madison, WI, USA.

Malik RK, Kumar V, Yadav A and McDonald A. 2014. Conservation agriculture and weed management in south Asia: Prospective and development. *Indian Journal of Weed Science* **46**: 31–35.

Morton CT and Buchele WF. 1960. Emergence energy of plant seedlings. *Agricultural Engineering* **41**: 428–431.

Murphy SD, Clements DR, Belaoussoff S, Kevan PG and Swanton CJ. 2006. Promotion of weed species diversity and resuction of weed seed banks with conservation tillage and crop rotation. *Weed Science* **54**: 263–273.

Nichols V, Verhulst N, Cox R and Govaerts B. 2015. Weed dynamics and conservation agriculture principles: A review. *Field Crops Research* **183**: 56–68.

Rao AN, Johnson DE, Sivaprasad B, Ladha JK and Mortimer AM. 2007. Weed management in direct-seeded rice. *Advances in Agronomy* **93**: 153–255.

Shrestha A, Knejevic SZ, Roy RC, Ball-Coelho BR and Swanton CJ. 2002. Effect of tillage, cover crop and crop rotation on the composition of weed flora in a sandy soil. *Weed Research* **42**: 76–87.

Singh RK, Bohra JS, Srivastava VK and Singh RP. 2008. Effect of diversification of rice-wheat system on weed dynamics in rice. *Indian Journal of Weed Science* **40**(3&4): 128–131.

Sosnoskie LM, Herms CP and Cardina J. 2006.Weed seed bank community composition in a 35 years old tillage and rotation experiment. *Weed Science* **54**: 263–273.

Swanton CJ, Shrestha A, Knezevic SZ, Roy RC and Ball-Coelho BR. 1999. Effect of tillage systems, N, and cover crop on the composition of weed flora. *Weed Science* **47**: 454–461.

Timsina J, Jat ML and Majumdar K. 2010. Rice-maize systems of South Asia: current status, future prospects and research priorities for nutrient management. *Plant and Soil* **335**: 65–82.

Indian Journal of Weed Science **51**(2): 123–128, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Control of herbicide resistant *Phalaris minor* by pyroxasulfone in wheat

Tarundeep Kaur*, M.S. Bhullar and Simerjeet Kaur

Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab 141 004, India

**Email: tarundhaliwal@pau.edu*

Article information

DOI: 10.5958/0974-8164.2019.00028.5

Type of article: Research article

Received : 3 May 2019
Revised : 21 June 2019
Accepted : 24 June 2019

Key words

Phalaris minor

Pyroxasulfone

Resistance

Wheat grain yield

ABSTRACT

Evolution of multiple herbicide resistance in *Phalaris minor* in wheat has resulted from the repeated use of herbicides with a similar mode of action which could threaten the sustainability of the rice-wheat cropping system in North-West India. In this context, field studies were conducted at Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana during 2011-12, 2012-13 and 2013-14 in randomized block design replicated four times and at farmer's field during 2016-17 and 2017-18 with the objective to evaluate the efficacy of herbicide with alternative mechanism of action for the control of resistant *P. minor* in wheat. The treatments included pyroxasulfone 85, 102, 127.5 g/ha, pendimethalin 750 g/ha as pre-emergence (PE), sulfosulfuron 25 g/ha, clodinafop 60 g/ha as post-emergence (PoE) and unsprayed control. However, the treatments during 2013-14 included pyroxasulfone 85, 102, 127.5 g/ha, pendimethalin 750 g/ha and unsprayed control with pendimethalin 1125 g/ha as PE at farmers' field instead of pendimethalin 750 g/ha. The results indicated that pyroxasulfone at 127.5 g/ha recorded effective control of *P. minor* and its biomass and gave the highest wheat grain yield (4.87, 4.80 and 5.43 t/ha) during 2011-12, 2012-13 and 2013-14, respectively. At farmer's field, pyroxasulfone 127.5 g/ha has been found effective against the resistant populations of *Phalaris* with 5.37 and 5.42 t/ha grain yield. The current study demonstrated that PE application of pyroxasulfone at 127.5 g/ha would be a suitable option for the control of resistant populations of *Phalaris* in wheat in Punjab.

INTRODUCTION

The rice-wheat cropping system is the most commonly followed cropping system in irrigated ecologies of North-West India. Wheat (*Triticum aestivum* L.) is an important cereal crop of Punjab, which is a highly productive zone in the Indo-Gangetic Plains and contributes about 69% of the total food output in the country (about 84% wheat and 54% rice). Punjab is the major wheat growing state in India with an area of 3.5 million ha, 16.1 million tonnes of production and productivity of 4.58 t/ha (Anonymous 2017). In rice-wheat cropping system, *Phalaris minor* Retz. is still the most pernicious and competitive weed in wheat in Punjab, causing significant yield losses in north-west India including Punjab, Haryana, Western Uttar Pradesh states of the north-western Indo-Gangetic Plains of India. Severe reductions in grain yield of wheat have been reported by many researchers.

Being the most problematic weed in wheat, it has a long track record of developing resistance to many herbicides. Continuous use of isoproturon in wheat for more than a decade led to the evolution of resistance in *P. minor* in the early 1990s (Malik and Singh 1993, Walia *et al*. 1997). It was widely used by the farmers due to its cost effectiveness, wider application window, flexibility in the method of application and broad-spectrum weed kill, along with its fair selectivity under wheat-mustard intercropping (Chhokar *et al*. 2009). Number of other herbicides introduced after isoproturon such as clodinafop, fenoxaprop, sulfosulfuron performed fairly well for several years. Unfortunately, the farmers forgot the golden rule of herbicide rotation and it showed resistance to fenoxaprop, clodinafop and sulfosulfuron. In Punjab, *P. minor* is showing resistance to fenoxaprop, clodinafop and sulfosulfuron and pinoxaden. This indicates multiple-herbicide resistance in *P. minor* across three modes of action: photosynthesis at the photosystem II site, acetyl-coA carboxylase (ACCase), and acetolactate synthase (ALS) inhibitors (Heap 2019). Some herbicide mixtures such as mesosulfuron +

iodosulfuron and fenoxaprop + metribuzin were also introduced for controlling resistant *P. minor*. Pre-mix of fenoxaprop + metribuzin have not been widely used due to the sensitivity of some wheat varieties like '*PBW 550*' to this herbicide. Period of continuous repeated sprays with a similar mode of action herbicides, reduced or overdose application, faulty spray techniques, mixing of two or more chemicals, delay in application leads to the evolution of herbicide resistance of *P. minor* in the state.

Farmers having an infestation of multiple herbicide resistant populations are facing significant yield reductions in the absence of effective alternative herbicides. Till today, microtubule inhibitors, ACCase and ALS-inhibitors are the key herbicide options available for the control of *Phalaris* in wheat in north-west India. In Punjab, herbicide resistance in *P. minor* continues to escalate in wheat which is threatening the grain production and is adding more to farmers' worry. Diversity of weed management programme by using herbicides with different modes of action is important in preventing or delaying the evolution of herbicide-resistant weeds. There is a dire need to have a PE herbicide with a different mode of action and having sufficient residual activity which can prove as an effective tool for managing herbicide resistant *P. minor* in the state. In this context, a new class of herbicide chemistry pyroxasulfone has provided an alternative to already recommended herbicides (ACCase inhibitors, ALS inhibitors, PSII inhibitors) in wheat in Punjab. Pyroxasulfone has provided effective control of group A and B resistant annual ryegrass in wheat for about 10 years in Australia (Boutsalis *et al*. 2014). Currently, there are relatively few data describing the weed control provided by pyroxasulfone across a diverse spectrum of environments (Knezevic *et al.* 2009). It provides an alternative and unique mode of action which makes it an ideal chemical for herbicide group diversification and resistance management (Yamaji *et al.* 2014).

The objective of this research was to standardize the dose of new herbicide pyroxasulfone (PIH 485 85% WG) for the management of herbicide-resistant *P. minor* in wheat through on-station experiments and farmers' participatory trials.

MATERIALS AND METHODS

A field experiment to investigate the effect of new herbicide pyroxasulfone against resistant *P. minor* in wheat was conducted during 2011-12, 2012-13 and 2013-14 at Research Farm, Department of Agronomy, Punjab Agricultural University (PAU), Ludhiana (30° 56' N, 75° 52' E , 247 m above sea level), Punjab, India. The region is characterized by a sub-tropical and semi-arid climate with a hot dry summer (March–June), wet monsoon season (late June–mid September) and cool, dry winter (October–February). The soil of the experimental site at PAU was a sandy loam in texture, normal in reaction (pH 7.2) and electrical conductivity (0.11dS/m), low in organic carbon (0.42%) and available nitrogen (222.2 kg/ha) and very high in available phosphorus (16.9 kg/ha) and potassium (201.43 kg/ha).

The experimental site had been under a rice-wheat system for more than 10 years and having resistant *P. minor* population. The seven treatments in the study included pyroxasulfone at 85, 102 and 127.5 g/ha applied as pre-emergence (PE), pendimethalin 750 g/ha as PE, sulfosulfuron 25 g/ha, clodinafop 60 g/ha were applied as post-emergence (PoE) and unsprayed control. The pre-emergent herbicides were applied immediately after sowing in moist soil, and other post-emergent herbicides were applied at 35 days after sowing (3-4 leaf stage) with a knapsack sprayer fitted with a flat fan nozzle using a spray volume of 500 L/ha. The experiment was conducted in randomized complete block design replicated four times. The wheat variety *'PBW 550'*, *'PBW 621'* and *'HD 2967'* was sown in mid-November of 2011, 2012 and 2013, respectively, by using seed rate of 112.5 kg/ha by seed cum fertilizer drill at 20 cm row spacing. The recommended doses of fertilizers were applied (125 kg N/ha, 50 kg P_2O_5/ha and 30 kg K_2O/ha) to the crop. The source of NPK used was urea, DAP and muriate of potash, respectively. Half of the recommended dose of N and whole of phosphorus and potassium were applied at the time of sowing and the remaining half dose of N was applied as top dressing at the time of first irrigation. All the recommended plant protection measures were carried out as per the local recommendations of the state. The gross plot size was 7 × 3 m.

The data on weed density was recorded from two randomly selected spots for each plot at 70 days after sowing (DAS) using 0.5 × 0.5 m quadrat. Weed biomass was recorded at 70 days after spray by cutting the weed plants above the ground by randomly placing the two quadrats of 0.5 × 0.5 m and then the samples were oven dried at 60 ±2°C until they reached to a constant weight. The data on plant height was collected from five randomly selected plants per plot at the time of harvest. The data on grain yield was taken from the middle of each plot by manually harvesting and threshing the samples at the time of harvest. The wheat crop was harvested at full maturity in mid-April of 2012, 2013 and 2014. An area of 1 m on each side of the plot and one border row on both sides of the experimental plots were harvested first, thereafter the net area separately. The grain weight was recorded at 14% moisture after threshing, cleaning and drying. The grain yield was expressed as tonnes per hectare.

In addition to the experiments at the research farm, farmers' participatory trials were also conducted at farmers' fields in District Moga, India, during 2016-17 and 2017-18 with an objective to assess the performance of new herbicide pyroxasulfone against resistant *P. minor* in real field situations. Based on survey conducted by weed scientists from Punjab Agricultural University, Ludhiana (Punjab) alongwith team from CCS Haryana Agricultural University, Hisar (Haryana) at farmer's field, District Moga (more complaints/ reports of herbicide resistance in wheat from this district), location was chosen at farmer's field where the problem of herbicide resistance was quite high to conduct an experiment. During 2016-17 and 2017-18, the experiment was laid out at the farmer's field. The objective of an experiment was to evaluate the efficacy of new chemistry herbicide pyroxasulfone against resistant *P. minor* in wheat. The soil of the experimental site was loamy sand in texture at farmer's field. The soil was slightly alkaline in reaction (pH 8.2) and electrical conductivity (0.12 dS/m), low in organic carbon (0.33%) and available nitrogen (220 kg/ha) and medium in available phosphorus (16.2 kg/ha) and potassium (271.5 kg/ ha). Wheat variety *'HD 2967'* was sown on 10.11.2016 and 14.11.2017 at farmers' field. The treatments of second experiment at farmers' field included pyroxasulfone 85, 102 and 127.5 g/ha, pendimethalin 1125 g/ha as PE and unsprayed control. The experiments were laid out in a randomized complete block design with three replications, with a plot size of 50 m^2. The observations on weed density and grain yield were taken as explained in Experiment I. The crop was harvested in mid-April 2017 and 2018. The crop was managed according to the standard agronomic practices of the state university. Sampling for grain yield of the crop was done from two random places of 4.0 m × 4.0 m size from each plot at the time of harvesting.

The data of actual number of weeds were transformed by square root transformation for statistical analysis. The data were subjected to the analysis of variance (ANOVA). The significant treatment effect was judged with the help of 'F' test at the 5% level of significance.

RESULTS AND DISCUSSION

Effect on *P. minor*

P. minor was a major grass weed in wheat crop during all the years of investigation. Statistical analysis showed significant differences in weed density and biomass reductions of *P. minor* with pyroxasulfone and pendimethalin. Pyroxasulfone at 102 g and 127.5 g/ha provided effective control of *P. minor* (0 to 5 plants/m^2) during 2011-12 and 2012-13. Sulfosulfuron at 25 g/ha and pyroxasulfone at 85 g/ ha were comparable in providing control of *P. minor* however clodinafop and fenoxaprop recorded significantly more density of *P. minor* but less than unsprayed control (27 and 80 plants/m^2). The highest dose of 127.5 g/ha pyroxasulfone improved the control of *P. minor* (100 and 98.8%) followed by pyroxasulfone 102 g/ha (96.3 and 93.8%) and pendimethalin (96.3 and 93.8%) respectively, in 2011-12 and 2012-13 as compared to unsprayed control. During 2012-13, weed control level increased with the increase in the dose of pyroxasulfone than the other recommended herbicides namely sulfosulfuron and clodinafop. Both sulfosulfuron and clodinafop showed less efficacy on *P. minor*. Pyroxasulfone at 102 and 127.5 g/ha significantly reduced the density of *P. minor* as compared to pyroxasulfone at 85 g/ha and recommended herbicides *i.e.* sulfosulfuron, clodinafop and unsprayed control (**Table 1**). It is clear from the data of weed density that pyroxasulfone 127.5 g/ha had an edge for the control of *P. minor* in wheat. Pyroxasulfone 127.5 g and 102 g/ha gave the best control of *P. minor* as compared to other herbicides. The plots were even free from the second flush of *P. minor*.

Weed biomass also showed a decreasing trend with the increase in the dose of pyroxasulfone during both the years. This could be explained by the evidence that better control of weeds in pyroxasulfone treated plots resulted in significantly less accumulation of weed biomass. Weed biomass at 70 days after spray (DAS) varied significantly among weed control treatments during both the cropping seasons (**Table 1**). In both the years, plots treated with clodinafop, sulfosulfuron and pyroxasulfone 85 g/ha had the highest weed biomass, which was higher than the plots treated with pyroxasulfone 102 g and 127.5 g/ha and pendimethalin 750 g/ha. Pyroxasulfone 127.5 g/ha had the lowest weed biomass (2 g/m^2) than all other treatments during

2011-12 and 2012-13. Weed control efficiency being the highest 88.9 and 99% obtained in pyroxasulfone 127.5 g/ha (**Table 1**). Weed control efficiency followed the trend pyroxasulfone 127.5 g/ha > pyroxasulfone 102 g/ha > pendimethalin 750 g/ha. Pyroxasulfone provided longer weed control than pendimethalin. Weed control efficiency was highest in pyroxasulfone at 127.5 g/ha as it recorded the least density of *P. minor* (**Table 1**) so less weed biomass was obtained. PE application of pyroxasulfone prevented the germination and establishment of resistant *P. minor*. Similarly, pendimethalin also helped in giving weed free environment in the initial days of crop establishment. Therefore, PE herbicides provided weed free environment which gave a strong edge to the crop to flourish. This helps the crop to utilize all the available resources efficiently. Another factor could be that wheat foliage has covered the ground completely which allowed less penetration of light from the wheat foliage, so very less germination of later flush of weeds took place. In PoE applied herbicides *P. minor* compete with the crop for all the available resources in the field nearly for the first 30 days. During 2013-14, pyroxasulfone at 127.5 g/ha had an edge for the control of *P. minor* as compared to its lower doses of 102 and 85 g/ha (**Table 3**).

Pyroxasulfone at 100 g/ha provides efficient control of both herbicide-resistant and susceptible annual ryegrass (*Lolium multiflorum*) populations in wheat (Tanetani *et al.* 2009). Pyroxasulfone provided 88% or better control of kochia (*Kochia scoparia*) and velvetleaf (*Abutilon theophrasti* Medik.) four months after planting, which was greater than metolachlor in furrow-irrigated corn (*Zea mays* L.) (King and Garcia 2008). Pyroxasulfone 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.) (Knezevic *et al.* 2009, Geier *et al.* 2006, Gregory *et al.* 2005).

Effect on crop

There was no significant effect observed on plant height of the crop (**Table 2**). Spike length is an important yield attributing character which is directly related to the number of grains per ear and thus holds significance in determining the grain yield. The herbicide sprayed plots produced significantly more spike length as compared with unsprayed plots. Higher spike length (12 and 11.7 cm) was recorded in pyroxasulfone 127.5 g/ha as compared to check herbicides viz. sulfosulfuron (11.7 and 10.8 cm) and clodinafop (11.6 and 10.5 cm). The differences in spike length were reflected in variation in wheat grain yield under different treatments. All the herbicidal

Table 1. Effect of different weed control treatments on weed density and biomass of *P. minor* in wheat at 70 DAS at Ludhiana

Treatment	Dose (g/ha)	Application time	Weed density (no./m^2)		Weed biomass (g/m^2)		WCE (%)	
			2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Pyroxasulfone	85	PE	2.07 (3)*	3.33 (10)	3.21 (9)	5.0 (24)	50.0	88.3
Pyroxasulfone	102	PE	1.24 (1)	2.38 (5)	2.18 (5)	3.87 (14)	72.2	93.2
Pyroxasulfone	127.5	PE	1.07 (0)	1.38 (1)	1.73 (2)	1.73 (2)	88.9	99.0
Pendimethalin	750	PE	1.30 (1)	2.42 (5)	2.20 (5)	3.83 (14)	72.2	93.2
Sulfosulfuron	25	PoE	2.13 (4)	4.86 (23)	3.44 (11)	5.13 (26)	38.9	87.3
Clodinafop	60	PoE	3.89 (14)	6.28 (39)	3.69 (13)	7.28 (52)	27.8	74.6
Unsprayed control	-	-	5.25 (27)	9.00 (80)	4.35 (18)	14.37(205)	-	-
LSD (p=0.05)			0.61	0.77	0.87	0.56	-	-

*Figures in parentheses are original means and data is subjected to square root transformation; PE - pre-emergence; PoE - Post-emergence

Table 2. Effect of different weed control treatments on growth, yield and yield attributes of wheat at Ludhiana

Treatment	Dose (g/ha)	Application time	Plant height (cm)		Spike length (cm)		Grain yield (t/ha)	
			2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Pyroxasulfone	85	PE	72.5	76.7	11.6	10.8	4.49	4.15
Pyroxasulfone	102	PE	73.1	78.4	11.8	10.9	4.68	4.79
Pyroxasulfone	127.5	PE	72.9	77.3	12.0	11.7	4.87	4.80
Pendimethalin	750	PE	72.4	77.9	11.9	10.9	4.70	4.79
Sulfosulfuron	25	PoE	73.4	76.4	11.7	10.8	4.47	4.39
Clodinafop	60	PoE	74.5	77.2	11.6	10.5	3.66	3.84
Unsprayed control	-	-	70.4	77.3	11.1	8.9	2.89	2.62
LSD (p=0.05)			NS	NS	0.3	0.5	0.19	0.28

PE - pre-emergence; PoE - Post-emergence treatments recorded significantly higher wheat grain yield and yield attributes (spike length) than the unsprayed control during both the years. The grain yield in pyroxasulfone at 102 g and 127.5 g/ha was higher than pyroxasulfone 85 g/ha, sulfosulfuron and clodinafop. In both the years, pyroxasulfone 127.5 g/ha recorded similar wheat grain yield (4.87 t and 4.80 t/ha, respectively in 2011-12 and 2012-13) in the plots treated with 102 g/ha pyroxasulfone (4.68 and 4.79 t/ha, respectively in 2011-12 and 2012-13) (**Table 2**). The data with respect to sulfosulfuron and clodinafop was statistically at par with pyroxasulfone at 102 g/ha and pendimethalin 750 g/ha. It was due to more spike length (**Table 2**) and less *P. minor* density and biomass (**Table 1**). The grain yield was found to be 61.9 and 82.8% more in pyroxasulfone at 102 g/ha than unsprayed plots. The higher grain yield obtained in pyroxasulfone at 102, 127.5 and pendimethalin 750 g/ha might be due to better weed control which resulted in better utilization of available resources. Significantly less grain yield in PoE herbicide sprayed plots was mainly due to more *P. minor* density and weed biomass (**Table 1**). Uncontrolled weed competition throughout the season resulted in the lowest grain yield (2.89 and 2.62 t/ha, respectively) in unsprayed plots (**Table 1**). During 2013-14, pyroxasulfone 127.5 g/ha recorded significantly higher grain yield (5.43 t/ha) than all other herbicide treatments due to better control of *P. minor* (**Table 3**).

Correlation matrix

The data based on 2011-12 and 2012-13 depicted in **Table 5** on the correlation matrix revealed that weed biomass showed negative coefficients. All the yield attributes were found significant with grain yield of wheat. The mean spike length (r=0.94) was found a highly significant and positive correlation with grain yield (**Table 3**). This suggests the inter-dependence of these characters as important yield determinants. The effective control of weeds also led to higher correlation between yield and yield parameters. However, weed biomass has negative relation (r=-0.95) on grain yield. Grain yield of wheat decreased linearly as the weed biomass increased and infestation of *P. minor* accounted for 91.3% variation in grain yield (**Figure 1**).

At farmer's field, during 2016-17 and 2017-18, pyroxasulfone at both 102 and 127.5 g/ha gave effective control of *P. minor* and gave statistically similar wheat grain yield and were at par to pendimethalin 1125 g/ha. PE herbicides pendimethalin 1125 g/ha and pyroxasulfone 127.5 g/ha provided good control of *P. minor* (**Table 4**).

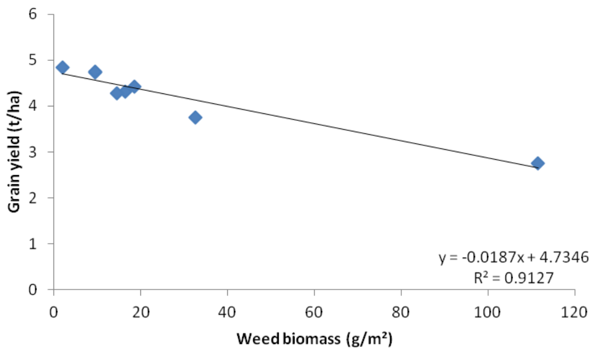


Figure 1. Relationship between weed biomass of *P. minor* and grain yield of wheat (mean of 2011-12 and 2012-13)

Table 3. Effect of different weed control treatments on *P. minor* density and biomass at Ludhiana (2013-14)

Treatment	Dose (g/ha)	*P. minor* density (no./m^2)	*P. minor* biomass (g/m^2)	Wheat grain yield (t/ha)
Pyroxasulfone	85	3.67 (13)*	6.16 (37)	4.31
Pyroxasulfone	102	2.87 (7)	4.21 (17)	5.22
Pyroxasulfone	127.5	1.71 (2)	3.26 (10)	5.43
Pendimethalin	750	3.00 (8)	4.35 (18)	5.19
Unsprayed control	-	9.38 (87)	11.1(122)	3.12
LSD (p=0.05)		0.79	0.44	0.15

*Figures in parentheses are original means and data is subjected to square root transformation

Table 4. Effect of different weed control treatments on *P. minor* density and wheat grain yield at farmer's field (district Moga) in 2016-17 and 2017-18

Treatment	Dose (g/ha)	*P. minor* density at 45 DAS (no./m^2)		Wheat grain yield (t/ha)	
		2016-17	2017-18	2016-17	2017-18
Pyroxasulfone	85	3.59 (12)*	2.99 (8)	4.85	5.03
Pyroxasulfone	102	1.75 (2)	1.63 (2)	5.18	5.36
Pyroxasulfone	127.5	1.49 (1)	1.28 (0.7)	5.37	5.42
Pendimethalin	1125	1.63 (2)	1.82 (2)	5.57	5.40
Unsprayed control	-	16.9 (284)	16.0 (257)	3.92	4.13
LSD (p=0.05)	-	1.06	0.65	0.21	0.11

*Figures in parentheses are original means and data is subjected to square root transformation

Table 5. Correlation matrix among growth and yield attributes, grain yield and weed biomass in wheat (mean of 2011-12 and 2012-13 at Ludhiana)

	Grain yield	1000 grain wt.	Spike length	Plant height	Weed Biomass
Grain yield	1				
1000 grain weight	0.85498**				
Spike length	0.94325**	0.79497**			
Plant height	0.559032	0.237704	0.608222		
Weed biomass	-0.95535	-0. 76495	-0.94509	0.69044	1

**Correlation is significant at 0.01 level (two-tailed)

The findings of the present study provide herbicide options for the management of herbicide resistant *P. minor*. Pre-emergence application of pyroxasulfone at 127.5 g/ha recorded effective control of *P. minor* and gave the highest wheat grain yield during all the years. Pyroxasulfone 127.5 g/ha and pendimethalin 1125 g/ha, as a single pre-emergence herbicide, has proved quite effective against resistant *P. minor* at farmers' field. PE herbicides emerged from this study will help in delaying the process of cross and multiple resistance development in *P. minor* particularly in Punjab. However, there is a need to evaluate pyroxasulfone under different soil textures and moisture conditions for the management of multiple herbicide-resistant *P. minor*. Its field efficacy will depend on its large scale field use after availability to the farmers. These results indicate that pyroxasulfone has the potential being a PE herbicide to be a valuable tool for wheat growers to control resistant *P. minor* populations in wheat in future.

ACKNOWLEDGMENT

The financial assistance from PI Industries Ltd. is thankfully acknowledged. The guidance and financial assistance from authorities of Punjab Agricultural University, Ludhiana, India is thankfully acknowledged.

REFERENCES

Anonymous. 2017. *Package of Practices for Rabi Crops.* Punjab Agricultural University, Ludhiana.

Boutsalis P, Gill GS and Preston C. 2014. Control of rigid ryegrass in Australian wheat production with pyroxasulfone. *Weed Technology* **28**: 332–339.

Chhokar RS, Sharma RK and Sharma I. 2009. Weed management strategies in wheat- A review. *Journal of Wheat Research* **4**2: 1–21.

Geier PW, Stahlman PW and Frihauf JC. 2006. KIH-485 and S-metolachlor efficacy comparisons in conventional and no-tillage 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.

Heap I. 2019. International Survey of Herbicide Resistant Weeds. http://www.weedscience.com.

Knezevic SZ, Datta A, Scott J and Porpiglia PJ. 2009. Dose-response curves of KIH-485 for pre-emergence weed control in corn. *Weed Technology* **23**: 34–39.

Malik RK and Singh S. 1993. Evolving strategies for herbicide use in wheat: resistance and integrated weed management. pp. 225–38. *In: Integrated Weed Management for Sustainable Agriculture. Proceedings of the International Symposium*, (Ed. Malik RK), Indian Society Weed Science, Hisar, India.

Tanetani Y, Kaku K, Kawai K, Fujioka T and Shimizu T. 2009. Action mechanism of a novel herbicide, pyroxasulfone. *Pesticide Biochemistry and Physiology* **95** (1): 47–55

Walia SS, Brar LS and Dhaliwal BK. 1997. Resistance to isoproturon in *Phalaris minor* Retz. in Punjab. *Plant Protection* **12**: 138–140.

Yamaji Y, Honda H, Kobayashi M, Hanai R and Inoue J. 2014. Weed control efficacy of a novel herbicide, pyroxasulfone. *Journal of Pesticide Science* **39** (3): 165–169.

Indian Journal of Weed Science **51**(2): 129–132, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Performance of different herbicides on wheat grain yield and correlation between growth and yield attributes of wheat and weeds

Amandeep Kaur* and Samunder Singh

Department of Agronomy CCSHAU, Hisar, Haryana 125 004, India

**Email: aman.in.pau@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00029.7

Type of article: Research article

Received : 16 March 2019
Revised : 1 June 2019
Accepted : 7 June 2019

Key words
Correlation coefficient

Crop growth

Grain yield

Herbicide mixture

Weeds

Wheat

ABSTRACT

A field experiment was conducted at Siswal, Hisar, Haryana during 2016-17 and 2017-18 to study the effect of different herbicides applied alone or mixtures on weeds and yield of wheat (*Triticum aestivum*). Significantly higher grain yield was obtained in weed free treatment, which was statistically similar with pinoxaden + metsulfuron and pendimethalin *fb* pinoxaden treatments, but significantly higher than all other treatments during both the years. Weed free, pinoxaden + metsufuron and pendimethalin *fb* pinoxaden treatments produced 70.9, 67.7 and 64.9; 69.4, 67.0 and 64.3% higher grain yield as compared to weedy check treatment, respectively during 2016-17 and 2017-18. Statistically similar grain yield was recorded in pyroxasulfone and pyroxasulfone + pendimethalin treatments, it was 54.1 and 51.1; 55.3 and 52.4% higher to weedy check treatment, respectively during 2016-17 and 2017-18. Application of flumioxazin and flumioxazin + pendimethalin provided effective weed control, but grain yield was lower due to crop phytotoxicity after first irrigation in light texture soils. Significant positive correlation between grain yield, growth and yield attributes, per cent control of weeds and weed control efficiency, but negative correlation was observed between grain yield and weed dry weight, panicle length, seeds/panicle, test weight of wild oat and weed index.

INTRODUCTION

Wheat is dominant crop in the temperate countries not only for human food, but also for livestock feed. Its success largely depends on adaptability to environmental conditions and agronomic practices. Productivity of wheat is governed by many factors, but one of the most serious and less noticed causes of low yield is the presence of weeds. Weeds reducing 10-82% yield loss depend upon weed density, weed species, time period of infestation and competitive ability of crop plant to weeds under different agro-ecological conditions (Heyne 1987). A lot of research work has been done on weeds in wheat, some of which support that wild oat (*Avena ludoviciana*) and wild canary grass (*Phalaris minor)* are two most dominant grassy weeds making wheat cultivation very difficult and major reasons for low yields (Singh *et al*. 1995). Wild oat is one of the ten worst annual weeds of temperate agricultural regions in the world (Holm *et al.* 1991) and difficult to control because of initial morphological and physiological similarities to wheat plants and long phase of emergence. While the weeds are a strong competitor for water and nutrients (Gonzaliz-Ponce and Santin 2001) grassy weed competes more vigorously with cereals. Although herbicides have played a vital role in improving crop yield and overall production efficiency, over-reliance and repetitive use of the herbicides belonging to the same site of action can also lead to development of herbicide resistant (HR) weed biotypes.

Wild oat is most susceptible to development of resistance (De Prado and Franco 2004). Wild oat biotypes have high genetic diversity, aggressive nature and respond to high fertility in comparison to wheat plants. Additionally, wild oat controlled with inhibiting acetyl-CoA carboxylase, characterized by single site of action which leads to selection pressure of resistant individuals in weed population. Nature of weed and herbicide mechanism may cause sudden development of Herbicide resistance (HR) in wild oat. Herbicide resistance action committee (HRAC) documented 43 biotypes of wild oat resistant to herbicides in different parts of world (www.weedscience.com). First case of HR was documented in wild oat with the use of herbicides in ACCase inhibitor group in Western Australia in 1985 (Heap 2015) followed by more reports documented

(Beckie *et al.* 2002). Now-a-days, sole dependence on these group of herbicides led to development of many cases of cross resistance (XR) or multiple-resistance (MR) in wild oat worldwide (Uludag *et al.* 2008). A wild oat population from Fatehabad District, Haryana was however found resistant under field and lab evaluation (Singh 2016, Unpublished data) Singh *et al.* (2016) reported poor efficacy of sulfosulfuron against wild oat and resistance against clodinafop and fenoxaprop to a population from farmer's field. Problem of herbicide resistant weeds is more challenging in the developing countries because of less availability of alternate herbicides for efficient control. Hence, study was carried out to manage *A. ludoviciana* resistant population to 'Fops' below threshold level and assess the effect of different herbicides on yield of wheat.

MATERIALS AND METHODS

Field experiment was conducted at farmer's field at village Siswal, (Longitude 29°23"113' and Latitude 75°47"490') district Hisar (Haryana) during *Rabi* seasons of 2016-17 and 2017-18. Fourteen treatments, *viz.* pendimethalin at 1500 g/ha (PE) *fb* pinoxaden at 50 g/ha (PoE), pendimethalin + metribuzin at 1500 g/ha (PE), metribuzin at175 g/ha (PE), pyroxasulfone at 127.5 g/ha (PE), pyroxa-sulfone at 106 g/ha + pendimethalin at 1000 g/ha (PE), flumioxazin at 100 g/ha (PE), flumioxazin at 80 g/ha + pendimethalin at 1500 g/ha (PE), clodinafop at 60 g/ha + metsulfuron at 4 g/ha (PoE), metribuzin at 175 g/ha (PoE), sulfosufuron + metsulfuron 32 g/ha (PoE), pinoxaden at 50 g/ha + metsulfuron at 4 g/ha (PoE), isoproturon at 1000 g/ha (PoE), weedy check and weed free were evaluated in randomized block design having gross plot size 65.0 x 7.7 m and replicated thrice. Wheat cultivar '*WH-1105*' was sown on November 13, 2016 and November 22, 2017 using a seed rate 100 kg/ha in rows at 20 cm apart.

Crop was fertilized with recommended dose of N 150 kg/ha and P_2O_5 60 kg/ha during both the years. Nitrogen was applied in two equal splits *i.e.* ½ at sowing and remaining ½ with first irrigation. Diammonium phosphate at 130 kg/ha was drilled at the time of sowing providing 23 kg N/ha and 60 kg P_2O_5/ha. Rest of N was applied through urea, broadcast at 52 kg N/hajust before sowing of wheat and at 75 kg N/ha immediately before the first irrigation. Pre-emergence (PE) herbicides were sprayed immediately after sowing, post-emergence (PoE) herbicides applied at 35 DAS with the help of knapsack sprayer fitted with flat fan nozzles using 500 lit/ha spray volume for PE herbicides and 300 lit/ha for PoE herbicides. Growth, yield attributes of crop and weeds and yield was recorded at harvest and statistically analyzed by using software SPSS version 7.5.

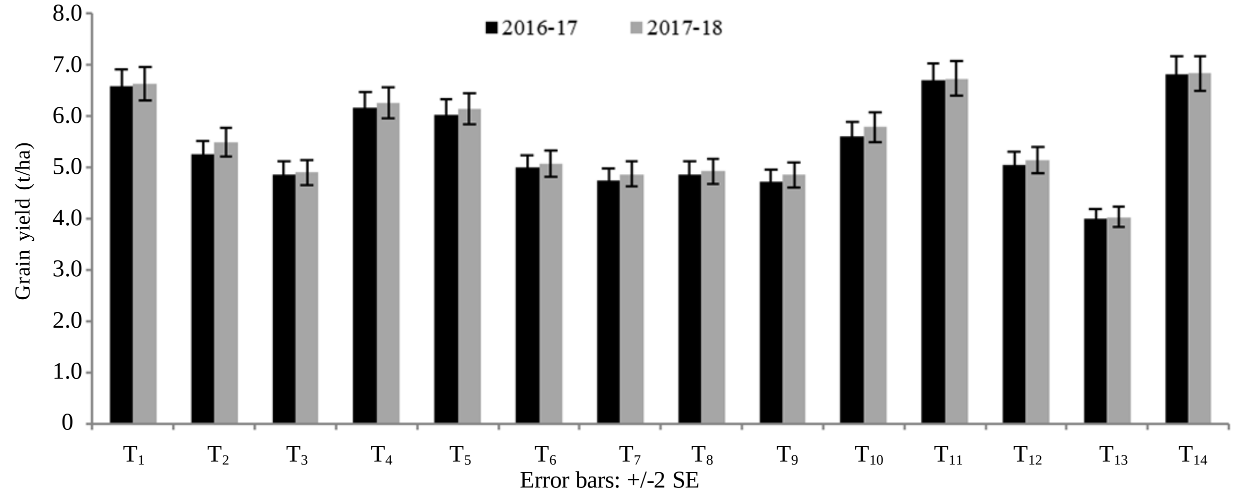
RESULTS AND DISCUSSION

Grain yield

Grain yield was significantly affected with different weed control treatments (**Figure 1**). Significantly higher grain yield in weed free treatment, which was statistically similar with pinoxaden + metsulfuron and pendimethalin *fb* pinoxaden treatments, but significantly higher than all other treatments during both the years. Weed free, pinoxaden + metsufuron and pendimethalin *fb* pinoxaden treatments produced 70.9, 67.7 and 64.9; 69.4, 67.0 and 64.3% higher grain yield as compared to weedy check treatment, during 2016-17 and 2017-18, respectively. Sequential application of herbicides and herbicide mixtures reduced crop-weed competition by killing grassy as well as broad-leaf weeds that helped to wheat for utilization of available nutrients, moisture, light and space more efficiently, thus produced higher tillers, spike length, grains/spike, test weight and hence increase in grain yield and delayed HR in different weed species.

Yadav *et al* (2016) attained wheat grain yields similar to the weed free treatment with sequential application of herbicides as compared to alone herbicides. Pendimethalin + metribuzin and sulfosulfuron + metsulfuron treatments provided statistically similar grain yield, but significantly lower than pinoxaden + metsulfuron and pendimethalin *fb* pinoxaden. Singh *et al.* (2012) reported that sulfosulfuron, pendimethalin + metribuzin and clodinafop was not effective as pinoxaden because all weed cohorts were not killed by alone PE and PoE herbicides, hence weeds were continued to grow and competing with crop plants for the natural resources, thus resulting in poor crop growth in terms of lower dry weight, tillers, grains/spike, 1000 grains weight and finally lower grain yield.

Metribuzin (PE) and (PoE) treatments also provided statistically similar grain yield during both the years but significantly lower than sequential application of pendimethalin *fb* pinoxaden and tank mixture of pinoxaden + metsufuron because alone PE and PoE herbicides did not control all weed cohorts, which resulted in lower grain yield. Statistically similar grain yield was recorded in pyroxasulfone and pyroxasulfone + pendimethalin treatments during



T_1 - Pendimethalin at 1500 g/ha (PE) *fb* pinoxaden at 50 g/ha (PoE); T_2 - Pendimethalin + metribuzin at 1500 g/ha (PE); T_3 - Metribuzin at 175 g/ha (PE); T_4 - Pyroxasulfone at 127.5 g/ha (PE); T_5 - Pyroxasulfone at 106 g/ha + pendimethalin at 1000 g/ha (PE); T_6 - Flumioxazin at 100 g/ha (PE); T_7 - Flumioxazin at 80 g/ha + pendimethalin at 1500 g/ha (PE); T_8 - Clodinafop at 60 g/ha + metsulfuron at 4 g/ha (PoE); T_9 - Metribuzin at 175 g/ha (PoE); T_{10} - Sulfosufuron + metsulfuron 32 g/ha (PoE); T_{11} - Pinoxaden at 50 g/ha + metsulfuron at 4 g/ha (PoE); T_{12} - isoproturon at 1000 g/ha (PoE); T_{13} - Weedy check; T_{14} - Weed free

Figure 1. Grain yield influenced by different weed control treatments

Table 1. Correlation coefficient between different growth and yield attributes of wheat and weeds during 2016-17

Parameter	Grain yield	Plant height	CDW	Spike length	Grains/ spike	Test weight	Mort (%)	WDW	Panicle length	Seeds/ panicle	Test weight	WCE	WI
Grain yield	1												
Plant height	.667**	1											
CDW	.981**	.639*	1										
Spike length	.969**	.611*	.979**	1									
Grains/spike	.986**	.621*	.973**	.985**	1								
Test weight	.981**	.641*	.964**	.956**	.982**	1							
Mortality (%)	.809**	.272	.770**	.780**	.821**	.854**	1						
WDW	-.784**	-.401	-.726**	-.765**	-.827**	-.852**	-.922**	1					
Panicle length	-.937**	-.557*	-.901**	-.914**	-.921**	-.908**	-.839**	.760**	1				
Seeds/panicle	-.865**	-.272	-.844**	-.856**	-.864**	-.851**	-.925**	.797**	.921**	1			
Test weight	-.606*	-.558*	-.632*	-.614*	-.583*	-.621*	-.517	.429	.690**	.559*	1		
WCE	.786**	.401	.727**	.767**	.828**	.854**	.924**	-1.000**	-.762**	-.799**	-.430	1	
WI	-1.000**	-.667**	-.981**	-.970**	-.987**	-.980**	-.809**	.784**	.938**	.866**	.607*	-.786**	1

**Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed)
CWD, crop dry weight; WDW, weed dry weight; WCE, weed control efficiency; WI, weed index.

2016-17 and 2017-18. Pyroxasulfone kill only grass weeds especially littleseed canary grass and wild oat, whereas combination of pyroxsulfone + pendimethalin controlled complex weed flora, thus provide more available nutrients, space, moisture and sun light to crop plants so that crop plants flourish well, resulted in higher tillers and ultimately higher yield.However, pendimethalin was not effective against *A. ludoviciana*. Herbicide resistant weeds like *P. minor* and *R. dentatus* were sensitive to PE herbicides such as pendimethalin, trifluralin, metribuzin, pyroxasulfone and flufencet (Singh 2014, Kaur *et al*. 2017, Punia 2017). Application of flumioxazin and flumioxazin + pendimethalin provided effective weed control, but grain yield was lower due to crop phytotoxicity after first irrigation in light texture soils. Statistically lower grain yield recorded in clodinafop + metsulfuron and isoproturon, due to poor control of HR wild oat. Grassy weeds were strong competitor of cereals than broadleaf weeds, thus resulted in reduction in grain yield of wheat. Singh *et al*. (2016) reported that poor efficacy of sulfosulfuron against wild oat and resistance against clodinafop and fenoxaprop to a population from farmer's field.

Correlation studies

Plant height,dry weight, yield attributes of wheat, mortality percentage in weeds and weed control efficiency (WCE) had significantly positive

Table 2. Correlation coefficient between plant height, crop and wild oat dry weight, yield attributes of wheat and weeds during 2017-18

Parameters	Grain yield	Plant height	CDW	Spike length	Grains/ spike	Test weight	Mort (%)	WDW	Panicle length	Seeds/ panicle	Test weight	WCE	WI
Grain yield	1												
Plant height	.662**	1											
CDW	.978**	.636*	1										
Spike length	.956**	.653*	.942**	1									
Grains/spike	.988**	.632*	.984**	.953**	1								
Test weight	.971**	.695**	.950**	.926**	.978**	1							
Mortality (%)	.828**	.271	.806**	.719**	.814**	.788**	1						
WDW	-.796**	-.395	-.749**	-.712**	-.792**	-.831**	-.917**	1					
Panicle length	-.933**	-.537*	-.899**	-.890**	-.910**	-.852**	-.850**	.767**	1				
Seeds/panicle	-.867**	-.298	-.857**	-.765**	-.869**	-.801**	-.939**	.814**	.927**	1			
Test weight	-.570*	-.495	-.658*	-.558*	-.581*	-.520	-.546*	.456	.651*	.573*	1		
WCE	.797**	.395	.751**	.714**	.793**	.832**	.919**	-1.000**	-.770**	-.816**	-.458	1	
WI	-1.000**	-.662**	-.978**	-.956**	-.988**	-.971**	-.827**	.796**	.933**	.867**	.571*	-.797**	1

** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed)
CWD, crop dry weight; WDW, weed dry weight; WCE, weed control efficiency; WI, weed index.

correlation with grain yield butweed dry weight, panicle length, seeds/panicle, test weight of wild oat were negatively correlated during both the years (**Table 1** and **2**). Highest positive correlation was recorded between grains/spike and grain yield of wheat (0.986**). Grain yield also had positive relationship with crop dry weight (0.981**), test weight (0.981**), spike length (0.969**), mortality percentage in weeds (0.809**), WCE (0.786**), crop growth rate (0.902*) during 1st year. Correlation coefficient was negative between grainyield and weed dry weight(-0.784**), panicle length of wild oat (-0.937**), seeds/panicle (-0.865**), test weight of wild oat (-0.606*) and weed index (-1.000**) during 2016-17. Similar trend was observed in 2017-18.

REFERENCES

Beckie HJ, Thomas AG and Stevenson FC. 2002. Survey of herbicide-resistant wild oat (*Avena fatua*) in two townships in Saskatchewan. *Canadian Journal of Plant Science* **82**: 463–471.

De Prado RA and Franco AR. 2004. Cross-resistance and herbicide metabolism in grass weeds in Europe: Biochemical and physiological aspects. *Weed Science* **52**: 441–447.

Gonzaliz-Ponce R and Santin I. 2001. Competitive ability of wheat cultivars with wild-oats depending on nitrogen fertilization. *Agronomie* **21**: 119–125.

Heap I. 2015. International survey of herbicide resistant weeds. *http://www.weedscience.com*. Accessed 10 May 2015.

Heyne EG. 1987. *Wheat and Wheat Improvement*, 2nd edition Madison, Wisconsin, USA.

Holm LG, Plucknett DL and Pancho JV. 1991. *The World's Worst Weeds. Distribution and Biology*. The University Press of Hawaii, Honolulu, HI.

Kaur M, Punia SS, Singh J and Singh S. 2017. Confirmation of multiple herbicide resistance inlittleseedcanarygrass and possible management with herbicide mixtures and sequences. Pp. 67. In: *Proceedings of Biennial Conference of the Indian Society of Weed Science on "DoublingFarmers' Income by 2022, The Role of Weed Science*", MPUA&T, Udaipur, India during 1-3 March, 2017.

Punia SS. 2017. Bio-efficacy and phytotoxicity evaluation of pendimethalin + metribuzin (RM) PlatForm 385 for the control of weeds in wheat crop and its residual effect on succeeding crops.*Abstracts*. pp. 212. *The 26th Asian-Pacific Weed Science Society Conference-Weed Science for People,Agriculture, and Nature,* September 19-22, 2017, Kyoto, Japan.

Singh R, Shyam R, Singh VK, Kumar J, Yadav SS and Rathi SK. 2012. Evaluation of bioefficacy of clodinafop-propargyl + metsulfuron-methyl against weeds in wheat. *Indian Journal ofWeed Science* **44**(2): 81–83.

Singh S, Dhaka AK and Hooda VS. 2016. Evaluation of Traxos 5% EC (Pinoxaden + Clodinafop propargyl) against *Phalaris minor* and other grassy weeds in wheat. *Haryana Journal ofAgronomy* **31**: 1–8.

Singh S. 2014. Pyroxasulfone efficacy against *Phalaris minor* in Wheat in India. Joint 2014 *Meeting Weed Science Society of America and Canadian Weed Science Society/ Sociétécanadienne de malherbologie.* Vancouver, BC, Canada, Abst. 239.

Singh S. 2016. Clodinafop resistance in a population of *Avena ludoviciana* in wheat in India. pp. 383. In: *Proceedings of 7th International Weed Science Congress June 19-25, 2016* - Prague, Czech Republic.

Singh S, Malik RK, Balyan RS and Singh S. 1995. Distribution of weed flora in wheat in Haryana. *Indian Journal of Weed Science* **27**(3): 114–121.

Uludag A, Park KW, Cannon J and Mallory-Smith CA. 2008. Cross resistance of acetyl-CoA carboxylase (ACCase) inhibitor-resistant wild oat (*Avenafatua*) biotypes in the Pacific Northwest. *Weed Technology* **22**: 142–145.

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

Indian Journal of Weed Science **51**(2): 133–138, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Pre- and post-emergence herbicide sequences for management of multiple herbicide-resistant littleseed canary grass in wheat

Maninder Kaur*, Satbir Singh Punia, Jagdev Singh and Samunder Singh

Department of Agronomy, CCS Haryana Agricultural University, Hisar 125 004, India

[1]Forage and Millet Section, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, Punjab 141 004, India

**Email: maninder.sindhu@yahoo.com*

Article information

DOI: 10.5958/0974-8164.2019.00030.3

Type of article: Research article

Received : 2 March 2019
Revised : 29 May 2019
Accepted : 1 June 2019

Key words

Herbicide sequence

Phalaris minor

Post-emergence

Wheat

ABSTRACT

Littleseed canary grass (*Phalaris minor*) is the ubiquitous and pernicious grass weed of wheat in rice-wheat cropping system in north-western Indo- Gangetic plains of India. A field experiment was conducted during *Rabi* 2014-15 and 2015-16 in a farmers field infested with *P. minor* having history of poor control with acetyl-CoA-carboxylase inhibitors in village Nangla, district Fatehabad, Haryana, India with an objective to compare pre-emergence only, post-emergence only and pre-emergence followed by post-emergence herbicide treatments for control of *P. minor* in wheat. The sequential application of pre-emergence pendimethalin 1.5 kg/ha *fb* post-emergence pinoxaden + metsulfuron 64 g/ha and pre-emergence pendimethalin 1.5 kg/ha *fb* post-emergence mesosulfuron + iodosulfuron 14.4 g/ha provided 88-93% control of *P. minor* compared to alone pre- and post-emergence herbicide treatments. Grain yield of wheat increased significantly by 69-78% with pre-emergence pendimethalin 1.5 kg/ha *fb* post-emergence pinoxaden + metsulfuron 64 g/ha or pre-emergence pendimethalin 1.5 kg/ha *fb* post-emergence mesosulfuron + iodosulfuron 14.4 g/ha due to significant increase in yield attributes. Alone pre- or post-emergence herbicides provided ineffective control of *P. minor* (44-66%) and recorded lower grain yield. It was concluded that herbicide sequences having both pre- and post-emergence herbicides would be better option as compared to their alone applications in order to manage resistant populations of *P. minor* in wheat.

INTRODUCTION

Littleseed canary grass (*Phalaris minor* Retz.) is a native weed of Mediterranean region, and is widely distributed in many parts of the world covering all the continents except the Polar Regions (Singh *et al.* 1999). In India, it is the pervasive and most troublesome grass weed of irrigated wheat in rice-wheat cropping system in the northwestern Indo-Gangetic plains (Punia *et al.* 2017). Although *P. minor* infests several winter season crops but it has become pernicious in wheat due to its similar morphology and growth requirements. It emerges with the germinating wheat crop, competes for water and nutrients, and sig-nificantly reduces the grain yield due to its highly competitive ability.

Herbicides were largely accepted by the farmers to control this notorious weed. Isoproturon, a urea substituted herbicide, was the sole herbicide used for more than 15 years which provided very effective control of *P. minor* until the evolution of resistance in 1990s in Haryana and Punjab (Malik and Singh 1995). The indiscriminate and continuous use of isoproturon for more than a decade with an unbroken rice-wheat cropping pattern accentuated by poor application rates, spray techniques and timing, led to resistance in *P. minor*. An emergency recommendation of diclofop-methyl was made in 1992, which was withdrawn in two years due to the evolution of cross-resistance in *P. minor* without any history of previous use of this herbicide in India (Singh *et al.* 1999). Later, four alternative herbicides, *i.e.*, fenoxaprop, clodinafop, sulfosulfuron and tralkoxydim were recommended during 1997-98 for controlling *P. minor* (Chhokar and Malik 2002). In spite of their new mode of action as compared to isoproturon, these herbicides also met the fate similar to isoproturon after their continuous use for 8-10 years and complaints of their poor efficacy started appearing at farmers' fields (Singh *et al.* 2009).

Hence, new herbicide recommendations such as pinoxaden, mesosulfuron + iodosulfuron were introduced for the control of *P. minor* (Punia *et al.* 2008). However, the dreadful *P. minor* evolved biological defense against these new herbicides too. Some *P. minor* populations from Punjab and Haryana have been found to be insensitive to the application of pinoxaden without any prior history of exposure, indicating evolution of cross-resistance (Kaur *et al.* 2015). Similarly, few populations have been found to have very high GR_{50} value for mesosulfuron + iodosulfuron (Dhawan *et al.* 2012).

With the continued evolution of resistance to post-emergence (PoE) herbicides, the use of pre-emergence (PE) herbicides has emerged as an important approach to manage herbicide resistance. Herbicide-resistant weeds in wheat have been found susceptible to PRE herbicides such as pendimethalin, trifluralin, metribuzin, pyroxasulfone and flufenacet. However, if PE herbicides are used alone, these are not sufficient to achieve the objective of bringing down weed seed bank numbers but when used amongst a suite of tactics, these can be particularly effective. Some of the benefits of using PRE herbicides are that these offer an alternate mode of action to many PoE herbicides, reduce selection pressure on subsequent PoE herbicide applications and remove much of the early season weed competitive pressure on the crop (Singh 2015).

The objective of the present work was to investigate sequential applications of pre-emergence herbicides followed by post-emergence herbicides for the effective control of multiple herbicide-resistant *P. minor* in wheat.

MATERIALS AND METHODS

To evaluate the bio-efficacy of PE and PoE herbicides alone and in sequence against resistant *P. minor* in wheat, a field experiment was conducted in village Nangla district Fatehabad of Haryana, India (located at a latitude of 29º52' in the North and longitude of 75º45' in the East) in winter seasons of 2014-15 and 2015-16 in a grower's field infested with *P. minor* with a history of poor control with clodinafop and fenoxaprop. Nangla is characterized by semi-arid climate with hot and dry summers and extremely cold winters. The average annual rainfall varied from 350 to 400 mm. *P. minor* was the predominant weed species at the experimental site along with sparsely distributed broad-leaf weeds. The field had been under wheat in winter season with reliance on post-emergence herbicides mainly ACCase inhibitors for the control of *P. minor* for at least 8 years. The soil at the experimental site was determined as sandy loam in texture, slightly alkaline in reaction (pH 8.3) and normal in electrical conductivity (0.43 dS/m). The soil was found to be low in organic carbon (0.35%), nitrogen (210 kg/ha) and phosphorus (16 kg/ha). However, the soil was high in potassium (407 kg/ha). The wheat variety '*HD-2967*' was planted in a conventionally tilled seed bed using 100 kg seed per ha in rows spaced 18 cm apart. Wheat planting was done on 14^{th} November and 15^{th} November during 2014-15 and 2015-16, respectively. Standard agronomic practices of the state university were followed to raise the crop successfully.

The field experiment was arranged in a randomized complete block design with each treatment replicated thrice. The herbicide treatments evaluated to control resistant *P. minor* consisted of PE pendimethalin + metribuzin at two doses (1000 + 150 and 1500 + 150 g/ha), PoE mesosulfuron + iodosulfuron 14.4 g/ha, PoE sulfosulfuron + metsulfuron 32 g/ha, PoE pinoxaden + metsulfuron 64 g/ha applied alone and in sequences with PE pendimethalin 1.0 and 1.5 kg/ha, early post-emergence (EPoE) sulfosulfuron + metsulfuron 32 g/ha *fb* sulfosulfuron + metsulfuron 32 g/ha, PoE sulfosulfuron + clodinafop 25 + 60 g/ha and EPoE sulfosulfuron 25 g/ha *fb* PoE pinoxaden 60 g/ha. Weed free and weedy treatments were also included for comparison of efficacy. The PE herbicides were applied immediately after sowing in moist soil, EPoE herbicides were applied at 20 DAS and PoE herbicides were applied at 35 DAS with a knapsack sprayer fitted with a flood jet nozzle calibrated to deliver 500 l/ha spray volume for PE herbicides and a flat fan nozzle delivering 375 l/ha spray volume for EPoE and PoE herbicides.

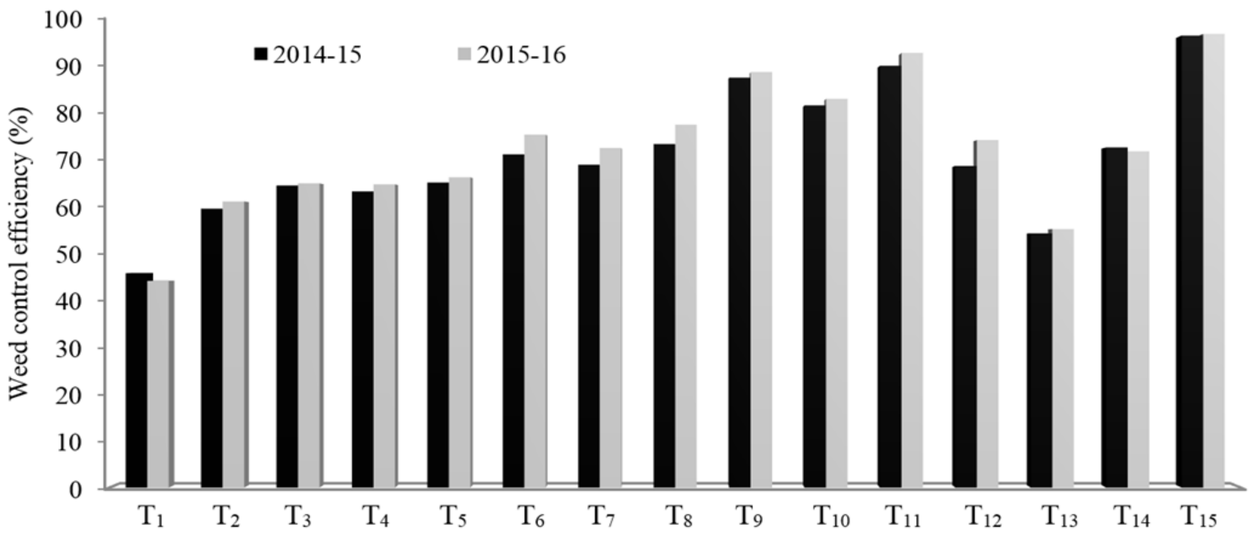
P. minor control was visually assessed at 30, 60, 90 DAS of wheat and at harvest stage of wheat on a scale of 0- to 100% with 0 percent meaning no control of *P. minor* and 100% meaning complete control of *P. minor*. The densities and dry weight of *P. minor* and broad-leaf weeds were also recorded on the same dates as mentioned for the visual control of *P. minor*. The weed samples from two randomly selected places in each plot were taken with the help of a quadrat (0.5 x 0.5 m). Each weed sample was separated as *P. minor* and broadleaf weeds. The number of plants of *P. minor* and broadleaf weeds in each sample was counted and is presented as number of plants/m^2. The plants of *P. minor* and broad-leaf weeds from each quadrat were first dried under the sun and then kept in oven at 65 ± 5^0C until a constant weight was achieved. Then dried weed samples were weighed and the weight taken was expressed as g/m^2. The weed control efficiency was computed as a percent reduction in weed density under different treatments in comparison to weedy at harvest. At physiological maturity, the crop was harvested and the grain yield was adjusted to 14% moisture content.

In order to see the significance of treatment's effect, the data were subjected to the statistical analysis by analysis of variance (ANOVA) technique. The significant treatment effect was judged with the help of F-test at 5 per cent level of significance. The data were analyzed separately for each year. The data on per cent visual weed control and biomass were arcsine and square root transformed, respectively before analysis.

RESULTS AND DISCUSSION

The weed flora of the experimental field constituted mainly of *Phalaris minor*. Broad-leaf weeds were present at comparatively lower densities and consisted mainly of *Chenopodium album*, *Rumex dentatus*, *Anagallis arvensis* and *Medicago denticulata*. The sequential herbicide mixture treatments had significant advantage over alone PE or PoE herbicide treatments in controlling *P. minor* indicated the importance of role of PE residual herbicides followed by PoE herbicides for *P. minor* control. The sequential application of PE pendimethalin 1.5 kg/ha *fb* PoE pinoxaden + metsulfuron 64 g/ha was the most effective treatment and provided 90% control of *P. minor* (**Figure 1**). Yadav *et al.* (2016) also indicated that the sequential application of pendimethalin with POE herbicides could improve weed control when PoE herbicides have a slightly poor efficacy. There was >90% reduction in dry weight of *P. minor* over weedy treatment with PE pendimethalin 1.5 kg/ha *fb* PoE pinoxaden + metsulfuron 64 g/ha (16.8-19.4 g/m^2) followed by 83-88% reduction compared to weedy plots with PE pendimethalin 1.5 kg/ha *fb* PoE mesosulfuron + iodosulfuron 14.4 g/ha (25.5-30.8 g/m^2) and sulfosulfuron + metsulfuron 32 g/ha (33.8-36.7 g/m^2). Sequential application of PE pendimethalin 1.0 kg/ha *fb* PoE herbicides improved weed control compared to alone PE or PoE herbicide treatments, however, their effect was less when compared to PRE pendimethalin 1.5 kg/ha *fb* PoE herbicides (**Table 1**).

Among sequential herbicide treatments, EPoE sulfosulfuron + metsulfuron 32 g/ha *fb* sulfosulfuron + metsulfuron 32 g/ha had more dry weight accumulation by *P minor* (57.2-64.7 g/m^2). PE pendimethalin + metribuzin 1000 + 150 g/ha recorded poor control of *P. minor* during both the seasons. The lack of mortality of *P. minor* plants at lower dose of



T_1- Pendimethalin + metribuzin, PE (1000 + 150 g/h); T_2 - Pendimethalin + metribuzin, PE (1500 + 150 g/ha); T_3 - Mesosulfuron + iodosulfuron, PoE (14.4 g/ha); T_4 - Sulfosulfuron + metsulfuron-methyl, PoE (32 g/ha); T_5 - Pinoxaden + metsulfuron-methyl, PoE (64 g/ha); T_6 - Pendimethalin *fb* mesosulfuron + iodosulfuron, PE/PoE (1000/14.4 g/ha); T_7 - Pendimethalin *fb* sulfosulfuron + metsulfuron-methyl, PE/PoE (1000/32 g/ha); T_8 - Pendimethalin *fb* pinoxaden + metsulfuron-methyl, PE/PoE (1000/64 g/ha); T_9 - pendimethalin *fb* mesosulfuron + iodosulfuron, PE/PoE (1500/14.4 g/ha); T_{10} - pendimethalin *fb* sulfosulfuron + metsulfuron-methyl, PE/PoE (1500/32 g/ha); T_{11} - pendimethalin *fb* pinoxaden + metsulfuron-methyl, PE/PoE (1500/64 g/ha); T_{12}- Sulfosulfuron + metsulfuron-methyl *fb* sulfosulfuron + metsulfuron-methyl, EPoE/PoE (32/32 g/ha); T_{13} -Sulfosulfuron + clodinafop, PoE (25+ 60 g/ha); T_{14} - Sulfosulfuron *fb* pinoxaden, EPoE/PoE (25/60 g/ha); T_{15} - Weed free;

PE, pre-emergence; PoE-post-emergence; EPoE, early post-emergence

Figure 1. Weed control efficiency (%) of different herbicide treatments for *P. minor* in wheat

pendimethalin could be attributed to the unavailability of lethal dose of herbicide to the weeds to cause mortality. The inefficacy of lower doses of pendimethalin has been found by earlier workers also. Yadav *et al*. (2016) found consistently ineffective control of *P. minor* with PE pendimethalin 1000 g/ha. Increasing the dose of pendimethalin in PE herbicide treatment significantly improved *P. minor* control and PE pendimethalin + metribuzin 1500 + 150 g/ha gave control of *P. minor* similar to alone PoE herbicides, however, these treatments were less effective compared to sequential herbicide treatments. Herbicide treatments with sulfosulfuron as mixture partner had reduced efficacy against *P. minor* compared to herbicide treatments with pinoxaden or mesosulfuron + iodosulfuron. This variation in weed control with different PoE herbicides could be due to variable resistance pattern observed in *P. minor* populations. *P. minor* populations have been reported to have high levels of heterogeneity which could be responsible for variable efficacy of different herbicides at different locations (Singh *et al*. 2004). Less control of *P. minor* in the present investigation with herbicide treatments having sulfosulfuron and clodinafop might be due to the evolution of resistance to these herbicides in *P. minor* population studied in the field.

Pre-emergence application of pendimethalin 1.5 kg/ha *fb* PoE mesosulfuron + iodosulfuron 14.4 g/ha caused maximum suppression of broad-leaf weeds (2.8-2.9 g/m^2) and brought >90% reduction in dry weight over weedy plots (30.2-32.5 g/m^2) (**Table 1**). Other sequential herbicide treatments produced similar reduction in dry weight accumulation by broadleaf weeds, however; EPoE sulfosulfuron 25 g/ ha *fb* PoE pinoxaden 60 g/ha was the least effective treatment against broad-leaf weeds and had significantly more dry weight accumulation by broad-leaf weeds (11.1-12.6 g/m^2). This perhaps is due to the reason that EPoE sulfosulfuron 25 g/ha provided control of first cohorts of broad-leaf weeds and later emerging weeds were not controlled by pinoxaden which is a grass weed herbicide. Punia and Yadav (2010) also found pinoxaden as very effective against grassy weeds but did not control broad-leaf weeds. Dry weight accumulation by broad-leaf weeds was more in alone PE and alone PoE herbicide treatments compared to sequential herbicide treatments. Among herbicide treatments, highest dry weight by broad-leaf weeds was accumulated in plots treated with PE pendimethalin + metribuzin 1000 + 150 g/ha (16.1-17.6 g/m^2).

Better weed control with sequential herbicide treatments having herbicide mixtures is due to the enhanced period of weed control and weed spectrum. PRE pendimethalin eradicated first cohorts of weeds while the weak second and third cohorts were controlled by PoE herbicides. However, in alone PE herbicides the later emerging weeds continued to compete with the crop while in PoE alone treatments the primary weed cohorts get an early head start due to initial slow growth of crop and are then not

Table 1. Dry weight of weeds as influenced by different treatments

Treatment	Dose (g/ha)	Dry weight of *P. minor* (g/m^2)		Dry weight of BLW (g/m^2)	
		2014-15	2015-16	2014-15	2015-16
Pendimethalin + metribuzin, PE	1000 + 150	10.2 (103.7)	10.0 (99.1)	4.3 (17.6)	4.1 (16.1)
Pendimethalin + metribuzin, PE	1500 + 150	8.4 (69.6)	8.0 (63.0)	3.3 (10.1)	3.3 (9.8)
Mesosulfuron + iodosulfuron, PoE	14.4	8.3 (67.5)	7.7 (58.2)	2.6 (6.0)	2.7 (6.5)
Sulfosulfuron + metsulfuron-methyl, PoE	32	9.0 (80.7)	8.4 (69.6)	3.0 (8.1)	2.9 (7.7)
Pinoxaden + metsulfuron-methyl, PoE	64	8.4 (69.4)	7.8 (60.3)	3.2 (9.6)	3.3 (9.6)
Pendimethalin *fb* mesosulfuron + iodosulfuron, PE/PoE	1000/14.4	6.9 (47.0)	6.6 (43.3)	2.5 (5.2)	2.3 (4.3)
Pendimethalin *fb* sulfosulfuron + metsulfuron-methyl, PE/PoE	1000/32	7.9 (61.1)	7.1 (49.8)	2.6 (5.7)	2.4 (5.0)
Pendimethalin *fb* pinoxaden + metsulfuron-methyl, PE/PoE	1000/64	7.0 (47.9)	6.4 (39.4)	2.7 (6.0)	2.6 (5.8)
Pendimethalin *fb* mesosulfuron + iodosulfuron, PE/PoE	1500/14.4	5.6 (30.8)	5.1 (25.5)	2.0 (2.9)	1.9 (2.8)
Pendimethalin *fb* sulfosulfuron + metsulfuron-methyl, PE/PoE	1500/32	6.1 (36.7)	5.9 (33.8)	2.3 (4.2)	2.1 (3.6)
Pendimethalin *fb* pinoxaden + metsulfuron-methyl, PE/PoE	1500/64	4.5 (19.4)	4.2 (16.8)	2.4 (4.7)	2.2 (3.9)
Sulfosulfuron + metsulfuron-methyl *fb* sulfosulfuron + metsulfuron-methyl, EPoE/PoE	32/32	8.0 (64.7)	7.6 (57.2)	2.9 (7.3)	2.3 (4.4)
Sulfosulfuron + clodinafop, PoE	25+ 60	8.9 (78.2)	8.8 (77.1)	3.0 (8.0)	2.8 (7.0)
Sulfosulfuron *fb* pinoxaden, EPoE/PoE	25/60	7.6 (56.4)	7.4 (53.8)	3.7 (12.6)	3.5 (11.1)
Weed free	-	1.9 (2.7)	1.6 (1.5)	1.2 (0.5)	1.1 (0.3)
Weedy	-	14.8 (217.6)	14.4 (206.4)	5.6 (30.2)	5.8 (32.5)
LSD (p=0.05)		0.9	0.9	0.4	0.5

Original values in parentheses subjected to square root transformation before data analysis

PE, pre-emergence; PoE-post-emergence; EPoE, early post-emergence; DAS, days after so effectively killed by PoE herbicides. Besides, the resistant plants of *P. minor* are not effectively controlled by alone PE or PoE herbicides (Singh 2015). Similarly, Yadav *et al.* (2016) found that the sequential application of pendimethalin 1000 g/ha or trifluralin 1000 g/ha just after sowing followed by clodinafop 60 g/ha or sulfosulfuron 25 g/ha at 35 DAS provided 90-100% control of *P. minor* along with broad-leaf weeds in wheat, thus resulted in improved grain yields when compared to clodinafop 60 g/ha or sulfosulfuron 25 g/ha alone. Abbas *et al.* (2016) attained effective control of fenoxaprop resistant as well susceptible *P. minor* with herbicide mixtures having 75% lethal dose of the herbicide without any adverse effect on wheat crop.

The high infestation of weeds in the weedy treatment robbed the crop of common resources from initial stages onwards. Hence, under stress the crop plants could not grow to their full potential, which ultimately reduced the grain yield to the extent of 43-45% (**Table 2**). In the present investigation, *P. minor* dominated the weed flora and severe reduction in wheat yield due to competition from *P. minor* has been reported earlier also (Brar and Walia 2008). The grain yield was significantly more in all the herbicide treatments as compared to weedy treatment. Further, the sequential herbicide mixture treatments were superior to alone PE or PoE herbicide mixture treatments and recorded higher grain yield. The sequential application of PE pendimethalin 1.5 kg/ha *fb* PoE pinoxaden + metsulfuron 64 g/ha recorded significant increase in grain yield (73-78%) over weedy treatment and produced grain yield (5.48-5.80 t/ha) comparable to weed free (5.65-5.88 t/ha) during both the crop growing seasons. PE pendimethalin 1.5 kg/ha *fb* mesosulfuron + iodosulfuron 14.4 g/ha (5.28-5.66 t/ha) being at par with PE pendimethalin 1.5 kg/ha *fb* sulfosulfuron + metsulfuron 32 g/ha (5.20-5.52 t/ha) produced wheat grain yield similar to PE pendimethalin 1.5 kg/ha *fb* pinoxaden + metsulfuron 64 g/ha. This could be ascribed to reduction in weed density and dry weight by the application of herbicides in sequence killing most of the weed cohorts which helped the crop to utilize nutrients, moisture, light and space more efficiently and thus produced more dry weight, more effective tillers, more grains per spike and test weight and hence increased grain yield. As compared to weed free check, the grain yield was reduced by 17-33% with the application of alone PE or PoE herbicide treatments and PE pendimethalin + metribuzin 1000 + 150 g/ha (3.76-4.04 t/ha) followed by sulfosulfuron + clodinafop 25 + 60 g/ha (4.40-4.61 t/ha) recorded the lowest grain yield among all herbicide treatments. This was perhaps because all the weed cohorts were not killed by alone PE and PoE herbicides and hence these weeds continue to grow with the crop plants competing with them for the natural resources and thus resulted in suppressed crop growth in terms of lower dry weight, lesser number of effective tillers, grains per spike and less bold grains and finally lower grain yields. Yadav *et al.* (2010) found superior or similar wheat grain yields with herbicide combinations compared to alone herbicides.

Table 2. Yield attributes and yield of wheat as influenced by different treatments

Treatment	Dose (g/ha)	Effective tillers/m^2		Grains/ spike		Test weight (g)		Grain yield (t/ha)	
		2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Pendimethalin + metribuzin, PE	1000 + 150	319	350	44	45	42.7	43.0	3.76	4.04
Pendimethalin + metribuzin, PE	1500 + 150	350	380	45	46	42.7	43.7	4.45	4.72
Mesosulfuron + iodosulfuron, PoE	14.4	366	396	47	47	41.5	43.0	4.52	4.75
Sulfosulfuron + metsulfuron-methyl, PoE	32	360	383	45	50	42.4	42.3	4.40	4.65
Pinoxaden + metsulfuron-methyl, PoE	64	373	395	48	50	42.5	43.3	4.67	4.90
Pendimethalin *fb* mesosulfuron + iodosulfuron, PE/PoE	1000/14.4	384	415	49	52	42.8	43.5	4.86	5.16
Pendimethalin *fb* sulfosulfuron + metsulfuron-methyl, PE/PoE	1000/32	380	409	50	51	43.0	43.0	4.71	5.05
Pendimethalin *fb* pinoxaden + metsulfuron-methyl, PE/PoE	1000/64	386	411	51	52	43.4	44.0	5.00	5.30
Pendimethalin *fb* mesosulfuron + iodosulfuron, PE/PoE	1500/14.4	417	461	54	54	43.3	44.6	5.28	5.66
Pendimethalin *fb* sulfosulfuron + metsulfuron-methyl, PE/PoE	1500/32	402	448	51	53	42.9	44.0	5.20	5.52
Pendimethalin *fb* pinoxaden + metsulfuron-methyl, PE/PoE	1500/64	439	472	55	54	45.0	45.0	5.48	5.80
Sulfosulfuron + metsulfuron-methyl *fb* sulfosulfuron + metsulfuron-methyl, EPoE/PoE	32/32	382	403	51	50	41.4	42.5	4.69	5.08
Sulfosulfuron + clodinafop, PoE	25+ 60	352	388	49	47	41.5	41.0	4.40	4.61
Sulfosulfuron *fb* pinoxaden, EPoE/PoE	25/60	388	391	53	52	43.5	43.8	4.72	5.15
Weed free	-	446	474	56	55	45.4	45.5	5.65	5.88
Weedy	-	272	300	31	32	35.3	38.3	3.08	3.34
LSD (p=0.05)		40	45	4	6	NS	NS	2.76	2.69

PE, pre-emergence; PoE-post-emergence; EPoE, early post-emergence

The findings of the present study clearly demonstrate that alone PE or PoE herbicide treatments are not effective against *P. minor*. However, the sequential application of PE followed by PoE herbicide with more than one mode of action could effectively control resistant *P. minor* in wheat by reducing the number of weeds to be killed by PoE herbicides and thus reducing the selection pressure on PoE herbicides. However, the continued evolution of resistance in *P. minor* due to the almost exclusive reliance on herbicides and also reduced discovery and commercialization of new herbicide chemistries over the last two decades, requires integration of herbicides with non-chemical weed control tactics so as to conserve herbicide resources for the future.

REFERENCES

Abbas T, Nadeem MA, Tanveer A and Ahmad R. 2016. Identifying optimum herbicide mixtures to manage and avoid fenoxaprop-p-ethyl resistant *Phalaris minor* in wheat. *Planta Daninha* **34**(4): 787–793.

Brar AS and Walia US 2008. Effect of rice residue management techniques and herbicides on nutrient uptake by *Phalaris minor* Retz. and wheat (*Triticum aestivum* L.). *Indian Journal of Weed Science* **40**(3&4): 121–127.

Chhokar RS and Malik RK 2002. Isoproturon-resistant littleseed canary grass (*Phalaris minor*) and its response to alternate herbicides. *Weed Technology* **16**: 116–123.

Dhawan RS, Singh Neha and Singh S. 2012. Littleseed canary grass resistance to sulfonylurea herbicides and its possible management with pendimethalin. *Indian Journal of Weed Science* **44**(4): 218–224.

Kaur N, Kaur T, Kaur KS and Bhullar MS. 2015. Development of cross resistance in *Phalaris minor* Retz. L. in Punjab. *Agriculture Research Journal* **53**(1): 69–72.

Malik RK and Singh S. 1995. Little seed canary grass (*Phalaris minor*) resistance to isoproturon in India. *Weed Technology* **9**: 419–425.

Punia SS and Yadav DB. 2010. Bioefficacy of pinoxaden against little seed canary grass in wheat and residual effect on succeeding crops. *Indian Journal of Weed Science* **41**(3&4): 148–153.

Punia SS, Yadav DB, Amarjeet and Sindhu VK. 2017. Investigations on weed flora of wheat in Haryana. *Agriculture Research Journal* **54**(1): 136–138.

Punia SS, Yadav DB, Singh S and Dhawan RS. 2008. Evaluation of different herbicides against clodinafop resistant population of *Phalaris minor* in wheat. pp. 322–323. In: *Proceedings of National Symposium on New Paradigm Shifts in Agronomic Research*, 19-21 November 2008, GAU, Navsari.

Singh DV, Gaur AK and Mishra DP. 2004. Biochemical and molecular mechanisms of resistance against isoproturon in *Phalaris minor*. Variations in protein and RAPD profiles of isoproturon resistant and sensitive *Phalaris minor* biotypes. *Indian Journal of Weed Science* **36**: 256–259.

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

Singh S, Kirkwood RC and Marshall G. 1999. Biology and control of *Phalaris minor* Retz. (littleseed canarygrass) in wheat. *Crop Protection* **18**: 1–16.

Singh S, Punia SS and Malik RK. 2009. Multiple resistance in isoprotuorn resistant biotypes of *Phalaris minor* in India. *Proceedings of Weed Science Soc. America 49th Annual Meeting and Southern Weed Science Soc. 62nd Meeting*, 9-13 February 2009, Orlando, Florida, USA.

Yadav DB, Punia SS, Yadav A and Balyan RS. 2010. Evaluation of tank-mix combinations of different herbicides for control of *Phalaris minor* in wheat. *Indian Journal of Weed Science* **42**(3&4): 193–197.

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 **51**(2): 139–144, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Floristic composition and distribution of weeds in different crop ecosystems of Jorhat in India

Rupam Sarmah*

Department of Ecology and Environmental Science, Assam University, Silchar, Assam 788 011, India

**Email: rupam1915@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00031.5

Type of article: Research article

Received : 15 March 2019
Revised : 2 June 2019
Accepted : 4 June 2019

Key words

Crop ecosystem
Floristic composition
Kharif and *Rabi* crops
Transplanted rice
Weeds

ABSTRACT

The present communication pertains to major weeds of different crop ecosystems of Jorhat in India. The study was based on extensive and intensive fields surveys made during different months of rainy and dry season 2016-2018. Surveys were made in five important crops ecosystems of total eight developmental blocks of Jorhat district during both *Kharif* and *Rabi* seasons of the year. Vegetation data were collected followed by quadrat methods and analyzed for density, frequency, diversity and importance value index (IVI) for each crop ecosystems. Interspecific association was also analyzed for ten dominant weed species followed by Cole's index. During this period, a total of 82 weed species were reported of which 56 species were recorded from the transplanted *Kharif* rice fields, while 61 weed species were recorded from the *Rabi* crop fields. The five dominant weed families in the study area were Cyperaceae, Poaceae, Onagraceae, Asteraceae and Fabaceae.

INTRODUCTION

Farmers have long realized the interference of weed with crop productivity as weeds are regarded as old as agriculture itself and that eventually led to the co-evolution of agro-ecosystems and weed management (Ghersa *et al.* 1994, 2000). Worldwide yield loss due to weeds in rice field was found to be 15% (De Datta 1990). Weed competes with crops for natural and applied resources and reduces both quantity and quality of agricultural productivity (Rao and Nagamani 2010, Rao *et al.* 2015). It has also been reported that weeds are notorious yield reducers that are, in many situations, economically more important than insects, fungi and other pest organisms in agricultural fields (Savary *et al.* 1997, 2000). In India, weeds are one of the major biological constrains that limit crop productivity and reduce crop yields by 30.5% that amounts to 22.7% in winter and 36.5% in summer and *Kharif* season (Bhan *et al.*1999). It has been reported that reduction of rice yield due to weed competition ranged from 9-51% and uncontrolled weed growth may cause 75.8, 70.6, 62.6% yield reduction in dry seeded rice, wet seeded rice and transplanted rice, respectively (Mani *et al.* 1968).

The information on the presence, composition, abundance, importance and ranking of weed species is needed to formulate appropriate weed management strategies to produce optimum yields of rice (Begum *et al.* 2005). A through survey is necessary to address the current weed problems in cropping systems as it will help in developing target-oriented research programmes (Boldtand Devine1998). Specific sound knowledge on the nature and extent of infestation of weed flora is essential to plan the control measures and formulate target oriented research programme. The Jorhat district falls under the Upper Brahmaputra Valley Agro-climatic Zone and is characterized by the existence of hills, high land, plain land and char (riverine) areas. Transplanted *Kharif* rice and different *Rabi* crops like black gram/green gram, pea, mustard, potato and different winter vegetables are the dominant agricultural crops of Jorhat in India. The soil is drained by a number of perennial tributaries of the Brahmaputra River and pH ranges from 4.5 to 6.0. However, detailed information regarding the status and distribution of weeds are rare from the study area. Therefore, the present study was undertaken.

MATERIALS AND METHODS

Study area

The study was conducted in Jorhat in India. The study area was situated in the Upper Brahmaputra

Valley Zone of Assam covering an area of 2,851 sq. km. The area has sub-tropical climate with average temperature range from 8˚C to 36˚C and around 2,100 mm average rainfall. The relative humidity varied from 78% to 98%. The district is surrounded by Sibasagar in the East, Golaghat in the West, Lakhimpur in the North and Nagaland state in the South. The major river is Brahmaputra and its tributaries in the district. The largest freshwater river island in India,Majuli is located at about 20 km. from the heartland of the city of Jorhat.

Jorhat district comprised of total eight developmental blocks. Repeated field survey was done followed by interaction with the farmers and agricultural officers prior to selection of study sites. Finally, five dominant crop ecosystems namely transplanted *Kharif* rice, mustard, mixed winter vegetables, green/black gram and potato were selected in study area and all the eight developmental blocks were surveyed. GPS reading were recorded for each sampling sites. Both quadrat and line transect methods (Akwee *et al.* 2010) were used to collect data from study area. Quadrats of 1×1 m size were plotted in random systematic design for collection of data by following the method as described by Kent and Coker (1994). All the plant species enumerated in the quadrat, were identified and counted.

Ecological analysis of weed flora was done following quantitative measures as density, frequency dominance and their relative values were used to calculate the importance value index (IVI). Similarity coefficient of different weed community of different crop ecosystems was calculated using Sorenson Index (Jansonand Vegelius 1981) to compare of species affiliation among weed Communities between crop ecosystems.

The inter-specific association among the dominant weed species occurring in the different crop ecosystem of entire study area was computed (Sutomo and Putri 2011), to find out the inclination and repulsion effects among the weed species.

RESULTS AND DISCUSSION

Weed flora in transplanted *Kharif* rice

Based on pooled data (2016-18), a total of 56 weed species were recorded in the transplanted *Kharif* rice crop ecosystem of Jorhat district during the study; of which 17 were sedges, 10 grasses and 29 Broad-leaved weed (BLW) species (**Table 1**). Among the weed groups, highest density was recorded for BLW (627.20/m^2), followed by sedge (519.13/m^2) and grass (226.29/m^2) (**Figure 1**). Species richness was the maximum in BLW (29), followed by sedges (17) and grasses (10) (**Figure 2**). Among the weed flora recorded from rice fields *Fimbristylis miliacea* was the most widely distributed species with a frequency value of 73.10%, followed by *Rotala rotundifoilia* (50%) and *Isachne himalaica* (47.53%). During the study, high value of IVI was recorded for *Eleocharis acicularis* (32.77) followed by *Cyperus iria* (24.57), *I. himalaica* (24.49), *Fimbristylis miliacea* (22.86) and *Rotala rotundifolia* (19.41) (**Table 1**). In the present study, a significant difference was found in the weed types in rice fields of entire Jorhat district ($F_{2, 873}$= 97.06, P <0.01).*F. miliacea* was the most common, widely distributed and the most serious weed with highest frequency, field uniformity and highest density values in the rice fields of different parts of the country (Baki 1993, Begum *et al.* 2005). It has also been observed that the change of cultivation practice from transplanting to direct-seeding has no influence on *F. miliacea* (Tomita *et al*. 2003). In fact, because of the tremendous size of the soil seed bank accumulated over years of transplanting, *F.miliacea* would remain as a dominant weed species in direct-seeded rice areas (Azmi and Mashhor 1996).

Table 1. Consolidated account of different parameters of weed species in different crop ecosystems of Jorhat in India

Parameters	Crop ecosystems				
	Transplanted *Kharif* rice	Winter vegetables	Potato	Mustard	Green and black gram
Density (no./m^2)					
Grass	226.3	378.6	153.6	1296.7	436.5
Sedge	519.1	393.4	71.2	598.7	336.8
BLW	627.2	144.0	121.6	104.7	196.5
Species richness					
Grass	10	9	1	4	10
Sedge	17	11	4	9	11
BLW	29	27	7	12	28
Species with highest IVI					
Five most dominant species (IVI)	*Eleocharis acicularis* (32.77) *Cyperus iria* (24.57) *Isachne himalaica* (24.49) *Fimbristylis miliacea* (22.86) *Rotala rotundifolia* (19.41)	*Cynodon dactylon* (39.16) *Ageratum houstonianum* (25.26) *Fimbristylis bisumbellata* (22.87) *Cyperus compressus* (19.20) *Cyperus brevifolius* (17.20)	*Colocasia esculenta* (54.73) *Ageratum houstonianum* (51.33) *Cynodon dactylon* (48.51) *Cyperus haspan* (24.16) *Hygrophilla auriculata* (23.19)	*Cynodon dactylon* (59.93) *Cyperus compressus* (49.05) *Paspalum conjugatum* (26.54) *Fimbristylis ittoralis* (26.03) *Eragrostis unioloides* (19.42)	*Cynodon dactylon* (54.79) *Cyperus compressus* (35.60) *Cyperus brevifolius* (14.79) *Ludwigia perennis* (14.57) *Fimbristylis littoralis* (14.48)

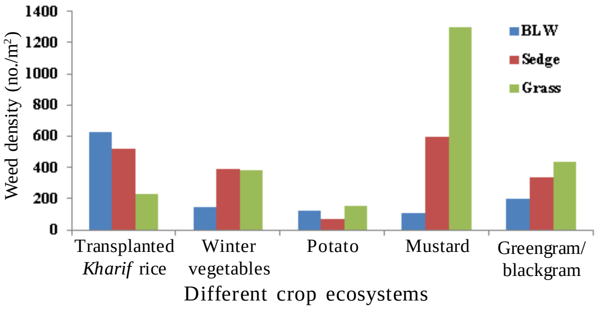


Figure 1. Weed density (no./m²) in different crop ecosystems of Jorhat in India

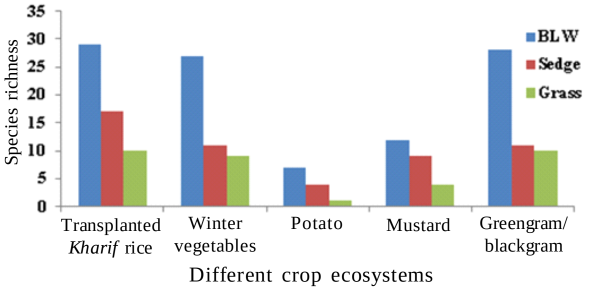


Figure 2. Weed species richness in different crop ecosystems of Jorhat in India

Weed flora in major *Rabi* crops

Out of the four major *Rabi* crops, 47 weed species were recorded in different mixed winter vegetables, 12 species from potato fields, 25 species in mustard and 49 weed species were recorded in the green gram/ black gram crop ecosystem in Jorhat district (**Table 1**). Pumpkin, tomato, brinjal, radish, cauliflower, cabbage, garlic, bean *etc*. were cultivated as mixed winter vegetable crops in *Rabi* season in all the eight developmental blocks of Jorhat, district. Among the weed groups, highest density was recorded for grasses in potato (153.60/m²) followed by mustard (1296.67/m²) and green gram/black gram cultivated fields (436.47/m²). However, in winter vegetables, highest density was recorded for sedge (393.35/m²). Among the weeds *Cynodon dactylon* had the highest IVI value 59.93 followed by *Colocasia esculenta* (54.73), *Ageratum houstonianum* (51.33), *Cyperus compressus* (49.05) and *Paspalum conjugatum* (26.54) in different *Rabi* season crop ecosystems of Jorhat district, Assam (**Table 1**). These were the most dominant weed species with high density and wide distribution. Similar findings were reported in West Bengal, where *C. dactylon* was the dominant weed species in different winter crops like rapeseed mustard, wheat and potato fields (Duary *et al.* 2015). Pramanick *et al.* (2012) also reported that, *C. dactylon* and *F. littoralis* were the most dominant and well distributed species in potato fields of West Bengal. Besides these, *F. littoralis, F. miliacea* and *F. bisumbellata* were reported as dominant species amongst the five dominant weed species from mixed winter vegetables, mustard, green gram and black gram cultivated fields with the exception of potato fields. Weed succession and distribution patterns in crop fields are dynamic in nature and composition of weed flora may differ depending on location (Begum *et al.* 2008).

In the present study, a significant difference in weed types (sedge, grass and BLWs) was found among different crop ecosystems in all the developmental blocks (**Table 2**). All the three weed types were found to be significantly different among eight developmental blocks in transplanted rice and green gram/black gram crop ecosystems, while BLWs and grass were not significantly different in winter vegetables (**Table 3**).

Table 2. Differences among weed types (sedge, grass and broad-leaved weed) in different crop ecosystems in eight developmental blocks of Jorhat district, Assam (one-way ANOVA)

Crop ecosystem	Developmental blocks	F value	df (Degrees of freedom)	Result
Kharif rice	Jorhat Central	39.9	2, 105	< 0.01
	East Jorhat	63.25	2, 107	< 0.01
	Jorhat	72.94	2, 114	< 0.01
	Kaliapni	97.97	2, 123	<0.01
	Majuli	8.436	2, 87	<0.01
	North West Jorhat	51.41	2, 111	<0.01
	Titabar	117.4	2, 117	<0.01
	UjoniMajuli	6.255	2, 72	<0.01
Winter vegetable	East Jorhat	15.05	2, 33	<0.01
	Jorhat	10.05	2, 72	< 0.01
	Kaliapni	3.969	2, 27	< 0.05
	North West Jorhat	5.336	2, 33	< 0.01
Potato	Central Jorhat	17.47	2, 27	< 0.01
Green gram/ Black gram	East Jorhat	14.71	2, 27	< 0.01
	Kaliapni	4.227	2, 27	< 0.01
	Majuli	3.338	2, 63	< 0.05
	North West Jorhat	6.289	2, 36	< 0.01
	UjoniMajuli	9.854	2, 72	< 0.01

However, weed species diversity differed significantly among all the crop ecosystems of different developmental blocks of the entire study area (**Table 4**). On the other hand, there was a difference in the weed types among transplanted rice fields of Jorhat district ($F_{2,\ 873}$ = 97.06, P < 0.01).

Similarity analysis

Similarity analysis among the weed communities of different crop ecosystems of Jorhat district recorded that the highest similarity (0.79%) was among the weed communities of mixed winter vegetable crop fields and greengram/blackgram crop

Table 3. Difference of weed types in *Kharif* rice, mixed winter vegetables, green gram/ black gram cultivated fields among different developmental Blocks of Jorhat district (one-way ANOVA)

Crop ecosystem	Weed types	F value	df (Degrees of freedom)	Result
Kharif rice	Sedge	17.4	7, 284	< 0.01
	Broad-leaf	93.69	7, 284	< 0.01
	Grasses	11.25	7, 284	< 0.01
Winter vegetable	Sedge	8.286	4, 62	< 0.01
	Broad-leaf	0.61	4, 62	NS*
	Grass	1.251	4, 62	NS*
Greengram/ blackgram & mustard	Sedge	10.35	4, 75	< 0.01
	Broad-leaf	4.017	4, 75	< 0.01
	Grass	2.869	4, 75	< 0.05

NS*= Non significant

Table 4. Difference of weed species diversity among different Developmental blocks of Jorhat district in different crop ecosystem (one-way ANOVA)

Crop ecosystem	F Value	df (Degrees of freedom)	Result
Kharif rice	16.57	7, 274	< 0.01
Mixed winter vegetables	6.893	5, 61	< 0.01
Greengram, blackgram and mustard	6.339	6, 73	< 0.01

fields followed by Mustard and greengram/blackgram (0.65%), rice and greengram/blackgram (0.57%) and mustard and mixed winter vegetables (0.56 %) (**Table 5**). However, only 0.29% similarity could be found among the weed communities of potato and green gram/black gram cultivated fields of the study area.

Interspecific association

The positive and negative association was analyzed for the ten most dominant (highest IVI value) weed species found in different crop ecosystems of Jorhat district. Out of ten of positively associated weed pairs, *Fimbristylis miliacea* showed high degree of positive association with *Elocharis accicularis* (0.292 ± 0.001; p < 0.01). Similarly, significant positive association was recorded between *Rotala rotundifolia* and *Isachne himalaica* (0.351 ± 0.002), *Cynodon dactylon* and *Ageratum haustonianum* (0.272 ± 0.001), *Fimbristylis miliacea* and *Cyperus iria* (0.237 ± 0.001) and so on (**Table 6**). Barua and Gogoi (1995) studied the association among different weed groups in sugarcane cultivated areas in Assam. Positive association between various species pairs can be attributed to their similar requirement for growth and development (Sundriyal 1991) and the competition between them in fairly stable habitat is not to eliminate one by the other from the area (Smith and Cottam 1967).

Table 5. Similarity index of weed communities among different crop ecosystems of Jorhat in India

Crop ecosystems	Rice	Mixed winter vegetables	Potato	Mustard	Greengram/ blackgram
Rice	***				
Winter vegetables	0.54	***			
Potato	0.32	0.34	***		
Mustard	0.42	0.56	0.37	***	
Greengram/black gram	0.57	0.79	0.29	0.65	***

However, out of nine negatively associated weed pairs, broad-leaved weed *Rotala rotundifolia* showed high degree of negative association with *Cynodon dactylon* (0.702 ± 0.007; p < 0.01) followed by *E. accicularis*and *C. dactylon* (0.727 ± 0.012), *F. miliacea* and *C. dactylon* (0.336 ± 0.003) and *F.littoralis* and *F.miliacea* (0.335 ± 0.003) (**Table 6**). Interspecific association is that if species are independent to each other, they will occur together more or less by chance, while if they are not dependent they will occur together more often or less often than can be expected by chance, which is expressed in terms of Coles index (Brey 1956). The positive association between species is due to habitat suitability, requirement of shade by herbaceous species and requirement of light, space and nutrition (Mishra and Mishra 1981). Several factors might have attributed to the negative associations of the weeds of rice fields as well as different winter crop ecosystems in the present study area, and the major factor might be the divergence of niches. Higher degree of negative associations between different *Fimbristylis* species with other sedges, BLW weeds and grass species were recorded in both the cropping season (monsoon and post monsoon) in Jorhat district, Assam. The other important factors might be topography, site condition, microclimate, differential growth pattern, allelopathy and management and other biotic pressures (Barua and Gogoi 1995). Whatever may be, these species had wider ecological and sociological amplitude in the weed communities of different crop fields of Jorhat district, Assam.

Overall, the study revealed that, grasses were the most dominant weed groups in different winter crop ecosystems of Jorhat in India and *C. dactylon* was one of the most dominant and well distributed species followed by different BLW species and sedge. Similar findings had been reported by Tiwari *et al.* (2014) from Bilaspur district, Chattisgarh where they found *Poaceae* as the dominant family followed by BLW families like Asteraceae, Fabaceae, Amaranthaceae and Cyperaceae (sedge). The

Table 6. Chi-square ($\chi 2$) values (*,p < 0.05; **,p<0.01) showing association and Cole's index showing degree of association of different weed pairs in different crop fields of Jorhat district, Assam

Name of the species	Cole's index ± Standard error	Chi- square Value
Positive association		
Cynodon dactylon x *Ageratum haustonianum*	0.272 ± 0.001	60.55**
Cyperus compressus x *Cynodon dactylon*	0.563 ± 0.013	24.65**
Fimbristylis miliacea x *Cyperusiria*	0.237 ± 0.001	56.93**
Fimbristylismiliacea x *Eleocharis accicularis*	0.292 ± 0.001	69.62**
Ishacne himalaica x *Eleocharisaccicularis*	0.179 ± 0.001	21.52*
Ishachne himalaica x *Fimbristylismiliacea*	0.425 ± 0.006	28.67**
Rotala rotundifolia x *Eleocharisaccicularis*	0.220 ± 0.001	37.10**
Rotala rotundifolia x *Isachnehimalaica*	0.351 ± 0.002	66.69**
Schoenoplectella juncoides x *Fimbristylis miliacea*	0.519 ± 0.011	24.70**
Schoenoplectella juncoides x *Ishacne himalaica*	0.321 ± 0.004	27.87**
Negative association		
Eleocharis accicularis x *Ageratum haustonianum*	0.743 ± 0.021	26.08**
Eleocharis accicularis x *Cynodon dactylon*	0.727 ± 0.012	43.66**
Fimbristylis miliacea x *Cynodon dactylon*	0.336 ± 0.003	38.64**
Fimbristylis littoralis x *Fimbristylis miliacea*	0.335 ± 0.003	35.75**
Isachene himalaica x *Ageratum haustonianum*	0.515 ± 0.015	17.76*
Rotala rotundifolia x *Ageratum haustonianum*	0.480 ± 0.013	17.71*
Rotala rotundifolia x *Cynodon dactylon*	0.702 ± 0.007	66.13**
Schoenoplectella juncoides x *Ageratum haustonianum*	0.827 ± 0.026	26.26**
Schoenoplectella juncoides x *Cynodon dactylon*	0.563 ± 0.015	21.24*

dominance of sedge was slightly lesser in winter crop ecosystems as compared to the transplanted *Kharif* rice in Jorhat in India. As the different winter crops were cultivated in upland situation in the post-monsoon season of the year, therefore, the dominance of sedges were comparatively lesser in *Rabi* crops. While, it was higher in transplanted *Kharif* rice in the study area, as all experimented rice fields were inundated about 5-10 cm in water. In rice, water and weeds are often considered to be closely interlinked. Bhagat *et al.* (1999) reported that weed species respond differently to changing water regimes and the dominance of grass species was favoured by saturated and below saturated conditions, whereas aquatic broad-leaved weeds and sedges grow rapidly when soil was submerged with water (Bhagat *et al.* 1999, Juraimi *et al.* 2011). This may be the most important factor for grass dominance over sedge and broad-leaved weeds in different winter crop ecosystems of Jorhat in India.

Different crop ecosystems are infested by various problematic weeds for which modern technology should be used to address the issue and ensure increased crop productivity in a sustainable way, with the minimum of environmental degradation and loss of diversity of many important plant species. Weed control must be done to increase the crop productivity but there are some weeds and some situations in which more may be lost than gained by their destruction (Hillocks 1998).

REFERENCES

Akwee PE, Palapala VA and Gweyi-Onyango JP.2010. A comparative study of plant species composition of grasslands in Saiwa Swamp National Park and Kakamega Forest, Kenya. *Journal of Biodiversity* **1**(2): 77–83.

Azmi M and Mashhar M .1996.Effect of continuous direct seeding on weed species diversity in SebrerangPerai Rice Granary, Malaysia.*Malaysian Agricultural Research and Development Institute Research Journal* **24**: 93–105.

Baki BB. 1993. Spatial pattern analysis of weeds in selected rice fields of Samarahan, Sarawak. *Malaysian Agricultural Research and Development Institute Research Journal* **21**(2): 121–128.

Barua IC and Gogoi AK. 1995. Phytosociological studies of sugarcane weeds in Assam.*World Weeds* **2**: 107–115.

Begum M, Juraimi AS, Azmi M, Rajan A and Syed-Omar SR. 2005. Weed diversity of rice fields in four districts of Muda Rice Granary Area, North-west Peninsular Malaysia. *Malaysian Applied Biology* **34**(2): 31–41.

Begum M, Juraimi AS, Omar SRS, Rajan A and Azmi M. 2008.Effect of herbicides for the control of *Fimbristyli-smiliacea* (L.) Vahl. in rice. *Agronomy* **7**(3): 251–257.

Bhagat RM, Bhuiyan SI, Moody K and Estorninos LE. 1999. Effect of water, tillage and herbicides on ecology of weed communities in an intensive wet-seeded rice system. *Crop Protection* **18**: 293–303.

Bhan VM, kumar S and Raghuwanshi MS. 1999. Weed management in India. *Indian Journal of Plant Protection* **17**: 71–202.

Boldt S and Devine B. 1998. Educational disadvantage in Ireland: literature review and summary report. pp.10. In: *Educational Disadvantage and Early School Leaving*

Discussion Papers, (Eds. Boldt S, Devine B, Mac Devitt D and Morgan M), Combat Poverty Agency, Dublin.

Brey JR. 1956.A study of mutual occurrence of plant species. *Ecology* **37**: 21–28.

De Datta SK. 1990. Strategic weed research forrelevant rice technology. pp. 277–286. In: *Proceedings of the third Tropical Weed Science Conference,* Kuala Lumpur, Malaysia.

Duary B, Mukherjee A and Bhowmick MK. 2015.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.

Ghersa CM, Benech-Arnold RL, Satorre EH and Martinez-Ghersa MA. 2000. Advances in weed management strategies. *Field Crops Research* **67**: 95–104.

Ghersa CM, Roush ML, Radosevich SR and Cordray SM. 1994.Coevolution of agroecosystems and weed management. *Journal of Biological Science* **44**: 85–94.

Hillocks RJ. 1998. The potential benefits of weeds with reference to small holder agriculture in Africa. *Integrated Pest Management Reviews* **3**: 155-167.

Janson S and Vegelius J. 1981.Measures of Ecological Association.*Oecologia* **49**: 371–376.

Juraimi AS, Saiful AHM, Uddin MK, Anuar AR and Azmi M. 2011. Diversity of weed communities under different water regimes in bertam irrigated direct seeded rice field. *Australian Journal of Crop Science* **5**(5): 595–604.

Kent M and Coker P. 1994. *Vegetation Analysis and Description*, International Book Distributors, Dehradun.

Mani VS, Gautam KC and Chakraberty TK. 1968. Losses in crop yield in India due to weed growth. *Proceedings of the National Academy of Science* **42**: 142–158.

Mishra MK and Mishra BN. 1981.Species diversity and dominance in a tropical grassland community.*Folia Geobotanicaet Phytotaxonomica* **16**(3): 309–316.

Pramanick B, Karmakar S, Brahmachari K and Deb R. 2012. An integration of weed management practices in potato under new alluvial soil.*The Journal of Plant Protection Sciences* **4**(2): 32-36.

Rao AN and Nagamani A. 2010. Integrated weed management in India-revisited. *Indian Journal of Weed Science* **42**: 1-10.

Rao AN, WaniSP, Ramesha M. and Ladha JK. 2015. Weeds and weed management of rice in Karnataka state, India. *Weed Technology* **29**(1): 1-17.

Savary S, Srivastava RK, Singh HM and Elazegui FA. 1997. A characterization of rice pests and quantification of yield losses in the rice–wheat system of India. *Crop Protection* **16**: 387–398.

Savary S, Willocquet L, Elazegui FA, Castilla NP and Teng PS. 2000. Rice pest constraints in tropical Asia: quantification of yield losses due to rice pests in a range of production situations. *Plant Disease* **84**: 357–369.

Smith BE and Cottam G. 1967.Spatial relationship of mesic forest herbs in southern Wisconsin. *Ecology* **48**(4): 546–558.

Sundriyal RC. 1991. Alpine vegetation of the Garthwal Himalay, *Journal of the Indian Botanical Society* **70**: 79–85.

Sutomo FD and Putri LSE. 2011. Species composition and interspecific association of plants in primary succession of Mount Merapi, Indonesia. *Biodiversitas* **12**(4): 212–217.

TiwariAK,SahuPK, Shrivastava AK and Moni T. 2014.Plant diversity and distribution of weeds in winter season crops of agro-ecosystems in Bilaspur district, Chhattisgarh. *Journal of Biodiversity and Environmental Sciences* **5**(2): 251–259.

Tomita S, Nawata E, Kono Y, Nagata Y, Noichana C, Sributta A and Inamura T. 2003.Differences in weed vegetation in response to cultivating methods and water conditions in rainfed paddy fields in northeast Thailand. *Weed Biology and Management* **3**: 117–127.

Indian Journal of Weed Science **51**(2): 145–150, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Indian Journal of Weed Science

Mesotrione and atrazine combination to control diverse weed flora in maize

R.S. Chhokar*, R.K. Sharma, S.C. Gill and R.K. Singh

Resource Management Unit, ICAR-Indian Institute of Wheat and Barley Research, Karnal, Haryana 132001, India

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

Article information

DOI: 10.5958/0974-8164.2019.00032.7

Type of article: Research article

Received : 27 March 2019
Revised : 7 June 2019
Accepted : 9 June 2019

Key words

Atrazine, Grass weeds

Maize

Mesotrione

2,4-D-Na

Synergism

Tank-mix

ABSTRACT

Field and pot studies were conducted during two rainy *(Kharif)* seasons of 2013 and 2014 to identify the effectiveness and optimum dose of mesotrione and atrazine combination for diverse weed flora management in maize. The weed control treatments evaluated in field experiment were pre-emergence atrazine 1000 g/ha and post-emergence 2,4-D-Na 1000 g/ha, mesotrione 120 g/ha and ready mixture of mesotrione with atrazine in ratio of 1:10 w/w (Calaris Xtra 275 SC) at 750, 875 and 1000 g/ha. The major weeds infested were *Dactyloctenium aegyptium*, *Digitaria sanguinalis*, *Echinochloa crus-galli*, *Trianthema portulacastrum*, *Digera arvensis* and *Phyllanthus niruri*. The uncontrolled weed competition reduced the maize yield by 38.7 to 54.0%. Mesotrione 120 g/ha was effective in controlling the broad-leaved weeds but was poor in controlling grass weeds. The weed control with pre-emergence atrazine 1000 g/ha was also not consistent. However, in pot and field studies, ready or tank mixture of mesotrione with atrazine was synergistic and superior in controlling weeds than to sole mesotrione and atrazine applications. The weed control efficiencies with ready-mixture of mesotrione + atrazine (1:10 w/w) at 875 and 1000 g/ha ranged 89-99%. Mesotrione plus atrazine at 875 and 1000 g/ha yielded (7.74-8.11 t/ha) significantly higher as compared to mesotrione 120 g/ha (5.83-5.96 t/ha), atrazine 1000 g/ha (5.93-6.70 t/ha) and 2.4-D-Na 1000 g/ha (3.82-5.30 t/ha) applications, as well as, untreated weedy check (3.73-4.76 t/ha). The results showed that mesotrione and atrazine combination has synergistic effect, which can be used for managing diverse weed flora in maize.

INTRODUCTION

Weed infestation in maize is the key detrimental factor causing huge grain yield losses because of wide row spacing and slow initial crop growth along with frequent rains during rainy season. Yield reductions, as much as, 90% have been reported depending upon the type and intensity of weed flora (Massing *et al*. 2003, Sharma and Thakur 1998). Among herbicides, atrazine is widely used in maize because of its lower cost, broad-spectrum weed kill, application flexibility (pre-emergence or post-emergence), and compatibility with numerous herbicide mixtures (Walsh *et al*. 2012). However, the continuous use of atrazine is causing weed flora shift and evolution of resistance in weeds. Globally, 45 weed species across many corn growing areas have exhibited resistance against photosystem II (PSII) inhibitor herbicides, like atrazine (Heap 2019). This necessitates, having alternative modes of action herbicides in maize to decrease the probability of herbicide resistance evolution.

Mesotrione a p-hydroxyphenylpyruvate dioxygenase (HPPD) enzyme inhibitor controls the major annual broad-leaved weeds with lesser effect against grassy weeds (Armel *et al*. 2003a, Zhang *et al*. 2013). However, its dose varies depending on weed species. Mesotrione at 90 g/ha is needed for higher efficacy (95%) on barnyard grass {*Echinochloa crus-galli* (L.) Beauv}; but even higher doses are not effective against common purslane-*Portulaca oleracea* L. (Pannacci and Covarelli 2009). Mesotrione provides both pre- and post-emergence weed control (Bollman *et al*. 2006, Armel *et al*. 2003b). However, pre-emergence efficacy is affected by the soil and environmental conditions (Tapia *et al*. 1997), as well as, crop establishment methods, such as, no-till (Zhang *et al*. 2013) or conservation agriculture.

Mesotrione is also an alternative to control triazine resistant weeds like common lambsquarters *i.e. Chenopodium album* L. (Bollman *et al*. 2006). The HPPD- inhibitor herbicides are being preferred by maize growers due to their broad range of weed kill, flexible application timing, tank-mix herbicide compatibilities, and better crop tolerance (Walsh *et al*. 2012, Bollman *et al*. 2008). Atrazine and HPPD inhibitor herbicides also effectively control glyphosate resistant weeds (Sutton *et al*. 2002). Moreover, HPPD (mesotrione) and PS II inhibiting herbicides in the mixtures show synergism (Sutton *et al*. 2002, Abendroth *et al*. 2006). Synergistic herbicide mixture reduces the cost by saving time and dose and also provides the broad spectrum weed control. Furthermore, the usage of herbicides having independent modes of action in tank-mix combination rather than in rotation, drastically delay the inception of herbicide resistance evolution (Diggle *et al*. 2003, Zhang *et al*. 1995). Under Indian conditions, there is paucity of information regarding the effectiveness of mesotrione alone or in combination with atrazine in maize against prevalent weed flora. Thus, the studies were conducted with the objective to identify the effectiveness of mesotrione and mesotrione 2.27% + atrazine 22.72% w/w (Calaris Xtra 275 SC) combination against weeds in maize.

MATERIALS AND METHODS

Field evaluation of mesotrione and atrazine against weeds in maize

Field experiments were carried out during rainy *(Kharif)* seasons of 2013 and 2014 at Indian Institute of Wheat and Barley Research, Karnal, India in sandy clay loam soil having pH 8.2 and organic carbon content 0.39%. Seven weed control treatments (**Table 1**) evaluated were: atrazine at 1000 g/ha, 2,4-D-Na salt 1000 g/ha, mesotrione at 120 g/ha, untreated weedy control and ready-mix combination of atrazine plus mesotrione *i.e.* CalarisXtra 275 SC (mesotrione 2.27% + atrazine 22.72% w/w) at 750 (68+682), 875 (80+795) and 1000 (91+909) g *a.i.*/ha. Atrazine alone as pre-emergence (PE) was applied one day after sowing (DAS) and post-emergence (PoE) applications of 2,4-D-Na, mesotrione and atrazine plus mesotrione was made at 15 and 18 DAS during 2013 and 2014, respectively. Herbicides were applied with backpack sprayer having flat fan nozzles delivering 400 litre water/ha.

Treatments replicated thrice were tested in randomized block design. Maize hybrid- '*DKC 9108*' was sown during last week of June having 60 cm row to row spacing and 15-20 cm plant to plant spacing (approximately 20 kg/ha seed rate). Gap filling and thinning were done at 10-12 DAS to maintain uniform plant stand. Fertilizer (150 kg N, 26.2 kg P and 33.3 kg K/ha) and irrigation were applied according to recommended package of practice for maize. Phosphorus and potash were applied at sowing time. Nitrogen was applied in four splits, at sowing, around 4 leaf stage (20 DAS), knee high and tasseling stage. Weed dry weights (3 and 6 weeks after herbicide application) were recorded at two spots in each plot using a quadrat of 50 x 50 cm. Based on total weed dry weights, weed control efficiency (WCE) was calculated. The crop was manually harvested in the first week of October and shelling done using small plot maize sheller.

Pot experiment: Synergistic effect of mesotrione + atrazine against weeds

To determine the comparative efficacy of tank mix combination of mesotrione + atrazine, a pot experiment was conducted. The test species, crow footgrass {*Dactyloctenium aegyptium* (L.) Willd} and barnyard grass {*Echinochloa crus-galli* (L.) Beauv} were sown in the pots of 4.5 kg soil capacity at a depth of 0.5-1.0 cm and 2.0 cm, respectively. After germination, 15 and 25 plants/pot were maintained for herbicide spraying. Herbicides and their rates consisted of mesotrione at 30, 60 and 120 g/ha, atrazine 250, 500 and 1000 g/ha and their combination (mesotrione + atrazine) at 30 + 250, 60 + 500 and 120 + 1000 g/ha (**Figures 1** and **2**). Cationic surfactant (leader mix) at 1000 ml/ha was used with mesotrione and its combination with atrazine. Fresh biomass/pot was recorded 4 WAS and from which, the % biomass reduction compared to control was worked out for determining the herbicide response. For pot studies, completely randomized design (CRD) with 3-7 replications in three sets/runs of experimentation for each weed species was used.

Field experiment data were statistically analyzed in RCBD using Statistical Analysis System (SAS, version 9.2) and before the ANOVA, weed dry weight data were square root- transformed ($\sqrt{x+1}$). Based on the transformed data analysis, the letters were mentioned with original values in the table for result interpretation. The weed and crop data for both years were analysed separately because of the variations in weed intensity and diversity. Fisher's protected least significant difference (LSD) test at the p= 0.05 level was used for detecting differences among treatment means. For pot study, based on the data of different observations of three runs, average and ± SEM were worked out after calculating % biomass reduction.

RESULTS AND DISCUSSION

Herbicides evaluation against weeds in maize

Major weed flora of the experimental plots was: crow footgrass, *Dactyloctenium aegyptium* (L.)

Willd.; barnyard grass, *E. crus-galli*; large crabgrass, *Digitaria sanguinalis* (L.) Scop; horsepurslane, *Trianthema portulacastrum* L.; *Digera arvensis* Forsk. and *Phyllanthus niruri* L.. Among these weeds, *E. crus-galli*, *T. portulacastrum*, *D. arvensis* and *D. aegyptium* were dominant during both the years of studies.

Various herbicide treatments significantly affected the dry weight of major weeds (**Table 1** and **2**). The maximum total weed dry weight was in untreated weedy check and the values were 393.0 and 304.4 g/m^2 at 3 and 6 weeks after spray (WAS), respectively, during first year and 577.1 and 474.5 g/m^2 at 3 and 6 WAS, respectively during second year. Under untreated weedy control, *D. aegyptium*, *E. crus-galli*, *D. arvensis* and *T. portulacastrum*, had the dry weight of 92.5-363.4, 8.9-21.5, 34.8-51.4 and 137.2-223.8 g/m^2 at 3 WAS and the respective dry weight at 6 WAS ranged 149.8-324.1, 13.0-47.5, 44.4-92.2 and 33.9-36.2 g/m^2, respectively. *T. portulacastrum* dry weight was reduced by 73.6-84.9% at 6 WAS (33.9 and 36.2 g/m^2) compared to 3 WAS (223.8 and 137.2 g/m^2) mainly due to maturity because of its short life cycle. Balyan and Bhan (1986) had reported that *T. portulacastrum*, a short duration weed, starts production of flowers and seeds 20 to 30 DAS. Whereas, *E. crus-galli* dry weight increased at 6 WAS. Thus, during early stages *T. portulacastrum* and *D. aegyptium* were more competitive and at later stages, *E. crus-galli* was the competitive weed.

Mesotrione 120 g/ha applied alone was very effective in decreasing the dry weights of broad-leaved weeds namely *T. portulacastrum* and *D. arvensis*. However, it was poor against dominant grass weed *D. aegyptium*, as evident from weed dry weights data (**Tables 1** and **2**). In comparison to untreated control, mesotrione did not reduce the *D. aegyptium* biomass significantly and even, it was significantly higher during year 2013 at 3 WAS. Earlier studies (Armel *et al.* 2003a, Zhang *et al.* 2013) have also shown that mesotrione is more effective for control of broad-leaf weeds but less against grass weeds. The total weed dry weight under mesotrione were 199.5 and 347.6 g/m^2 at 3WAS during 2013 and 2014, respectively, whereas at 6 WAS, the respective values were 209.9 and 380.5 g/m^2 during 2013 and 2014.

The atrazine 1000 g/ha as PE application provided the good control of *D. arvensis* and was poor against *D. aegyptium*. The total weed dry weights data with atrazine application were 63.4 and 389.9 g/m^2 at 3 WAS during first and second year, respectively and 101.3 and 429.9 g/m^2 at 6 WAS during 2013 and 2014, respectively. Application of 2,4-D effectively controlled the broad-leaved weed *D. arvensis* but was relatively poor against *T. portulacastrum*. The grass weeds dry weights were greater in the mesotrione and 2,4-D treatments than in the weedy control (**Table 1** and **2**). This was due to the suppression of the grass weeds growth by broad-leaved weeds particularly *T. portulacastrum* in the untreated weedy control.

Table 1. Effect of herbicides on weeds in maize at 3 and 6 weeks after sowing in 2013

Treatments	Dose (g/ha)	Weed dry weight (g/m^2)							
		E. crus-galli	*Digera arvensis*	*D. aegyptium*	*Trianthema portulacastrum*	*Digitaria sanguinalis*	*P. niruri*	Other weeds	Total weeds
3 Weeks after sowing									
Untreated check	-	21.5 ^{A}	34.8 ^{A}	92.5 ^{C}	223.8 ^{A}	7.9 ^{AB}	1.7 ^{A}	10.9	393.0 ^{A}
Mesotrione + atrazine (1:10)- PoE	750	0.2 ^{B}	0.1 ^{C}	1.1 ^{E}	3.7 ^{C}	0.0 ^{C}	0.0 ^{B}	2.4	7.4 ^{D}
Mesotrione + atrazine (1:10)- PoE	875	0.1 ^{B}	0.1 ^{C}	0.2 ^{E}	0.2 ^{C}	0.0 ^{C}	0.0 ^{B}	0.4	0.9 ^{D}
Mesotrione + atrazine (1:10)- PoE	1000	0.1 ^{B}	0.1 ^{C}	0.1 ^{E}	0.2 ^{C}	0.0 ^{C}	0.0 ^{B}	1.9	2.4 ^{D}
Mesotrione- PoE	120	0.0 ^{B}	0.0 ^{C}	190.2 ^{B}	0.5 ^{C}	5.1 ^{B}	0.5 ^{B}	3.2	199.5 ^{B}
2,4-D- Na- PoE	1000	17.6 ^{A}	0.0 ^{C}	282.5 ^{A}	60.9 ^{B}	11.7 ^{A}	0.7 ^{B}	2.6	375.9 ^{A}
Atrazine pre-emergence at 1 DAS	1000	6.2 ^{B}	6.2 ^{B}	39.8 ^{D}	5.7 ^{C}	0.6 ^{C}	0.0 ^{B}	4.9	63.4 ^{C}
p-Value		0.0002	<0.0001	<0.0001	<0.0001	0.0001	0.0149	0.0606	<0.0001
6 Weeks after sowing									
Untreated check	-	47.5 ^{A}	44.4 ^{A}	149.8 ^{A}	33.9 ^{A}	23.8 ^{A}	0.1	5.1	304.4 ^{A}
Mesotrione +atrazine (1:10)-PoE	750	4.1 ^{C}	2.1 ^{C}	6.3 ^{C}	2.4 ^{B}	0.7 ^{B}	0.0	1.3	16.7 ^{D}
Mesotrione +atrazine (1:10)- PoE	875	2.4 ^{C}	1.6 ^{C}	1.4 ^{C}	0.3 ^{BC}	0.0 ^{B}	0.0	1.9	7.6 ^{D}
Mesotrione +atrazine (1:10)- PoE	1000	1.0 ^{C}	1.0 ^{C}	0.1 ^{C}	0.2 ^{BC}	0.0 ^{B}	0.0	1.6	4.0 ^{D}
Mesotrione- PoE	120	1.4 ^{C}	0.0 ^{C}	201.5 ^{A}	0.0 ^{C}	1.5 ^{B}	0.0	5.5	209.9 ^{B}
2,4-D- Na- PoE	1000	59.7 ^{A}	0.0 ^{C}	209.5 ^{A}	1.1 ^{BC}	14.3 ^{A}	0.0	0.0	284.5 ^{A}
Atrazine pre-emergence at 1 DAS	1000	22.5 ^{B}	10.1 ^{B}	52.6 ^{B}	1.0 ^{BC}	12.3 ^{A}	0.0	2.9	101.3 ^{C}
p-Value		<0.0001	<0.0001	<0.0001	<0.0001	0.0013	0.5440	0.2050	<0.0001

PoE = Post-emergence application at 15 DAS; Original values of weed dry weights data were square root transformed ($\sqrt{x+1}$) before statistical analysis and based on the analysis of the transformed data, letter have been assigned to original values for interpretation. Means with at least one letter common within a column are not statistically significant using Fisher's LSD at 5%

The ready mix combination (1:10 w/w) of mesotrione and atrazine at 750-1000 g/ha was more effective in decreasing the total weed dry biomass as compared to their alone applications. The reductions in weed infestation with ready mix combination at 875 and 1000 g/ha were significantly more compared to lower dose of 750 g/ha. The weed control efficiency (WCE) of ready mix combination of mesotrione and atrazine at 875 and 1000 g/ha was 97.5 and 98.7%, respectively, during 2013 whereas, during 2014, respective WCE was 88.9 and 92.1% (**Table 3**). However, sole application of mesotrione 120 g/ha and atrazine 1000 g/ha had lower WCE of 31.0 and 66.7%, respectively during first season and during second season, the corresponding values were 19.8 and 9.4%. The better efficacy in combination compared to alone application shows synergism in mixture. In earlier studies, the synergistic interactions between mesotrione and atrazine have been reported for control of many weeds (Bollman *et al.* 2008, Jhala *et al.* 2014, Johnson *et al.* 2002, Whaley *et al.* 2006, Woodyard *et al.* 2009, Abendroth *et al.* 2006). Janak and Grichar (2016) also reported the consistent annual grasses control including barnyardgrass (*E. crus-galli*) by three way combinations of S-metolachlor plus atrazine plus mesotrione than one active ingredient.

Weed control treatments also significantly (<0.0001) influenced the maize grain yield (**Table 3**). The uncontrolled weed competition during the crop duration resulted in the lowest grain yield of 4.76 and 3.73 t/ha in 2013 and 2014, respectively. Except, application of 2,4-D-Na 1000 g/ha, the rest of herbicide treatments (mesotrione, atrazine and their combinations) produced significantly higher grain yield compared with untreated weedy check. Grain

Table 2. Effect of herbicide treatments on weeds in maize at 3 and 6 weeks after sowing in 2014

Treatments	Dose (g/ha)	Weed dry weight (g/m^2) *Echinochloa crus-galli*	*Digera arvensis*	*D. aegyptium*	*Trianthema portulacastrum*	*P. niruri*	Other weeds	Total weeds
3 Weeks after sowing								
Untreated check	-	8.9^{B}	51.4^{A}	363.4^{AB}	137.2^{A}	7.0^{A}	9.2^{BC}	577.1^{A}
Mesotrione + atrazine (1:10)-PoE	750	0.4^{C}	0.4^{C}	7.7^{C}	0.3^{D}	0.0^{B}	21.6^{AB}	30.5^{C}
Mesotrione + atrazine (1:10)- PoE	875	0.2^{C}	0.0^{C}	0.7^{C}	0.4^{D}	0.0^{B}	8.0^{BC}	9.2^{C}
Mesotrione + atrazine (1:10)- PoE	1000	0.1^{C}	0.0^{C}	0.9^{C}	0.4^{D}	0.0^{B}	6.8^{BC}	8.2^{C}
Mesotrione- PoE	120	0.7^{C}	0.0^{C}	340.5^{AB}	0.6^{D}	0.1^{B}	5.8^{BC}	347.6^{B}
2,4-D- Na- PoE	1000	11.8^{AB}	0.0^{C}	451.1^{A}	6.8^{C}	0.0^{B}	1.3^{C}	471.0^{AB}
Atrazine pre-emergence at 1 DAS	1000	13.8^{A}	19.2^{B}	281.0^{B}	41.8^{B}	0.0^{B}	34.1^{A}	389.9^{B}
p-Value		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0320	<0.0001
6 Weeks after sowing								
Untreated check	-	13.0^{AB}	92.2^{A}	324.1^{B}	36.2^{A}	0.6^{A}	8.5	474.5^{A}
Mesotrione + atrazine (1:10)-PoE	750	2.1^{C}	5.5^{C}	53.1^{C}	4.1^{C}	0.2^{B}	12.3	77.3^{B}
Mesotrione + atrazine (1:10)- PoE	875	2.0^{C}	1.3^{C}	37.4^{C}	1.9^{CD}	0.1^{B}	9.8	52.5^{B}
Mesotrione + atrazine (1:10)- PoE	1000	1.8^{C}	1.1^{C}	24.9^{C}	1.3^{CD}	0.1^{B}	8.2	37.4^{B}
Mesotrione- PoE	120	0.0^{C}	0.0^{C}	379.1^{AB}	0.0^{D}	0.0^{B}	1.4	380.5^{A}
2,4-D- Na- PoE	1000	5.0^{BC}	0.0^{C}	423.1^{A}	0.9^{CD}	0.0^{B}	17.1	446.1^{A}
Atrazine pre-emergence at 1 DAS	1000	14.9^{A}	63.2^{B}	320.8^{B}	17.9^{B}	0.0^{B}	13.0	429.9^{A}
p-Value		0.0049	<0.0001	<0.0001	<0.0001	0.0018	0.8843	<0.0001

PoE = Post-emergence application at 18 DAS; Original values of weed dry weights data were square root transformed ($\sqrt{x+1}$) before statistical analysis and based on the analysis of the transformed data letter have been assigned to original values for interpretation. Means with at least one letter common within a column are not statistically significant using Fisher's LSD at 5%.

Table 3. Weed control efficiency and maize grain yield as influenced by herbicides during 2013 and 2014

Herbicide	Dose (g/ha)	Time of application (DAS) 2013	Time of application (DAS) 2014	Weed control efficiency (WCE) % at 6 WAS 2013	WCE 2014	*Grain yield (t/ha) 2013	*Grain yield (t/ha) 2014
Untreated check	-	-	-	0.0	0.0	4.76^{D}	3.73^{C}
Mesotrione + atrazine	68+682 (750)	15	18	94.5	83.7	7.55^{A}	7.73^{A}
Mesotrione + atrazine	80+795 (875)	15	18	97.5	88.9	7.74^{A}	8.11^{A}
Mesotrione + atrazine	91+909 (1000)	15	18	98.7	92.1	7.76^{A}	8.00^{A}
Mesotrione	120	15	18	31.0	19.8	5.96^{C}	5.83^{B}
2,4-D- Na	1000	15	18	6.5	6.0	5.30^{CD}	3.82^{A}
Atrazine	1000	01	01	66.7	9.4	6.70^{B}	5.93^{B}
p-Value						<0.0001	<0.0001

*Means with at least one letter common within a column are not statistically significant using Fisher's LSD at 5%; DAS - Day after sowing; WAS Week after sowing yields obtained in 2,4-D-Na (5.30 and 3.82 t/ha) and weedy check (4.76 and 3.73 t/ha) were not statistically different due the failure of 2,4-D-Na in controlling dominant grass weeds. Ready mix combination at 875-1000 g/ha applied as early PoE provided better yield (7.74-8.11 t/ha) compared to the lowest dose of 750 g/ha, untreated control, mesotrione 120 g/ha (5.83-5.96 t/ha), atrazine 1000 g/ha (5.93-6.70 t/ha) and 2,4-D-Na 1000 g/ha. However, grain yield under various doses of ready mixture was statistically similar but significantly better than mesotrione 120 g/ha, 2,4-D 1000 g/ha and atrazine 1000 g/ha. The improved yield was as a resultant of better broad spectrum weed control (grass and broad-leaved weeds) in herbicide mix combinations. Janak and Grichar (2016) also observed higher corn yield when herbicide treatments consisted of more than one active ingredient compared to single active ingredient. Moreover, this strategy of using ready mix combination of mesotrione + atrazine will help in delaying the herbicide resistance evolution as well as managing the problem of weed flora shift.

Synergistic effect of mesotrione + atrazine against weeds in pot studies

Mesotrione (30, 60 and 120 g/ha) and atrazine (250, 500 and 1000 g/ha) alone and in tank-mix combinations at 30 + 250, 60 + 500 and 120 + 1000 g/ha were evaluated on two grass weeds (*E. crus-galli* and *D. aegyptium*). Mesotrione and atrazine applied alone were poor in reducing the fresh biomass of both weeds compared to their combinations (**Figure 1**). The biomass reductions of *D. aegyptium* with application of mesotrione at 30, 60 and 120 g/ha with cationic surfactant (1000 ml/ha) were 49.9, 63.7 and 90.7%, respectively, compared to untreated control and with applications of atrazine 250, 500 and 1000 g/ha were 47.2, 64.8 and 83.5%, respectively. However, the tank mix combinations of mesotrione + atrazine 30 + 250, 60 + 500 and 120 + 1000 g/ha with surfactant caused respective *D. aegyptium* biomass reductions of 85.5, 96.5 and 99.3%. Similarly, the *E. crus-galli* fresh weight reductions with application of mesotrione at 30, 60 and 120 g/ha were 51.8, 83.5 and 93.7%, respectively (**Figure 1**). The applications of atrazine at 250, 500 and 1000 g/ha caused respective fresh weight reductions of 47.9, 79.1 and 88.9%. The combinations of mesotrione + atrazine 30 + 60, 60 + 500 and 120 + 1000 g/ha with 1000 ml/ha surfactant reduced the *E. crus-galli* fresh weight by 96.2, 98.6 and 100%, respectively. These pot studies results confirmed mesotrione plus atrazine synergism for weed control.

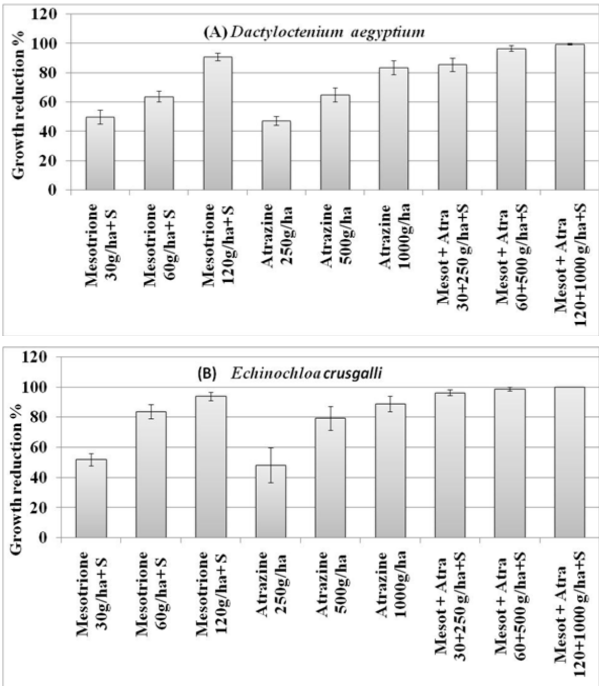


Figure 1. Fresh biomass reduction of (A) *Dactyloctenium aegyptium* and (B) *E. crus-galli* with application of mesotrione, atrazine and their combinations at various doses. Vertical error bars above means represent ±SEM. S - Surfactant

As compared to field studies, pot studies have shown better efficacies of mesotrione against grass weeds, as the external cationic surfactant (1000 ml/ha), was not added in field studies. Earlier results (Young *et al*. 2007, Chhokar *et al*. 2015) demonstrated that HPPD herbicides (mesotrione, tembotrione and topramezone) had good weed control efficacy, when applied as tank-mix with methylated seed oil (MSO) adjuvant. Therefore, further studies are needed to evaluate the effect of surfactant or adjuvant on mesotrione efficacy. In earlier studies, nitrogen enhanced the smooth crabgrass (*Digitaria ischaemum*) control with mesotrione and topramezone (Elmore *et al*. 2012). The ammonium sulphate (AMS) addition also enhanced the mesotrione efficacy (Devkota *et al*. 2016).

Since, mixtures of two or more herbicides can give more reliable control of some hardy weeds and reduce the risk of evolving herbicide resistance even with the application of lower amount of total herbicides (Zhang *et al*. 1995). Similarly, synergism resulted on the atrazine resistant (AR) velvetleaf biotype, when a constant rate of mesotrione 3.2 g/ha was tank mixed with atrazine (126 to 13,440 g/ha). Also, addition of mesotrione 1.5 g/ha enhanced the resistant wild radish (*Raphanus raphanistrum*) population control by a further 60% in mixture with atrazine 400 g/ha (Walsh *et al*. 2012) indicating the synergistic herbicide interactions in overcoming the target-site herbicide resistance mechanism.

It was concluded that ready mix combination (1:10 w/w) of mesotrione + atrazine at 875-1000 g/ha can be used for effective broad spectrum (grass and broad-leaf) weed management in maize. The atrazine and mesotrione mixture was synergistic in controlling weeds and was significantly better than the alone usage of atrazine 1000 g/ha and mesotrione 120 g/ha. Weed management strategies involving more than one herbicide mechanism of action are important in managing herbicide-resistant weeds and economic maize production. However, for long term sustainable and economic weed management, proper attention have to be given by integration of non-chemical weed control practices with diverse herbicide modes of actions.

REFERENCES

Abendroth JA, Martin AR and Roeth FW. 2006. Plant response to combinations of mesotrione and photosystem II inhibitors. *Weed Technology* **20**: 267–274.

Armel GR, Wilson HP, Richardson RJ and Hines TE. 2003a. Mesotrione combinations for postemergence control of Horsenettle (*Solanum carolinense*) in corn (*Zea mays*). *Weed Technology* **17**(1): 65–72.

Armel GR, Wilson HR, Richardson RJ and Hines TE. 2003b. Mesotrione, acetochlor, and atrazine for weed management in corn. *Weed Technology* **17**: 284–290.

Balyan RS and Bhan VM. 1986. Emergence, growth, and reproduction of Horse Purslane (*Trianthema portulacastrum*) as influenced by environmental conditions. *Weed Science* **34**(4): 516–519.

Bollman JD, Boerboom CM, Becker RL and Fritz VA. 2008. Efficacy and tolerance to HPPD-inhibiting herbicides in sweet corn. *Weed Technology* **22**(4): 666-674.

Bollman SL, Kells JJ and Penner D. 2006. Weed response to mesotrione and atrazine applied alone and in combination pre-emergence. *Weed Technology* **20**: 903–907.

Chhokar RS, Sharma RK and Sharma I. 2015. Improving the herbicide efficacy with tank mix adjuvant usage. *Pestology* **39**(5): 15–34.

Devkota P, Spaunhorst DJ and Johnson WG. 2016. Influence of carrier water pH, hardness, foliar fertilizer, and ammonium sulfate on mesotrione efficacy. *Weed Technology* **30**(3): 617–628.

Diggle AJ, Neve PB and Smith FP. 2003. Herbicides used in combination can reduce the probability of herbicide resistance in finite weed populations. *Weed Research* **43**: 371–382.

Elmore MT, Brosnan JT, Kopsell DA and Breeden GK. 2012. Nitrogen-enhanced efficacy of mesotrione and topramezone for smooth crabgrass control. *Weed Science* **60**(3): 480–485.

Heap I. 2019. The International survey of herbicide resistant weeds. Available from URL: http://weedscience.org/, Accessed date: 26 February 2019.

Janak TW and Grichar WJ. 2016. Weed control in corn (*Zea mays* L.) as influenced by pre-emergence herbicides. *International Journal of Agronomy*, Article ID 2607671, 9 pages http://dx.doi.org/10.1155/2016/2607671.

Jhala AJ, Sandell LD, Rana N, Kruger GR and Knezevic SZ. 2014. Confirmation and control of triazine and 4-hydroxyphenylpyruvate dioxygenase-inhibiting herbicide-resistant palmer amaranth (*Amaranthus palmeri*) in Nebraska. *Weed Technology* **28**(1): 28–38.

Johnson BC, Young BG and Matthews JL. 2002. Effect of post-emergence application rate and timing of mesotrione on corn (*Zea mays*) response and weed control. *Weed Technology* **16**: 414–420.

Massing RA, Currie RS and Trooien TP. 2003. Water use and light interception under Palmer amaranth and corn competition. *Weed Science* **51**: 523–531.

Pannacci E and Covarelli G. 2009. Efficacy of mesotrione used at reduced doses for post-emergence weed control in maize (*Zea mays* L.). *Crop Protection* **28**: 57–61.

Sharma V and Thakur DR. 1998. Integrated weed management in maize under mid-hill conditions of North-Western Himalayas. *Indian Journal of Weed Science* **30** (3, 4): 158–162.

Sutton P, Richards C, Buren L and Glasgow L. 2002. Activity of mesotrione on resistant weeds in maize. *Pest Management Science* **58**: 981–984.

Tapia LS, Bauman TT, Harvey RG, Kells JJ, Kapusta G, Loux MM, Lueschen WE, Owen MDK., Hageman LH and Strachan SD. 1997. Post-emergence herbicide application timing effects on annual grass control and corn (*Zea mays*) grain yield. *Weed Science* **45**: 138–143.

Walsh MJ, Stratford K, Stone K and Powles SB. 2012. Synergistic effects of atrazine and mesotrione on susceptible and resistant wild radish (*Raphanus raphanistrum*) populations and the potential for overcoming resistance to triazine herbicides. *Weed Technology* **26**(2): 341–347.

Whaley CM, Armel GR, Wilson HP and Hines TE. 2006. Comparison of mesotrione combinations with standard weed control programs in corn. Weed Technology **20**(3): 605–611.

Woodyard AJ, Hugie JA and Riechers DE. 2009. Interactions of mesotrione and atrazine in two weed species with different mechanisms for atrazine resistance. *Weed Science* **57**(4): 369–378.

Young BG, Zollinger RK and Bernards ML. 2007. Variability of tembotrione efficacy as influenced by commercial adjuvant products. *North Central Weed Science Society Proceeding* **62**: 141.

Zhang J, Hamill AS and Weaver SE. 1995. Antagonism and synergism between herbicides: trends from previous studies. *Weed Technology* **9**: 86–90.

Zhang J, Zheng Li, Jäck O, Yana D, Zhang Z, Gerhards R and Ni H. 2013. Efficacy of four post-emergence herbicides applied at reduced doses on weeds in summer maize (*Zea mays* L.) fields in North China Plain. *Crop Protection* **52**: 26–32.

Indian Journal of Weed Science **51**(2): 151–157, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Impact of imazethapyr and its ready-mix combination with imazamox to control weeds in blackgram

S.S. Rana*, Gurdeep Singh, M.C. Rana, Neelam Sharma, Sanjay Kumar, Gurpreet Singh and D. Badiyala

Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya Palampur, Himachal Pradesh 176 062, India

**Email: ranass_dee@rediffmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00033.9

Type of article: Research article

Received : 7 April 2019
Revised : 14 June 2019
Accepted : 16 June 2019

Key words

Blackgram
Combinations
Imazamox
Imazethapyr
Impacts
Weeds
Yield

ABSTRACT

The bio-efficiency of imazethapyr and its combination with imazamox or pendimethalin in comparison to hand weeding against weeds, their effect on growth, yield and phytotoxicity on black gram and residual effect on succeeding mustard crop were studied during 2014-15 and 2015-16. Hand weeding twice resulted in the highest overall weed control efficiency followed by pre-emergence application of imazethapyr + imazamox 80 g/ha, pre-emergence imazethapyr + imazamox 70 g/ha and pre-emergence imazethapyr + pendimethalin 1000 g/ha. Hand weeding twice and pre-emergence imazethapyr + pendimethalin 1000 g/ha were comparable to pre-emergence imazethapyr + imazamox 70 g/ha for seed yield. With every increase of one weed per square metre, the blackgram seed yield was reduced by 2.1 kg/ha. Similarly with every g/m^2 increase in weed weight, the blackgram yield was subjected to fall by 5.1 kg/ha. The economic threshold levels *i.e.* No/m^2 and g/m^2 with the weed management practices studied varied between 8.3 – 42.0/m^2 and 3.5-17.6 g/m^2. Weed persistence index (WPI) was lowest and crop resistance index (CRI) was highest in the hand weeding twice treatment. Post-emergence application of imazethapyr 70 and 80 g/ha and imazethapyr + imazamox 70 and 80 g/ha caused mild toxicity during 2014 and had therefore lower crop resistance index. Efficiency index was the highest under hand weeding followed by pre-emergence application of imazethapyr + imazamox 80 g/ha, pre-emergence imazethapyr + pendimethalin 1000 g/ha and pre-emergence imazethapyr 80 g/ha. Weed index indicated 55.4% reduction in yield of blackgram due to weeds. Pre-emergence imazethapyr 80 g/ha, imazethapyr + imazamox 80 g/ha, imazethapyr 70 g/ha and imazethapyr + pendimethalin 1000 g/ha had higher overall impact index than hand weeding due to lower cost. Residual effect/phytotoxicity was not observed on succeeding crop of mustard during 2014 and 2015 as well.

INTRODUCTION

Black gram is an important *Kharif* season pulse of Himachal Pradesh, which is grown in an area of 9.4 thousand ha with production of 12 thousand tonnes and productivity of 1286 kg/ha (https://iipr.icar.gov.in/pdf/6.4_270615.pdf). The yield of blackgram in the state is higher than the national average of 555 kg/ha, but below the potential (1600 kg/ha) of top varieties in the state. Among the various constraints to production, weeds so far are the major hindrance in exploiting the full production potential of the crop. Weeds are important biological constraints to production in short statured crops. Due to high rainfall, weeds grow luxuriantly and pose a serious threat to short statured *Kharif* blackgram. Up to 45 per cent yield losses in blackgram due to weeds have been reported (Yadav *et al.* 2015). This crop receives low priority in Himachal Pradesh as it is grown on poor and marginal soils. This crop offers poor competition to weed in early stages of growth especially between 3 and 6 weeks after sowing (Choudhary *et al.* 2012) and therefore, weed control early in the season is essential to ensure proper crop growth and productivity. If the weeding is delayed beyond critical period, the yield losses are reported to be 60-90%.

In Himachal Pradesh, pendimethalin is recommended for the control of weeds in blackgram as pre-emergence, but due to frequent rains, different flushes of weeds come up at later stages, which need to be controlled to achieve potential productivity. In order to improve weed control efficacy with minimum application costs, the use of formulated or tank mix herbicide mixtures (Chandrakar *et al.* 2014, Patel *et al.* 2014) as well as integration of herbicides with manual or mechanical means (Choudhary *et al.* 2012, Kumar *et al.* 2007 and 2013) seems better option. The present investigation was carried out to assess the economic impacts of new herbicide mixtures in blackgram.

MATERIALS AND METHODS

The field experiment with 12 treatments, *viz.* imazethapyr 70 and 80 g/ha (pre-emergence and at 3-4 leaf stage *i.e.* 20 DAS), ready-mix imazethapyr+ imazamox 70 and 80 g/ha (pre-emergence and at 3-4 leaf stage *i.e.* 20 DAS), pendimethalin 1000 g/ha (pre-emergence), ready-mix imazethapyr + pendimethalin 1000 g/ha (pre-emergence), hoeing (20 and 40 DAS)and weedycheck was conducted during 2014 and 2015. Blackgram variety '*UG-218*' was sown on July 3, 2014 and July 10, 2015 with a spacing of 30 x 10 cm and harvested on October 1, 2014 and October 5, 2015. The herbicide treatments were applied with knapsack power sprayer using 600 litres of water per hectare. The crop was fertilized with 20 kg N, 40 kg P_2O_5 and 20 kg K_2O per hectare. Nutrients were applied through IFFCO 12:32:16 and urea (46%) at the time of sowing. Observations on weed count and dry weight at 40, 60 DAS and at harvest were recorded by using a quadrate measuring 25 x 25 cm at two randomly selected spots in each plot and converted into one square metre area.

Without disturbing the layout, the residual effect of treatments on succeeding brown sarson (*Brassica rapa*) crop was studied. The sarson variety '*BSH 1*' was sown immediately after harvest of blackgram crop.

The economic threshold/economic injury level (*i.e.* the weed density at which the cost of treatment equals the economic benefit obtained from that treatment), was calculated as suggested by Stone and Pedigo (1972) as well as Uygur & Mennan (1995).

Economic threshold = Gain threshold/ Regression coefficient (Stone and Pedigo, 1972)

Where, gain threshold = Cost of weed control (Hc+Ac)/Price of produce (Gp), and regression coefficient (b) is the outcome of simple linear relationship between yield (Y) and weed density/ biomass (x), Y = a + bx; Hc, herbicide cost; Ac, application cost of herbicide; Gp, grain price.

Y= [{(100/He*Hc)+A_C}/(Gp*Yg)]*100 (Uygur & Mennan, 1995)

Where, Y is percent yield losses at a different weed density; He, herbicide efficiency; and Yg, yield of weed free.

The different impact indices were worked out after Walia (2003) and Rana and Kumar (2014) as follow:

$$\text{Weed control efficiency (WCE)} = \frac{\textit{Weed count in control (unweeded)} - \textit{Weed count in a treatment}}{\textit{Weed count in control (unweeded)}}$$

$$\text{Weed control index (WCI)} = \frac{\textit{Weed weight in control (unweeded)} - \textit{Weed weight in a treatment}}{\textit{Weed weight in control (unweeded)}}$$

$$\textit{Weed index} = \frac{\textit{Yield from weed free} - \textit{Yield of particular treatment}}{\textit{Yield of weed free}} \, x\ 100$$

Weed persistence index (WPI)

$$WPI = \frac{\textit{Weed weight in treated plot}}{\textit{Weed weight in control plot}} \, x \, \frac{\textit{Weed count in control plot}}{\textit{Weed count in treated plot}}$$

Crop resistance index (CRI)

$$CRI = \frac{\textit{Crop weight in treated plot}}{\textit{Crop weight in control plot}} \, x \, \frac{\textit{Weed weight in control plot}}{\textit{Weed weight in treated plot}}$$

Weed management index (WMI)

$$WMI = \frac{\textit{Per cent yield over control}}{\textit{Per cent control of the pest}}$$

Agronomic management index (AMI)

$$AMI = \frac{\textit{Per cent yield over control} - \textit{Per cent control of the pest}}{\textit{Per cent control of the pest (weed)}}$$

Integrated Weed Management index (IWMI)

$$IPMI = \frac{PMI + AMI}{2}$$

Efficiency index (EI)

$$EI = \frac{\dfrac{\textit{Yield of treatment} - \textit{Yield of control}}{\textit{Yield of control}} \, x\ 100}{\dfrac{\textit{Weed weight in treatment}}{\textit{Weed weight in control}} \, x\ 100}$$

$$\textit{Weed intensity}(\%) = \frac{\textit{Weed population}}{\textit{Weed + crop population}} \, x\ 100$$

$$\textit{Crop intensity} = 100 - \textit{weed intensity}$$

'Overall impact index' was determined, by calculating (i) the 'unit value' where the value under a particular treatment of a parameter was divided by the respective arithmetic mean of treatments for that parameter as given below:

$$U_{ij} = \frac{V_{ij}}{AM_j}$$

Where 'Uij' is the unit value for 'ith' treatment corresponding to 'jth' parameter, 'Vij' is the actual measured value for 'ith' treatment of 'jth' parameter and 'AMj' is the arithmetic mean value for jth parameter.

(ii) the overall impact index was calculated as an average of unit values (Uij) of all the parameters under consideration:

$$OI_i = \frac{1}{N}\sum_{i=1}^{N} U_{ij}$$

where 'OIi' is the overall impact index for 'ith' treatment and 'N' is the number of parameters considered in deriving overall impact index.

The data obtained were subjected to statistical analysis by analysis of variance (ANOVA) for the randomized block design to test the significance of the overall differences among the treatments by the "F" test and conclusion was drawn at 5% probability level.

RESULTS AND DISCUSSIONS

Effect on weeds

During 2014, the experimental field was infested with *Digitaria sanguinalis, Cyperus rotundus, Dactyloctenium aegypticum, Echinochloa colona, Commelina benghalensis, Eleusine indica* and *Setaria glauca* and in 2015, *Echinochloa* sp*., Dactyloctenium aegypticum* and *Cyperus iria* were dominating weed species. Weed control treatments brought about significant variation in the count and dry weight of weeds at all the stages of observation (**Table 1**). In general pre-emergence application of herbicides was better than their post-emergence application for controlling weeds. Similarly ready mix herbicide combinations had an edge over sole application of herbicides. Pre-emergence application of ready-mix imazethapyr + imazamox 80 g/ha remaining at par with pre-emergence imazethapyr + imazamox 70 g/ha resulted in significantly lower count and dry weight of weeds among the herbicidal treatments in 2015. While in 2014, the application of imazethapyr applied as pre-emergence at 80 g/ha remaining at par with imazethapyr 70 g/ha pre-emergence, imazethapyr 70 and 80 g/ha applied as post-emergence, imazethapyr + imazamox 70 and 80 g/ha applied as post-emergence and imazethapyr + pendimethalin pre-mix as pre-emergence had significantly lower weed count and dry weight. Similar was the trend with respect to total weed count at harvest of the blackgram crop. Chandrakar *et al.* (2014) also reported effectiveness of early post-emergence application (15-20 DAS) of imazethapyr at 40 g/ha and pendimethalin + imazethapyr (ready-mix) at 1.0 kg/ha as pre-emergence against weeds in black gram. Studies conducted by Patel *et al.* (2014) are also in conformity with above results.

Hand weeding twice resulted in the highest overall weed control efficiency followed by pre-emergence application of imazethapyr+imazamox 80g/ha, imazethapyr+imazamox 70 g/ha and imazethapyr + pendimethalin 1000 g/ha (**Table 2**). Post-emergence herbicidal weed control in general was poor. Weed control efficiency was highest *i.e.* 92.5% and 99.2% in 2014 and 2015, respectively, under hand weeding (twice) treatment which was comparable to imazethapyr 80 g/ha pre-emergence during 2014 and imazethapyr + imazamox (pre-mix) 80 g/ha in 2015.

Effect on crop

No toxicity of herbicide was observed with pre-emergence application of imazethapyr 70 and 80 g/ha or imazethapyr + imazamox (pre-mix) or pendimethalin. However, highest 18% phytotoxicity was observed with pre-mix imazethapyr + imazamox 80 g

Table 1. Effect of treatments on total weed count and total dry weight at different growth stages of blackgram

Treatment	Dose (g/ha)	Time of application (DAS)	Total weed count (no/m^2)				Total weed dry weight (g/m^2)			
			40 DAS	60 DAS	At harvest		40 DAS	60	At harvest	
			2014	2015	2014	2015	2014	2015	2014t	2015
Imazethapyr	70	Pre-	1.97(2.9)	14.2(202.7)	3.53(11.5)	13.8(192)	2.38(4.7)	7.8(60.2)	2.87(7.25)	8.7(75.6)
Imazethapyr	80	Pre-	1.82(2.3)	12.8(165.3)	3.56(11.7)	10.6(112)	1.73(2.0)	6.9(47.4)	2.79(6.8)	7.2(51.7)
Imazethapyr	70	20	2.89(7.3)	17.3(298.7)	3.71(12.8)	15.3(234.7)	2.28(4.2)	10.1(101.5)	2.26(4.1)	11.1(122.6)
Imazethapyr	80	20	2.64(6.0)	16.0(256)	3.73(12.9)	14.2(202.7)	1.92(2.7)	9.4(88.9)	1.84(2.4)	10.3(107)
Imazethapyr + imazamox	70	Pre-	2.61(5.81)	10.3(106.7)	2.43(4.9)	8.6(74.7)	2.26(4.1)	5.4(29)	2.0(3.0)	6.0(35.8)
Imazethapyr + imazamox	80	Pre-	2.57(5.6)	7.6(58.7)	2.41(4.8)	6.8(48)	1.92(2.7)	4.4(19)	1.55(1.4)	4.8(23.3)
Imazethapyr + imazamox	70	20	9.11(82.0)	14.6(213.3)	5.07(24.7)	13.1(170.7)	2.96(7.8)	8.6(73.2)	2.30(4.3)	9.6(92.7)
Imazethapyr + imazamox	80	20	7.03(48.4)	13.7(186.7)	3.51(11.3)	11.8(138.7)	2.36(4.6)	8.2(66.8)	2.24(4.03)	8.6(73.6)
Pendimethalin	1000	Pre-	3.87(14.0)	14.9(224)	3.11(8.7)	13.7(186.7)	2.14(3.6)	8.4(70.1)	2.98(7.9)	9.3(85.9)
Imazethapyr + pendimethalin	1000	Pre-	2.51(5.3)	11.3(128)	2.41(4.8)	9.5(90.7)	1.89(2.6)	5.9(34.8)	2.39*(4.7)	6.6(44)
Hand weeding	-	20 & 40	4.05(15.4)	2.9(10.7)	3.62(12.1)	4.1(16)	1.48(1.2)	1.5(1.9)	2.37 (4.6)	2.3(4.9)
Weedy check	-	-	10.5(110)	25.7(661.3)	9.27(85.0)	22.8(517)	4.12(16.0)	15.7(244.3)	4.44(18.7)	17.1(293.6)
LSD (p=0.05)			1.59	1.8	1.08	1.8	0.57	0.8	1.22	1.3

Pre- Pre-emergence; Values given in the parentheses are the original means applied on 20 DAS during 2014. However, at harvest of crop no phytotoxicity was observed.

Weed control treatments gave significant variation in plant height and yield of blackgram (**Table 3**). The superior control of weeds was reflected in growth and yield of blackgram. In 2014, significantly the highest seed yield of blackgram was recorded with pre-emergence application of imazethapyr 80 g/ha which remained at par with the pre-emergence imazethapyr 70 g/ha and imazethapyr + pendimethalin 1000 g/ha. Sasikala *et al.* (2014) found that imazethapyr applied at 100 g/ha on 15 DAS provided excellent control of grasses and broad-leaf weeds in blackgram and thereby higher yield. Aggarwal *et al.* (2014) found imazethapyr at 75 and 100 g/ha on 15 DAS effective against weeds in blackgram and gave its higher yield. The lowest seed yield was recorded in weedy check. In 2015, pre-emergence application of imazethapyr + imazamox 80 g/ha remaining at par with pre-emergence application of imazethapyr + imazamox 70 g/ha resulted in significantly higher seed yield of blackgram over other weed control treatments. Tiwari *et al.* (2006) obtained significantly higher soybean seed yield with application of Odyssey (imazethapyr + imazamox) at 2 L/ha. Hand weeding twice and pre-emergence application of

Table 2. Effect of treatments on weed control efficiency (%) and crop phytotoxicity (%) at different growth stages of blackgram

Treatment	Dose (g/ha)	Time of application (DAS)	Weed control efficiency (%)				Crop phytotoxicity (%) in black gram			
			40 DAS	60DAS	At harvest		40 DAS	40 DAS	Harvest	
			2014	2015	2014	2015	2014	2015	2014	2015
Imazethapyr	70	Pre-	70.6	75.4	61.2	71.9	0.0	0.0	0.0	0.0
Imazethapyr	80	Pre-	87.5	80.6	63.6	82.4	0.0	0.0	0.0	0.0
Imazethapyr	70	20	73.7	58.5	78.0	58.2	8.0	0.0	0.0	0.0
Imazethapyr	80	20	83.1	63.7	87.1	63.6	10.0	0.0	0.0	0.0
Imazethapyr + imazamox	70	Pre-	74.3	88.1	83.9	87.8	0.0	0.0	0.0	0.0
Imazethapyr + imazamox	80	Pre-	83.1	92.2	92.5	92.1	0.0	0.0	0.0	0.0
Imazethapyr + imazamox	70	20	51.0	70.1	77.0	68.4	10.0	0.0	0.0	0.0
Imazethapyr + imazamox	80	20	71.2	72.7	78.4	74.9	18.0	0.0	0.0	0.0
Pendimethalin	1000	Pre-	77.5	71.4	57.7	72.3	0.0	0.0	0.0	0.0
Imazethapyr + pendimethalin	1000	Pre-	83.8	85.8	74.8	85	0.0	0.0	0.0	0.0
Hoeing		20 & 40	92.5	99.2	75.4	98.3	0.0	0.0	0.0	0.0
Weedy check	-	-	-		-		-	-	-	-
LSD (p=0.05)	-		6.0	8.4	5.2	8.0	-	-	-	-

Table 3. Effect of different herbicide treatments on growth and yields of blacgram

Treatment	Dose (g/ha)	Time of application (DAS)	Plant height (cm)				Seed yield (kg/ha)	
			40 DAS	60 DAS	At harvest			
			2014	2015	2014	2015	2014	2015
Imazethapyr	70	Pre-	50.1	78.3	64.7	83.9	1100	1175
Imazethapyr	80	Pre-	46.9	84.9	66.3	89.0	1176	1270
Imazethapyr	70	20	42.3	64.9	70.3	67.1	807	762
Imazethapyr	80	20	40.2	68.7	71.2	72.1	869	952
Imazethapyr + imazamox	70	Pre-	51.3	89.0	65.9	92.8	701	1397
Imazethapyr + imazamox	80	Pre-	49.4	90.2	70.3	93.9	795	1492
Imazethapyr + imazamox	70	20	39.3	71.8	74.3	75.0	803	984
Imazethapyr + imazamox	80	20	40.2	75.3	82.3	78.5	612	1048
Pendimethalin	1000	Pre-	53.0	78.3	69.2	82.1	1000	1143
Imazethapyr + pendimethalin	1000	Pre-	48.7	87.1	73.3	90.4	1050	1302
Hand weeding		20 & 40	49.1	85.5	74.1	89.2	877	1333
Weedy check	-	-	49.2	60.8	60.3	63.9	510	476
LSD (p=0.05)			3.70	4.9	6.87	5.5	323	125

The linear relationship between count and dry weight (x) of weeds and yield (Y) of blackgram is given here as under;

Weed count

$Y = 1207 - 2.1x$ ($R^2 = 0.738$)........................(1)

Weed dry weight

$Y = 1193 - 5.1x$ ($R^2 = 0.754$)........................(2)

imazethapyr + pendimethalin at 1000g/ha were comparable to imazethapyr + imazamox 70 g/ha for seed yield of blackgram.

Equations 1 and 2 explain over 73.8 and 75.4% of the variation in blackgram seed yield due to count and dry weight of weeds, respectively. It further implies that with increase in one weed per square metre, the blackgram seed yield was expected to reduce by 2.1 kg/ha. Similarly with every g/m^2 increase in weed weight, the blackgram yield was subjected to fall by 5.1 kg/ha.

Economics

The highest gross returns, net returns and B: C ratio was recorded under imazethapyr + imazamox applied at 80 g/ha followed by imazethapyr applied at 80 g/ha (pre) (**Table 4**). Ram *et al.* (2013) also reported higher gross and net returns with imazethapyr 75 and 100 g/ha over 50 g/ha in soybean. Aggarwal *et al.* (2014) reported that in blackgram, the application of imazethapyr 100 g/ha at 15 DAS gave the highest gross and net returns, closely followed by imazethapyr at 100 g/ha applied at 25 DAS and hand weeding twice. Mansoori *et al.* (2015) found that imazethapyr + imazamox (pre-mix) at 50 g/ha as post-emergence (20 DAS) registered highest net returns and B: C ratio followed by imazethapyr + pendimethalin (pre-mix) at 1000 g/ha as pre-emergence in blackgram. The minimum gross retunes, net returns and B: C ratio was also recorded under weedy check.

The economic threshold levels of weeds at the current prices of treatment application and the crop production on the basis of weed infestation in blackgram are given in **Table 5**.

The economic threshold levels *i.e.* no./m^2 and g/m^2 with the weed management practices studied varied between 8.3 – 42.0/m^2 and 3.5-17.6 g/m^2 when determined after Stone and Pedigo (1972) and 2.0 to 8.9 after Uygur and Mennan (1995). It is

Table 4. Effect of treatments on economics of blackgram cultivation

Treatment	Dose (g/ha)	Time of cultivation (DAS)	Gross returns (INR/ha)	Net returns (INR/ha)	B:C
Imazethapyr	70	Pre-	104516	82689	3.87
Imazethapyr	80	Pre-	112717	90794	4.19
Imazethapyr	70	20	69907	48080	2.45
Imazethapyr	80	20	84384	62461	3.00
Imazethapyr + imazamox	70	Pre-	110933	88816	3.87
Imazethapyr + imazamox	80	Pre-	119440	97184	4.18
Imazethapyr + imazamox	70	20	85201	63084	2.97
Imazethapyr + imazamox	80	20	85320	63064	2.87
Pendimethalin	1000	Pre-	100430	78519	3.66
Imazethapyr + pendimethalin	1000	Pre-	112445	90203	4.04
Hand weeding		20 & 40	110561	85745	3.38
Weedy check	-	-	44268	23279	1.45
LSD (p=0.05)			-		

Table 5. Economic threshold of weeds as influenced by different treatments

Treatment	Dose (g/ha)	Time of application (DAS)	NRwc	MBCR	Gt	Et		
						S&P		U&M
						Count	DW	
Imazethapyr	70	Pre-	59410	35.4	17.7	8.3	3.5	2.1
Imazethapyr	80	Pre-	67515	36.1	19.7	9.2	3.9	2.0
Imazethapyr	70	20	24801	14.8	17.7	8.3	3.5	3.1
Imazethapyr	80	20	39182	21.0	19.7	9.2	3.9	2.8
Imazethapyr + imazamox	70	Pre-	65537	29.0	23.8	11.1	4.7	2.6
Imazethapyr + imazamox	80	Pre-	73905	29.1	26.8	12.6	5.3	2.6
Imazethapyr + imazamox	70	20	39805	17.6	23.8	11.1	4.7	3.8
Imazethapyr + imazamox	80	20	39785	15.6	26.8	12.6	5.3	4.2
Pendimethalin	1000	Pre-	55240	29.9	19.4	9.1	3.8	2.5
Imazethapyr + pendimethalin	1000	Pre-	66924	26.7	26.4	12.4	5.2	2.7
Hand weeding		20 & 40	62466	7.3	89.5	42.0	17.6	8.9
Weedy check	-	-	-	-	-	-	-	-
LSD(p=0.05)			-	-	-		-	

NRwc, net returns due to weed control; MBCR marginal benefit cost ratio; Gt gain threshold; Et economic threshold; S&P Stone and Pedigo; U&M Uygur and Mennan indicated that any increase in cost of weed control would lead to higher values of economic threshold, whereas an increase in price of crop produce would result in lowering of economic threshold. Hand weeding had higher values of economic threshold than the herbicidal treatments due to higher wages. Herbicidal treatments had lower application cost and thus had lower values of economic threshold.

Impact assessment

Weed persistence index (WPI) was lowest and crop resistance index (CRI) was highest in the hoeing and hand weeding treatment (**Table 6**).

Imazethapyr + imazamox 80 g/ha pre-emergence followed by imazethapyr + imazamox 70 g/ha pre and imezethapyr + pendimethalin 1000 g/ha followed the above treatment for crop resistance index. Imezethapyr 70 and 80 g/ha as post- and imazethapyr + imazamox 70 and 80 g/ha post-emergence caused mild toxicity during 2014 and had therefore lower crop resistance index than other treatments. Weed management index (WMI), Agronomic management index (AMI) and integrated weed management index (IWMI) were higher under pendimethalin 1000 g/ha and imazethapyr 70 and 80 g/ha pre-emergence than the other treatments. Efficiency index was highest under hoeing and hand weeding followed by imazethapyr + imazethapyr 80 g/ha pre, imazethapyr + pendimethalin 1000 g/ha pre and imazethapyr 80 g/ha pre. Weed index indicated 55.4% reduction in yield of blackgram due to uncontrolled growth of weeds. Weed intensity was maximum and crop intensity was minimum in weedy check. Hoeing followed by imazethapyr + imazamox 80 g/ha pre, imazethapyr + imazamox 70 g/ha pre- and imazethapyr + pendimethalin 1000 g/ha pre in that order followed the weedy check for weed and crop intensity. In the overall scenario, imazethapyr 80 g/ha

Table 6. Impact indices as influenced by weed control treatments

Treatment	Dose (g/ha)	Time of application (DAS)	WPI	CRI	WMI	AMI	IWMI	HEI	WI	Wi	Ci	Ii
Imazethapyr	70	Pre-	0.9	8.9	3.1	2.1	2.6	5.1	-2.9	77.3	22.7	1.12
Imazethapyr	80	Pre-	0.9	13.2	3.1	2.1	2.6	7.9	-10.7	70.1	29.9	1.22
Imazethapyr	70	20	1.0	3.9	2.7	1.7	2.2	1.5	29.0	81.6	18.4	0.78
Imazethapyr	80	20	1.0	5.3	2.8	1.8	2.3	2.4	17.6	79.7	20.3	0.92
Imazethapyr + imazamox	70	Pre-	0.9	16.9	2.4	1.4	1.9	9.0	5.1	62.0	38.0	1.13
Imazethapyr + imazamox	80	Pre-	1.0	28.6	2.5	1.5	2.0	16.3	-3.5	49.4	50.6	1.23
Imazethapyr + imazamox	70	20	0.9	5.8	2.6	1.6	2.1	2.6	19.1	79.5	20.5	0.90
Imazethapyr + imazamox	80	20	0.9	6.5	2.3	1.3	1.8	2.6	24.9	75.3	24.7	0.89
Pendimethalin	1000	Pre-	0.9	7.4	3.1	2.1	2.6	4.0	3.0	77.7	22.3	1.07
Imazethapyr + pendimethalin	1000	Pre-	0.9	15.9	2.8	1.8	2.3	9.2	-6.4	65.5	34.5	1.20
Hoeing		20 & 40	0.6	101.9	2.3	1.3	1.8	56.4	0.0	31.9	68.1	1.15
Weedy check	-	-	1.0	1.0	0.0	0.0	0.0	0.0	55.4	92.5	7.5	0.39
LSD (p=0.05)	-	-	-	-	-	-	-	-	-	-	-	-

WPI, Weed persistence index; CRI, Crop resistence index; WMI, Weed management index; AMI, Agronomic management index; IWMI, Integrated Weed management index; HEI, Herbicide efficiency index, WI, Weed index; Wi, Weed intensity; Ci, Crop intensity; Ii, overall impact index

Table 7. Residual effect of treatments applied in blackgram on succeeding crop of mustard

Treatment	Dose (g/ha)	Time of application (DAS)	Plant height (cm)	Crop phyto-toxicity (%)		Plants/m^2
				40DAS	At harvest	
Imazethapyr	70	Pre-	15.5	0.0	0.0	95.0
Imazethapyr	80	Pre-	15.8	0.0	0.0	98.7
Imazethapyr	70	20	15.2	0.0	0.0	94.7
Imazethapyr	80	20	15.7	0.0	0.0	96.7
Imazethapyr +imazamox*	70	Pre-	15.5	0.0	0.0	96.7
Imazethapyr +imazamox*	80	Pre-	15.3	0.0	0.0	96.7
Imazethapyr +imazamox*	70	20	15.4	0.0	0.0	95.7
Imazethapyr + imazamox*	80	20	15.7	0.0	0.0	96.3
Pendimethalin	1000	Pre-	15.0	0.0	0.0	96.7
Imazethapyr + pendimethalin*	1000	Pre-	15.9	0.0	0.0	97.0
Hand weeding	20 & 40 DAS	20 & 40	15.2	0.0	0.0	96.3
Weedy check	-	-	15.0	-	-	96.3
LSD (p=0.05)			0.50	-	-	0.17

*(Pre mix)

pre-emergence, imazethapyr + imazamox 80 g/ha pre-emergence, imazethapyr 80 g/ha pre-emergence and imazethapyr + pendimethalin 1000 g/ha pre-emergence were superior to hand weeding and hoeing as is indicated by the impact index because of lower cost of treatment than the later. Imazethapyr + imazethapyr 70 g/ha pre-emergence, imazethapyr 70 g/ha pre-emergence and pendimethalin 1000 g/ha pre-emergence also had higher values of overall impact index than the threshold value of 1. The other treatments had lower values of impact index than the threshold.

Residual studies

The impact of applied herbicide to blackgram crop was studied in succeeding mustard crop.There was no residual effect/phytotoxicity of herbicides on succeeding mustard crop (**Table 7**).

Thus in order of preference, imazethapyr + imazamox 80 g/ha pre, imazethapyr 80 g/ha pre, and imazethapyr + pendimethalin 1000 g/ha pre may be recommended for effective weed control, productivity and profitability in blackgram.

REFERENCES

Aggarwal N, Singh G, Ram H and Khanna V. 2014. Effect of post-emergence application of imazethapyr on symbiotic activities, growth and yield of blackgram (*Vigna mungo*) cultivars and its efficacy against weeds. *Indian Journal of Agronomy* **59**: 421–426.

Chandrakar DK, Nagre SK, Chandrakar K, Singh AP and Nair SK. 2014. Chemical weed management in black gram. p 242. *In*: *Extended Summary of Biennial Conference of Indian Society of Weed Science*, DSWR, Jabalpur (M.P.).

Choudhary VK, Suresh KP and Bhagawati R. 2012. Integrated weed management in black gram (*Vigna mungo*) under mid hills of Arunachal Pradesh. *Indian Journal of Weed Science* **57**: 382–385.

https://iipr.icar.gov.in/pdf/6.4_270615.pdf e-pulses data book. Indian Institute of Pulses Research, Kanpur (assessed on 27 June 2019).

Kumar S, Angiras NN and Singh R. 2007. Studies on planting and weed control methods on nutrient uptake by black gram (*Vigna mungo*) and associated weeds under mid-hill conditions of Himachal Pradesh. *Himachal Journal of Agricultural Research* **33**: 7–10.

Kumar S, Rana SS and Angiras NN. 2013. Weed management in blackgram with specific reference to *Ageratum conyzoides*. *Himachal Journal of Agricultural Research* **39**(2): 111–119.

Mansoori N, Bhadauria N and Rajput RL. 2015. Effect of weed control practices on weeds and yield of black gram (*Vigna mungo*). *Legume Research* **38**: 855–857.

Patel RB, Patel BD and Parmar JK. 2014. Combination of imazethapyr with other herbicides against complex weed flora in black gram. p 115. *In*: *Extended Summary of Biennial Conference of Indian Society of Weed Scienc*e, DSWR, Jabalpur (M.P.).

Ram H, Singh G, Aggarwal N, Buttar GS and Singh O. 2013. Standardization of rate and time of application of imazethapyr weedicide in soybean. *Indian Journal of Plant Protection* **41**: 33–37.

Rana SS and Kumar S. 2014. *Research Techniques in Agronomy*. Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, 64 p.

Sasikala K, Kumar CK and Ashok P. 2014. Efficacy of post emergence herbicides on weed flora and yield of zero till sown rice fallow black gram. p. 234. *In: Extended Summary of Biennial Conference of Indian Society of Weed Science*, DWR, Jabalpur (M.P.).

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.

Tiwari TK, Pawar VS and Mahatale PV. 2006. Effect of soil solarization and herbicide on weed control in soybean. *Annals of Plant Physiology* **20**: 56–58.

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. *ANPP Seizième Conférence Du Columa Journées Internationale Sur la Lutte Contre Les Mauvaises Herbes 6-8 décembre. Conference Proceedings* Volume 1: 347–354.

Walia US 2003. *Weed Management*. Kalyani Publishers, Ludhiana.

Yadav KS, Dixit JP and Prajapati BL. 2015. Weed management effects on yield and economics of black gram. *Indian Journal of Weed Science* **47**: 136–138.

Indian Journal of Weed Science **51**(2): 158–162, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Integrated weed management in cotton under irrigated conditions of Haryana

S.S. Punia*, Manjeet, Dhrambir Yadav and Ankur Choudhry

Department of Agronomy, CCS Haryana Agricultural University, Hisar, Haryana 125 004, India

**Email: puniasatbir@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00034.0

Type of article: Research article

Received : 4 May 2019
Revised : 22 June 2019
Accepted : 27 June 2019

Key words

Cotton

Herbicides

Nutrient uptake

Protected spray

Weeds

ABSTRACT

To study the effect of selective and non-selective post-emergence herbicides on weeds and yield of cotton, a field experiment was conducted during two consecutive seasons of *Kharif* 2014 and 2015 at CCS Haryana Agricultural University, Hisar.The experimental field was pre-dominantly infested with natural population of jungle rice (*Echinochloa colona* L.) and carpet weed (*Trianthema portulacastrum* L.) to the extent of 79 and 21% in 2014 and 71 and 29% during 2015, respectively. Application of pendimethalin at 1.0 kg/ha supplemented with other two hoeings at 20 and 50 DAS or one hoeing and post-emergence application of quizalofop-p-ethyl at 60 g/ha or one hoeing and post-emergence application of propaquizafop-p-ethyl at 62.5 g/ha at 60 DAS caused significant reduction in density and dry wt. of weeds as compared to weedy check up to harvest in both the years. Protected spray of glyphosate (0.5%) integrated with pendimethalin or paraquat (0.3%) with parthiobac Na *fb* quizalofop-p-ethyl being at par with three mechanical weedings (at 20,40 and 60 DAS) helped to significantly reduce the population and dry weight of weeds at 90 DAS over weedy check. Weeds throughout the crop growing season reduced seed yield by 49.9 and 47.2% during 2014 and 2015, respectively. During 2014, all the treatments involving directed spray of either glyphosate or paraquat caused 8.3 - 10% toxicity to cotton crop where in 2015 the toxicity in these treatments was 5-8%. In 2014, maximum WCE (96.9%) was obtained with use of pendimethalin *fb* directed spray of glyphosate but during 2015, it was 83.3 with application of parthiobac-Na *fb* quizalofop-p-ethyl *fb* directed spray of glyphosate.Pendimethalin *fb* parthiobac-sodium caused maximum uptake of nitrogen during 2014 and 2015, which was 23.37 kg/ha and 24.68 kg/ha, respectively.

INTRODUCTION

Cotton known as "*King of Fiber*" and "White Gold" is one of the most important fiber and commercial cash crop of India and of Haryana. It is also grown on an area of 6.56. lakh ha in the state under irrigated conditions (Anonymous 2017). Weed competition is one of the important biological constraints in cotton cultivation. Carpet weed (*Trianthema portulacastrum* L.), jungle rice (*Echinochloa colona* L.) and purple nut sedge (*Cyperus rotundus* L.) are major weeds that invade cotton crop in North-West India and cause yield losses ranging from 10-70% or more depending upon type and density of weeds (Balyan *et al.* 1983, Brar and Brar 1992). Cotton is very sensitive to weed competition in the first 60 days of crop growth. The period of weed interference, crop damage and the critical period of crop-weed competition is 30 to 60 days, which occupied 50% of the whole cotton growing period (Ayyadurai *et al.* 2013). Cotton is sown in wide spacing and grows slowly in summer due to very high temperature varying from 41 to 47°C (Prasad *et al.* 1997) and weeds get an ample space to grow profusely particularly in the initial two months of crop stage Manual weed control without herbicide application is the most labour intensive, expensive and impractical (due to labour scarcity) method in modernagricultural production system. Under such circumstances, herbicides have remained the principal tool and foundation of most effectiveweed control programmes (Zhang 2003, Norsworthy *et al.* 2012). Pre-emergence application of pendimethalin was found effective for the control of these weeds (Panwar *et al.* 1989) as it minimizes the early weed competition, however, as the pre-emergence herbicide loses its efficacy after few weeks thus problem of late emerging weeds becomes more serious. To manage late emerging weeds and more effective weed control during the crop growth period, manual or chemical methods need to be integrated with these pre-plant or pre-emergence herbicides. Information on efficacy of selective post-emergence herbicides and directed spray of glyphosate and paraquat in a wide spaced crop like cotton is limited under Haryana conditions. Therefore, the present study was undertaken to study the bio-efficacy of combination of herbicides against complex weed flora and their effect on growth and yield of cotton.

MATERIALS AND METHODS

The present study was conducted during rainy *(Kharif)* 2014 and 2015 at Department of Agronomy, CCS Haryana Agricultural University, Hisar under irrigated conditions. The soil of the experimental field was sandy loam in texture, having pH 8.1, low in organic carbon (0.29%) and available nitrogen (182 kg/ha), medium in available phosphorus (18 kg/ha) and high in available potassium (380 kg/ha) content. Fourteen treatments were tried in randomized block design replicated thrice in a plot size of 10x 6 m^2. The treatments were pendimethalin (pre-emergence) *fb* 2 hand weeding , pendimethalin (pre-emergence) *fb* hoeing *fb* quizalofop-p-ethyl/ propaquizafop-p-ethyl (post-emergence), pendimethalin *fb* parthiobac-sodium, pendimethalin *fb* hoeing *fb* parthiobac-sodium, pendimethalin *fb* quizalofop-p-ethyl, parthiobac Na *fb* quizalofop-p-ethyl,parthiobac sodium*fb* quizalofop-p-ethyl *fb* mechanical weeding, parthiobac Na *fb* quizalofop-p-ethyl *fb* directed spray of paraquat/glyphosate, pendimethalin *fb* directed spray of glyphosate, three mechanical weedings, weed free and weedy check. The cotton hybrid '*RCH 134*' was dibbled with 90 x 60 cm spacing on 17^{th} May and 14^{th} May during 2014 and 2015, respectively. The standard package of practices other than weed control treatments recommended for cotton were adopted. Rainfall received during July, August and September during cotton growing period was 180 mm in 2014 and 391 mm in 2015. Data on weed count and dry matter accumulation by weeds were recorded at 90 DAS and at harvest using a quadrate of 0.25 m^2. Seed cotton yield was recorded on net plot basis. Phytotoxic effect of different herbicides on cotton was recorded at 90 days after sowing (DAS0 using 0-100 scale.

RESULTS AND DISCUSSION

Weed flora

The experimental field was pre-dominantly infested with natural population of jungle rice (*Echinochloa colona* L.) and carpet weed (*Trianthema portulacastrum* L.) to the extent of 79 and 21% in 2014 and 71 and 29% during 2015, respectively.

Effect on weeds

All the weed control treatments significantly reduced density and dry weight of weeds at both stages as compared to untreated check at 90 DAS and harvest. Pendimethalin at 1.0 kg/ha as pre-emergence followed by two hand hoeing provided effective control of *T. portulacastrum* and *E. colonum* and this effect remained consistent up to 90 DAS (**Table 1**). When pre-emergence application of pendimethalin at 1.0 kg/ha was supplemented with two hoeings at 20 and 50 DAS, one hoeing at 30 DAS and post emergence application at 60 DAS of either quizalofop-p-ethyl at 60 g/ha or propaquizafop-p-ethyl at 62.5 g/ha at 60 DAS, it caused significant reduction in density and dry weight of weeds as compared to weedy check up to harvest. Veeraputhiran and Srinivasan (2015) reported excellent efficacy of pendimethalin *fb* hoeing *fb* post-emergence application of quizalofop-ethyl against weeds in cotton under Tamil Nadu conditions. Treatments involving use of parthiobac-Na at 20 DAS were not much effective in controlling weeds due to less moisture in the field and higher air temperature at the time of spray. Directed spray of glyphosate (0.5%) integrated with pendimethalin and paraquat (0.3%) with parthiobac Na *fb* quizalofop-p-ethyl being at par with three mechanical weedings helped to significantly reduce the population and dry weight of weeds at 90 DAS over weedy check (**Table 1** and **2**). Pendimethalin integrated with non-selective herbicides (paraquat or glyphosate) proved superior over application of pendimethalin *fb* quizalofop-p-ethylor parthiobac Na *fb* quizalofop-p-ethyl against both weeds as shown by weed control efficiency. Chaudhari *et al*.(2017) reported efficacy of pendimethalin as pre-emergence *fb* directed spray of glyphosate in cotton under Gujarat conditions During 2014, all the treatments involving directed spray of either glyphosate or paraquat caused 8.3 - 10% toxicity to cotton crop where in 2015, the toxicity in these treatments ranged between 5-8%. Weed control efficiency in all treatments except pendimethalin *fb* parthiobac-Na (72.8% and 60.7%) or parthiobac-Na *fb* quizalofop-p-ethyl (65.1% and 53%) varied between 88-99% at 90 DAS and 89-100% at harvest during 2014. However, WCE (%) ranged between 59.4-83.7% at 90 DAS and 53.4-83.3% at harvest for these treatments during 2015.

Effect on crop

All the weed control treatments gave significantly higher seed cotton yield over weedy check during both the years. (**Table 3**) except pendimethalin *fb* pyrithiobac-Na during 2015. Number of bolls/plant was affected significantly due to different herbicide treatments. In weed free treatment, number of bolls/plant was maximum (52 and 46 during 2014 and 2015, respectively) in weed free, which were significantly higher than all treatments except three mechanical weedings during both the years and parthiobac-Na *fb* quizalofop-p-ethyl *fb* directed spray of glyphosate in 2015. Maximum seed cotton yield (2.41 and 2.36 t/ha during 2014 and 2015, respectively) was obtained in weed free plots, which was at par with three mechanical weedings (2.37 t/ha) at 20,40 and 60 DAS during 2014 and significantly higher than all other treatments. Among herbicidal treatments, pre-emergence application pendimethalin *fb* hoeing *fb* quizalofop-ethyl gave seed cotton yield of 2.30 t/ha during 2014, which was significantly higher than that obtained with pendimethalin at 1.0 kg/ha supplemented with protected spray of glyphosate (0.5%) or paraquat although with higher WCE. It might be due to phytotoxic effect of non-selective herbicides and beneficial effect of hoeing employed at 30 DAS. (**Table 3**). However, during 2015, parthiobac-Na *fb* quizalofop-p-ethyl *fb* directed spray of glyphosate resulted in higher seed cotton yield among different herbicide treatments. During 2014, maximum WCE (96.9%) was obtained with use of pendimethalin *fb* directed spray of glyphosate but during 2015 it was 83.3 with application of parthiobac-Na *fb* quizalofop-p-ethyl *fb* directed spray of glyphosate. The reduction in dry weight of weeds under these conditions might be due to pendimethalin which inhibits cell division and root and shoot growth of weeds in the initial stages and excellent control by glyphosate in the later stages. Similarly superior yield

Table 1. Density and dry weight of weeds and weed control efficiency at different crop growth stages as affected by different treatments in cotton during 2014

Treatment	Dose (g/ha)	Time of application	Weed density (mo./m^2) 90 DAS				Harvest				Phytotoxicity on crop (%) at 90 DAS
			T. portula castrum	*Echino-chloa* spp.	Dry wt. (g/m^2)	WCE (%)	*T. portula castrum*	*Echino-chloa* spp.	Dry wt. of weeds (g/m^2)	WCE (%)	
Pendimethalin *fb* 2 HW	1000	Pre, 20 & 50 DAS	3.1 (8.6)	1.7 (2.0)	3.92 (14.4)	88.5	8.1 (2.8)	1.7 (2.0)	3.09 (8.53)	92.3	0
Pendimethalin *fb* hoeing *fb* quizalofop-p-ethyl	1000/ 60	Pre *fb* 30 DAS *fb* 60 DAS	1.7 (2.0)	1.7 (2.0)	3.09 (8.6)	93.2	1.7 (3.0)	1.5 (1.2)	2.73 (6.43)	92.2	0
Pendimethalin *fb* hoeing *fb* propaquizafop-p-ethyl	1000/ 65	Pre *fb* 30 DAS *fb* 60 DAS	2.2 (4.0)	1.4 (1.0)	2.89 (7.4)	94.1	2.2 (2.4)	1 (0.0)	2.68 (6.20)	93.7	0
Pendimethalin *fb* parthiobac-sodium	1000/ 62.5	Pre *fb* 20 DAS	3.2 (9.2)	3.1 (8.4)	5.95(34.4)	72.8	3.2 (7.1)	3.1 (8.4)	6.31 (38.83)	60.7	0
Pendimethalin *fb* hoeing *fb* parthiobac-sodium	1000/ 62.5	Pre *fb* 30 DAS *fb* 50 DAS	2.4 (4.6)	2.1 (3.5)	3.66 (12.4)	90.2	2.4 (2.4)	1.8 (2.3)	3.10 (8.63)	89.0	0
Pendimethalin *fb* quizalofop-p-ethyl	1000/ 60	Pre *fb* 20 DAS	2.7 (6.2)	1.7 (2.0)	3.95 (14.6)	88.4	2.7 (3.7)	2.1 (3.5)	3.18 (9.13)	90.7	0
Parthiobac Na *fb* quizalofop-p-ethyl	62.5/ 60	20 & 60 DAS	1.5 (11.4)	2.6 (5.6)	6.72 (44.2)	65.1	3.5 (19.2)	1.8 (2.4)	6.88 (46.40)	53.0	0
Mechanical weeding(3)	-	20, 40 and 60 DAS	1.4 (1.0)	1.9 (2.5)	2.39 (4.7)	96.2	1.4 (3.5)	1.7 (2.0)	2.62 (5.87)	92.8	0
Parthiobac Na *fb* quizalofop-p-ethyl *fb* Mechanical Weeding	62.5/60	20, 50 and 70 DAS	1.5 (1.2)	1 (0.0)	1.56 (1.4)	98.8	1.5 (2.5)	2 (3.2)	2.93 (7.60)	91.1	0
Parthiobac Na *fb* quizalofop-p-ethyl *fb* directed spray of paraquat	62.5/60 / 360	20, 50 and 70 DAS	1.4 (1.0	1 (0)	1.37 (0.9)	99.3	1.4 (5.8)	1.8 (2.3)	3.53 (11.50)	87.1	10
Parthiobac Na *fb* quizalofop-p-ethyl *fb* directed spray of glyphosate	62.5/60 /1000	20, 50 and 70 DAS	1 (0)	1 (0)	1(0)	100	1 (0)	1 (0)	1 (0)	100	10
Pendimethalin *fb* directed spray of glyphosate	1000/0.5%	PE and 60 DAS	1.5 (1.3)	1 (0)	1.4 (0.97)	99.2	1.5 (2.0)	1 (0.0)	1.69 (1.87)	96.9	8.3
Weedy check	-	-	8.1 (65.0)	4.1 (18.4)	11.28 (126.5)	0	8.1 (46.3)	3.5 (11.7)	9.99 (98.83)	0	0
Weed free	-	-	(0)	1 (0)	1 (0)	100	1 (0)	1 (0)	1 (0)	100	0
LSD (p=0.05)			0.5	0.2	0.29		0.5	0.4	0.22		

*Original figures in parentheses were subjected to square root transformation ($\sqrt{x+1}$) before statistical analysis.

Table 2. Density and dry weightof weeds and WCE at different crop growth stages as affected by different treatments in cotton 2015

Treatment	Dose (g/ha)	Time of application	Weed density (no./m^2) 90 DAS: *T. portula castrum*	Weed density (no./m^2) 90 DAS: *E. colona*	Weed density (no./m^2) 90 DAS: Dry wt. (g/m^2)	Weed density (no./m^2) 90 DAS: WCE *(%)*	Harvest: *T. portula castrum*	Harvest: *E. colona*	Harvest: Dry wt. of weeds (g/m^2)	Harvest: WCE (%)	Phytotoxicity on crop (%) at 90 DAS
Pendimethalin *fb* 2 HW	1000	Pre, 20 & 50 DAS	2.93 (7.6)	2.0 (3.0)	3.83 (13.70)	63.1	2.04 (3.2)	1.8 (2.3)	3.22 (9.41)	65.7	0
Pendimethalin *fb* hoeing *fb* quizalofop-p-ethyl	1000/60	Pre *fb* 30 DAS *fb* 60 DAS	2.2 (4.0)	1.4 (1.0)	2.91 (7.50)	72.0	1.5 (2.5)	1 (0)	2.61 (5.82)	72.2	0
Pendimethalin *fb* hoeing *fb* propaquizafop-p-ethyl	1000/60	Pre *fb* 30 DAS *fb* 60 DAS	2.44 (5.0)	1 (0)	2.74 (6.54)	73.6	1.71 (2.0)	2.04 (3.2)	2.77 (6.70)	70.5	0
Pendimethalin *fb* parthiobac-sodium	1000 /62.5	Pre *fb* 20 DAS	3.78 (14.3)	3.53 (11.5)	6.44 (40.5)	38.0	3.71 (12.8)	3.22 (9.4)	7.78 (59.56)	17.1	0
Pendimethalin *fb* hoeing *fb* parthiobac-sodium	1000/62.5	Pre *fb* 30 DAS *fb* 50 DAS	2.12 (3.5)	2.23 (2.0)	3.43 (11.77)	63.1	1.71 (2.0)	2.64 (6.0)	3.55 (11.64)	62.1	0
Pendimethalin *fb* quizalofop-p-ethyl	1000 / 60	Pre *fb* 20 DAS	3.30 (8.9)	2.12 (3.5)	4.22 (16.89)	59.4	2.72 (6.4)	8.30 (5.9)	4.34 (17.85)	53.4	0
Parthiobac Na *fb* quizalofop-p-ethyl	62.5/ 60	20 and 60 DAS	4.03 (15.3)	2.61 (5.82)	7.72 (58.60)	25.7	5.37 (27.9)	3.22 (9.4)	7.72 (58.7)	17.8	0
Mechanical weeding(3)	-	20, 40 and 60 DAS	1.81 (2.3)	2.23 (4.0)	2.93 (7.62)	71.8	2.40 (5.8)	2.36 (4.6)	2.92 (7.57)	69.0	0
Parthiobac Na *fb* quizalofop-p-ethyl *fb* mechanical weeding	62.5/60	20, 50 and 70 DAS	1 (0)	1.51 (1.3)	1.58 (1.51)	80.9	1.5 (2.5)	2 (3.2)	2.93 (7.60)	68.7	0
Parthiobac Na *fb* quizalofop-p-ethyl *fb* directed spray of paraquat	62.5/60 / 360	20, 50 and 70 DAS	1.71 (2)	1 (0)	2.13 (3.56)	79.5	2.62 (5.9)	1.71 (1.0)	3.72 (12.87)	60.3	8
Parthiobac Na *fb* quizalofop-p-ethyl *fb* directed spray of glyphosate	62.5/60 /1000	20, 50 and 70 DAS	1 (0)	1.71 (2)	1.85 (2.43)	82.2	1.71 (2)	1 (0)	1.56 (1.45)	83.3	0
Pendimethalin *fb* directed spray of glyphosate	1000/0.5 %	PE and 60 DAS	1 (0)	2.0 (3)	1.69 (1.86)	83.7	1.5 (2.0)	1 (0)	1.69 (1.87)	82.0	5
Weedy check	-	-	7.68 (59)	5.04 (24.5)	10.4 (109.7)	0	6.44 (40.58)	3.93 (14.5)	9.39 (87.21)	0	0
Weed free	-	-	1 (0)	1 (0)	1 (0)	100	1 (0)	1 (0)	1 (0)	100	0
LSD (p=0.05)			0.5	0.2	0.29		0.5	0.4	0.22		

*Original figures in parentheses were subjected to square root transformation ($\sqrt{x+1}$) before statistical analysis

Table 3. Seed cotton yield, no. of bolls/plant and nutrient uptake by weeds as affected by different treatments (2014 and 2015)

Treatment	Dose (g/ha)	Time of application	No. of bolls/plant		Seed cotton yield (t/ha)		N uptake by weeds (kg/ha)		P uptake by weeds (kg/ha)	
			2014	2015	2014	2015	2014	2015	2014	2015
Pendimethalin *fb* 2 HW	1000	Pre, 20 and 50 DAS	39	41	2.16	1.98	5.16	5.32	1.55	1.65
Pendimethalin *fb* hoeing *fb* quizalofop-ethyl	1000/60	Pre *fb* 30 DAS *fb* 60 DAS	42	42	2.30	2.15	3.89	3.77	1.18	1.28
Pendimethalin *fb* hoeing *fb* propaquizafop-p-ethyl	1000/65	Pre *fb* 30 DAS *fb* 60 DAS	40	42	2.15	2.17	3.74	4.05	1.16	1.65
Pendimethalin *fb* pyrithiobac-sodium	1000 /62.5	Pre *fb* 20 DAS	37	34	1.87	1.26	23.37	24.68	6.60	7.53
Pendimethalin *fb* hoeing *fb* pyrithiobac-sodium	1000/62.5	Pre *fb* 30 DAS *fb* 50 DAS	42	39	2.21	1.87	5.19	6.85	1.47	1.95
Pendimethalin *fb* quizalofop-p-ethyl	1000 / 60	Pre *fb* 20 DAS	42	40	1.96	1.92	5.57	7.85	1.61	2.15
Pathiobac Na *fb* quizalofop-p-ethyl	62.5/ 60	20 & 60 DAS	37	33	1.81	1.36	29.2	31.5	8.49	9.78
Mechanical weeding(3)	-	20, 40 and 60 DAS	51	45	2.37	2.28	3.63	4.52	10.1	1.35
Parthiobac Na *fb* quizalofop-p-ethyl *fb* mechanical weeding	62.5/60	20 ,50 and 70 DAS	44	42	2.26	1.98	4.78	5.42	1.33	1.56
Parthiobac Na *fb* quizalofop-p-ethyl *fb* directed spray of paraquat	62.5/60 / 360	20 ,50 and 70 DAS	39	40	1.94	1.93	6.91	3.91	2.01	2.58
Pathiobac Na *fb* quizalofop-p-ethyl *fb* directed spray of glyphosate	62.5/60 /1000	20 ,50 and 70 DAS	41	44	1.97	2.24	0	0	0	0
Pendimethalin *fb* directed spray of glyphosate	1000/0.5%	PRE and 60 DAS	45	43	2.08	2.20	0.72	4.95	0.33	1.32
Weedy check	-	-	30	30	1.21	1.25	62.3	62.3	17.88	17.88
Weed free	-	-	52	46	2.41	2.36	0	0	1(0)	1(0)
LSD (p=0.05)			3.5	2.9	0.06	0.06	0.44	0.74	0.26	0.24

attributes in Bt cotton due to pre-emergence pendimethalin followed by post emergence herbicide quizalofop-ethyl application at 50 g/ha + one hoeing were recorded earlier also by Prabhu *et al.* (2011) and Chaudhari *et al.* (2017).

Pendimethalin *fb* parthiobac-sodium caused maximum uptake of nitrogen during 2014 and 2015 which was 23.37 kg/ha and 24.68 kg/ha, respectively. Among herbicide treatments, highest P uptake (except weedy checks) during 2014 and 2015 was

8.49 and 9.78 kg/ha was recorded with the application of parthiobac-Na *fb* quizalofop-p-ethyl. (**Table 3**). Weedy condition throughout crop growth period accounted for 49.9% and 47.2% reduction in seed cotton yield during 2014 and 2015, respectively.

Application of pendimethalin at 1.0 kg/ha supplemented with other two hoeings at 20 and 50 DAS or one hoeing and post-emergence application of quizalofop-p-ethyl at 60 g/ha or one hoeing and post-emergence application of propaquizafop-p-ethyl at 62.5 g/ha at 60 DAS caused significant reduction in density and dry wt. of weeds as compared to weedy check up to harvest in both years. Protected spray of glyphosate (0.5%) integrated with pendimethalin or paraquat (0.3%) with parthiobac-Na *fb* quizalofop-p-ethyl being at par with three mechanical weedings (at 20,40 and 60 DAS) helped to significantly reduce the population and dry weight of weeds at 90 DAS over weedy check. Weeds throughout the crop growing season reduced seed yield by 49.9 and 47.2% during 2014 and 2015, respectively. Maximum wed control efficiency (WCE) can be obtained with use of pendimethalin *fb* directed spray of glyphosate and with application of parthiobac-Na *fb* quizalofop-p-ethyl *fb* directed spray of glyphosate. Maximum seed cotton yield (2.41 and 2.36 t/ha during 2014 and 2015, respectively) was obtained in weed free plots, which was at par with three mechanical weedings (2.37 t/ha) at 20, 40 and 60 DAS during 2014 and significantly higher than all other treatments.

REFERENCES

Anonymous. 2017. *Area, Production and Productivity of Cotton in India*. Cotton Advisory Board.

Ayyadurai P, Poonguzhalan R and Gokila J. 2013. Effect of crop-weed competition in cotton (*Gossypium hirsutum* L.). *Agricultural Review* **(34)**:157–161.

Balyan RS, Bhan VM and Malik RK. 1983. The effect of weed removal at different times on the seed yield of cotton. *Tropical Pest Management* **13**(2): 9–10.

Brar AS and Brar LS. 1992. Bioefficacy of herbicides for weed control in American cotton**.** *Journal of Cotton Research and Development* **6**: 143–150.

Chaudhari DD, Patel HK, Mishra Aakash, Patel VJ, Patel BD, Patel RB and Motka GN. 2017. Integrated weed management in cotton under irrigated condition of middle Gujarat. *Indian Journal of Weed Science* **49**(2): 156–158.

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

Panwar RS, Malik RK, Bhan VM and Malik RS. 1989**.** Evaluation of pre-and post-emergence herbicides in cotton. *Haryana Agricultural University Journal of Research* **21**: 235–39.

Prabhu G, Halepyati A, Pujari BT and Desai BK. 2011. Integrated weed management in Bt cotton (*Gossypium hirsutumL.*) under irrigated conditions. *Karnataka Journal of Agricultural Sciences* **24**(4): 529–530

Prasad H, Nehra PL and Nandiwal BS. 1997. Weed management studies in American cotton (*Gossypium hirsutum* L.). *Journal of Cotton Research and Development* **11**: 26–29

Veeraputhiran R and Srinivasan G. 2017. Post-emergence herbicides effect on weeds, yield and economics of Bt cotton. *Indian Journal of Weed Science* **49**(2): 379–382

Zhang Z. 2003. Development of chemical weed control and integrated weed management in China. *Weed Biology and Management* **4**: 197–203.

Indian Journal of Weed Science **51**(2): 163–168, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Atrazine use to control weeds and its residue determination in fodder crops of maize and sorghum

Pijush Kanti Mukherjee*, Shobha Sondhia[1], Putan Singh and R.L. Sagar

ICAR-Indian Veterinary Research Institute, Izatnagar (IVRI), Bareilly, Uttar Pradesh 243 122, India

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

**Email: pijushivri@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00035.2

Type of article: Research article

Received : 7 January 2019
Revised : 23 May 2019
Accepted : 28 May 2019

Key words

Atrazine

Economics

Fodder crops

Residues

Weeds

ABSTRACT

Field experiments were conducted at the fodder farm of ICAR-IVRI, Izatnagar campus, Bareilly. Different doses of atrazine (0.50, 0.75, 1.00 and 2.00 kg/ha) as pre- and post-emergence were applied. The weedy check plots of fodder maize were largely infested by *Trianthema portulacastrum, T. monogyna* followed by other broad-leaved weeds during 1st year. However, during 2nd year, infestation of these weeds were considerably lower due to higher seed rate and use of ferti-seed-drill. In double-cut fodder sorghum, *Trianthema* sp. recorded the highest absolute density and absolute frequency followed by sedge (*Cyperus esculentus*), grasses (*Digitaria ciliaris, Setaria glauca*) and other broad-leaved weeds (*Coccinia grandis, Celosia argentea* and *Cleome viscosa*). The broad-leaved weeds *Ageratum conyzoides* and *Sonchus oleraceus* appeared after 1st cutting. In fodder maize, atrazine with all the doses as pre- and post-emergence showed effectiveness. Weeds in weedy check treatment caused a yield reduction of 22.6%, however, in 2nd year the value was 1.7% due to restricted weed growth. Most significant results were recorded in weedy check treatment in which 60.3% yield increment of green fodder maize was registered in 2nd year over 1st year and this resulted in the highest benefit: cost ratio of 3.15. ` 52,400/ha more profit was recorded over broadcasting method of sowing. Higher seed rate (63 kg/ha) along with the use of ferti-seed-drill was equally effective with atrazine treatments. In double-cut sorghum, pre-emergence treatments of atrazine 0.75 kg/ha and above recorded comparatively higher green fodder yield than post-emergence treatments. Weedy check treatment recorded the weed index value of 17.9%. Cumulative green fodder yield (1st and 2nd cut) was highest in weed-free treatment closely followed by atrazine 2.0 kg/ha as pre-emergence treatment. Additional investment of ` 2020/ha after 1st cutting registered the additional net returns of ` 43,100/ha. This indicated the benefits of growing double-cut sorghum and also shown the importance of growing multi-cut and perennial fodder crops. Both the green fodder crops contained atrazine residue at harvest.

INTRODUCTION

Due to competing land use, area under cultivated fodder is static to around 8.4 million hectares since last two decades. The fodder production in the country is not sufficient to meet the requirements of the growing livestock population and also the forages offered to animal are mostly of poor quality. At present, the country faces a net deficit of 33.10% green fodder, 11.41% dry crop residues and 64% feeds. 54% of the total fodder is met from crop residue, while 18% fodder is met from grasslands and only 28% fodder is met from cultivated fodder crops (Anonymous 2013). Like grain crops, weeds are also considered as a major constraint in fodder crops. Weeds possess several characters and that attribute advantages of weeds on fodder crops. Rapid emergence capacity, development of large weed population and aggressive growth of the weeds suppress the growth of fodder crops and, inflict greatest damage to the crop in terms of low green fodder yield and impairing quality of green fodder. Admixture of weeds with green fodder during harvest like *Coronopus didymus* with berseem, *Coccinia grandis* with fodder maize and sorghum, *Celosia argentea* with fodder sorghum, *Trianthema* with fodder maize and sorghum, reduces palatability of green fodder and thus affects milk production of milch animal. The loss in fodder yield due to weed competition has been reported to the extent of 11.7% in lucerne and 8.3% in oat. In crops like sorghum, magnitude of yield loss was as high as 54%, while uptake of nitrogen, phosphorous and potassium by weeds was to the extent of 48.8, 22.0 and 55.0 kg/ha, respectively (Menhi Lal *et al.* 1994). In berseem, the infestation of weed flora reduced green fodder yield of 23 to 28% and seed yield of 38 to 44% (Wasnik *et al.* 2017). Therefore, the infestation of weed in forages needs to be checked starting from land preparation (Sunil *et al.* 2012). Yaduraju (2012) estimated a total economic loss in arable crops equivalent to approximately USD 13 billion/annum. In addition to direct effect on yield, weeds result in a considerable reduction in the efficiency of input used and quality (Yaduraju and Mishra 2018).

Some studies showed presence of atrazine residues in the soil and crop product at harvest. It has been reported that more than 95% of atrazine dissipated from the field at the time of crop harvest. The half-life values were found to be 9.38 - 21.54 days in soil (Sondhia 2002, Nag and Das 2009, Janaki *et al.* 2012). In an another study, atrazine residues in young sorghum plants treated with atrazine at a rate similar to those used commercially, were between 0.02 and 2.66 mg/kg in 30 day forage samples and less than 0.1 mg/kg in silage stage forage and mature fodder (Larson 1993). Levels of chlorometabolites of atrazine were less than 0.05 mg/kg in the 30 day forage. In mature fodder, residues of these metabolites were less than 0.01 mg/kg. The 2-amino-4isopropyl-6-hydroxy-*s*-triazine was found 0.48, 0.14, 0.019, and 0.06 mg/kg in 30 day forage, consisting of mature fodder, mature grain, and silage stage forage, respectively (Larsan and Ash 1992).

As very limited information is available about weed management in fodder crops, the investigation was planned and executed with the objective to study bio-efficacy of atrazine in managing weeds in fodder maize and double-cut fodder sorghum, and to determine atrazine residues in green fodder of maize and sorghum.

MATERIALS AND METHODS

Field experiments were conducted during the *pre-Kharif* (summer) season of 2016 and 2017 at the fodder farm of ICAR-IVRI, Izatnagar campus, Bareilly. The soil of the experimental field was sandy loam with the pH 6.5, low in available N (144 kg/ha), medium in available P (19.2 kg/ha), high in available K (298 kg/ha) and medium in organic carbon (0.56%). The weed control treatments comprised of atrazine 0.50 kg/ha as pre-emergence (PE); atrazine 0.75 kg/ha as PE; atrazine 1.0 kg/ha as PE; atrazine 2.0 kg/ha as PE; atrazine 0.50 kg/ha as post-emergence (PoE); atrazine 0.75 kg/ha as PoE; atrazine 1.0 kg/ha as PoE; atrazine 2.0 kg/ha as PoE; weedy check and weed-free. The treatments were laid out in a randomised block design with three replications. The PE atrazine was sprayed after sowing on wet soil and PoE was applied at 10 days after sowing (DAS) with the help of knap-sack sprayer fitted with flood-jet nozzle with discharge rate of 600 L water/ha. Variety of fodder maize '*African tall*' was grown on 06 February 2016 and 13 February 2017 and the variety of double cut fodder sorghum '*SSG* 59-3' was grown on 03 April 2016 in the experiments. Fodder maize was harvested on 62 DAS and double-cut fodder sorghum was harvested on 45 DAS for 1st cut and 45 days after 1st cutting for 2nd cut. During second year of experimentation, high density sowing (seed rate of fodder maize 63 kg/ha) with the help of ferti-seed-drill of narrow spacing (15 cm row to row distance) and localised placement of complex fertilizer (NPK ratio of 12:32:16) was adopted against the broadcasting method of sowing (seed rate of 43 kg/ha) and fertilizer (urea, single super phosphate and muriate of potash) application during 1st year of experimentation in maize. Green maize plant samples for atrazine residue analysis were collected at 60 days after application of atrazine (62 DAS). In case of fodder sorghum, atrazine at different doses was applied on 7 days after 1st cutting and green plant samples for residue analysis were collected on 38 days after application of atrazine (45 days after 1st cut). The atrazine residues were analyzed at residue laboratory of ICAR-Directorate of Weed Research, Jabalpur using a Shimadzu UFLC connected with PDA Detector with a flow of 0.35 ml/min using a solvent system of ACN: water 0.01% phosphoric acid (70:30).

The absolute and relative values of density, frequency, importance value index and summed dominance ratio for each of the weed was measured by following standard procedure and calculation for weed survey as followed by AICRP on Weed Management (ICAR), by plotting one meter square quadrats in randomized manner (Raju 1997). The weeds were dried in oven till a constant weight and then transformed into g/m^2 using the appropriate formula.

RESULTS AND DISCUSSION

Weed flora in fodder maize

Among the dominant weed flora, *Trianthema portulacastrum* and *T. monogyna* recorded the highest values of absolute density (no./m^2) and absolute frequency followed by *Cyperus esculentus, Digitaria ciliaris, Chinopodium album, Cleome viscosa* and *Coccinia grandis* during late *Rabi* season and early summer season. However, during second year, infestation of the weeds was considerably lower than the first year because of using higher seed rate and ferti-seed-drill (**Table 1**). In second year, *Celosia argentea* was found along with other broadleaved weeds.

Weed flora in double-cut fodder sorghum

Like fodder maize, the highest values of absolute density and absolute frequency of *Trianthema* sp. were recorded followed by the sedge *Cyperus esculentus*, the grasses *Digitaria ciliaris, Setaria glauca*, the broad-leaved weeds *Coccinia grandis*, *Celosia argentea* and *Cleome viscosa* (**Table 2**). The broad-leaved weeds, *Ageratum conyzoides* and *Sonchus oleraceus* appeared after 1st cutting mainly due to undisturbed soil conditions as both the weeds preferred to grow in undisturbed soil and non-crop situation.

Weed control efficiency of atrazine and weed index in fodder maize

Atrazine with all the doses as pre- and post-emergence treatments showed higher weed control efficiency resulted from efficient controlling of weeds especially *Trianthema* and other grasses during 1st year of experimentation. Weeds in weedy check treatment caused yield reduction to the tune of 22.6% (weed index value). However, during second year the weed index of weedy check treatment was 1.7% as weed growth was very much limited. The large differences in weed control efficiency and weed index values in two corresponding years of the experiment were mainly due to the use of high seed rate (63 kg/ha) and adoption of ferti-seed-drill for sowing of fodder maize against the broadcasting method of sowing with the seed rate of 43 kg/ha implemented in 1st year of experimentation. In addition to reduction in weed infestation, yield increments ranging from 26.8 to 32.6% were recorded during 2nd year compared to 1st year of experimentation to the corresponding herbicide treatments (**Table 3**). Most significant results were obtained in weedy check treatment in which 60.3%

Table 1. Absolute density, relative density, absolute frequency, relative frequency, importance value and summed dominance ratio of weed flora appeared in fodder maize at 45 DAS

Weed	Absolute density (no./m^2)		Relative density (%)		Absolute frequency (%)		Relative frequency (%)		Importance value		Summed dominance ratio	
	1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year
Trianthema sp.	41.0	9.3	36.4	26.4	100.0	66.7	20.0	18.2	56.4	44.6	28.2	22.3
Chinopodium album	14.0	5.0	12.4	14.2	100.0	33.3	20.0	9.1	32.4	23.2	16.2	11.6
Cleome viscosa	12.0	3.3	10.7	9.4	66.7	66.7	13.3	18.2	24.0	27.6	11.9	13.8
Coccinia grandis	5.0	2.3	4.4	6.6	33.3	33.3	6.7	9.1	11.1	15.7	5.5	7.8
Digitaria ciliaris	18.0	7.3	16.0	20.8	100.0	66.7	20.0	18.2	36.0	38.9	17.9	19.5
Cyperus esculentus	22.7	6.3	20.1	17.9	100.0	66.7	20.0	18.2	40.1	36.1	20.1	18.1
Celosia argentea		1.7		4.7		33.3		9.1		13.8		6.9

Table 2. Absolute density, relative density, absolute frequency, relative frequency, importance value and summed dominance ratio of weed flora appeared in double-cut fodder sorghum at 45 DAS in 1st cutting and 45 DAS after 1st cutting in 2nd cutting

Weed	Absolute density (no./m^2)		Relative density (%)		Absolute frequency (%)		Relative frequency (%)		Importance value		Summed dominance ratio	
	1st Cutting	2nd Cutting	1st Cutting	2nd Cutting	1st Cutting	2nd Cutting	1st Cutting	2nd Cutting	1st Cutting	2nd Cutting	1st Cutting	2nd Cutting
Trianthema sp.	49.0	65.3	28.0	37.9	100.0	100.0	13.6	13.0	41.6	51.0	20.8	25.5
Chinopodium album	6.0	0.0	3.4	0.0	66.7	0.0	9.1	0.0	12.5	0.0	6.3	0.0
Cleome viscosa	15.7	25.0	9.0	14.5	66.7	66.7	9.1	8.7	18.0	23.2	9.0	11.6
Coccinia grandis	17.3	4.7	9.9	2.7	100.0	33.3	13.6	4.3	23.5	7.1	11.8	3.5
Digitaria ciliaris	24.7	20.7	14.1	12.0	100.0	100.0	13.6	13.0	27.7	25.0	13.9	12.5
Cyperus esculentus	28.3	6.3	16.2	3.7	100.0	100.0	13.6	13.0	29.8	16.7	14.9	8.4
Celosia argentea	16.3	5.7	9.3	3.3	100.0	100.0	13.6	13.0	23.0	16.3	11.5	8.2
Setaria glauca	17.7	23.0	10.1	13.3	100.0	100.0	13.6	13.0	23.7	26.4	11.9	13.2
Ageratum conyzoides	0.0	12.3	0.0	7.2	0.0	100.0	0.0	13.0	0.0	20.2	0.0	10.1
Sonchus oleraceus	0.0	9.3	0.0	5.4	0.0	66.7	0.0	8.7	0.0	14.1	0.0	7.1

Table 3. Weed control efficiency, weed index and yield increment in second year over first year of experimentation in green fodder maize

Treatment	Weed control efficiency (%) at 45 DAS		Weed index (%)		Yield increment (%) in second year over first year
	1st Year	2nd Year	1st Year	2nd Year	
Atrazine 0.50 kg/ha as PE	79.8	9.8	6.5	1.7	32.7
Atrazine 0.75 kg/ha as PE	81.8	23.0	3.2	1.4	28.6
Atrazine 1.00 kg/ha as PE	85.3	36.1	3.2	1.5	28.4
Atrazine 2.00 kg/ha as PE	95.8	54.1	1.1	0.9	24.5
Atrazine 0.50 kg/ha as PoE	78.8	3.3	7.4	2.7	32.6
Atrazine 0.75 kg/ha as PoE	81.0	14.8	6.6	2.3	32.1
Atrazine 1.00 kg/ha as PoE	84.0	26.2	6.3	1.8	32.2
Atrazine 2.00 kg/ha as PoE	95.2	39.3	1.2	0.8	26.8
Weedy check	-	-	22.6	1.7	60.3

yield increment was found in 2nd year over weedy check treatment of 1st year. Lower weed control efficiency during 2nd year of experimentation was mainly because of lower level of weed infestation due to competitive advantages of fodder maize resulted from the use of ferti-seed-drill and higher seed rate. Weed index of weedy check treatment was almost equal with the atrazine treatments and the values indicated that the use of higher seed rate and ferti-seed-drill was equally effective with herbicide treatments for controlling weeds.

Weed control efficiency of atrazine and weed index in double-cut green fodder sorghum

Pre-emergence treatments of atrazine recorded comparatively higher green fodder yield than that of its post-emergence treatments in 1st cutting due to better weed control obtained from the application of atrazine. The lower dose of atrazine (0.50 kg/ha) was not effective in controlling weeds as it recorded low weed control efficiency (65 to 68% and 55 to 58%) and higher weed index (10.8 to 15.7%) based on cumulative yield in corresponding pre-emergence and post-emergence treatments of atrazine 0.50 kg/ha, respectively (**Table 4**). Weedy check treatment recorded the weed index value of 17.9%, which indicated yield reduction due to weeds. Cumulative green fodder yield from 1st and 2nd cutting was highest to the tune of 74.2 t/ha in weed-free treatment and was closely followed by 73.6 t/ha recorded by atrazine 2.0 kg/ha as pre-emergence treatment applied just after sowing and atrazine 2.0 kg/ha applied at 7 days after 1st cutting. Double-cut fodder sorghum gave more green fodder yield than single-cut fodder sorghum in which double cut fodder sorghum was harvested at 45 DAS as 1st cutting and 45 days after 1st cutting as 2nd cutting. This indicated the benefits of growing double-cut sorghum without turnaround time, several tillage operations and, sowing operations and this has shown the importance of growing multi-cut and perennial fodder crops instead of growing single-cut fodder crops.

Green fodder yield and economics of fodder maize cultivation

Data pertaining to economics of green fodder maize production are given in **Table 5.** Use of ferti-seed-drill with higher seed rate resulted in highest benefit: cost ratio of 3.15 in weedy check treatment. Yield increment due to adoption of higher seed rate and use of ferti-seed-drill recorded ` 52,400/ha more profit over broadcasting method of sowing with traditional seed rate in weedy check treatment. Higher seed rate (63 kg/ha) and use of ferti-seed-drill was equally effective with weed management by atrazine in terms of green fodder yield and net returns.

Green fodder yield and economics of double-cut green fodder sorghum production

Data on economics of double-cut green fodder sorghum production presented in **Table 6** revealed that weed control with the use of atrazine 2.0 kg/ha as pre-emergence treatment followed by application of atrazine with the same dose at 7 days after 1st cutting recorded highest net returns of ` 94,200/ha in two cumulative cuttings, which was closely followed by

Table 4. Weed control efficiency and weed index of double-cut fodder sorghum

Treatment	Weed control efficiency (%)		Weed index (%) based on cumulative yield
	1st Cutting (at 45 DAS)	45 days after 1st cutting	
Atrazine 0.50 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	67.6	64.7	10.8
Atrazine 0.75 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	77.7	72.7	4.9
Atrazine 1.00 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	83.4	76.2	4.5
Atrazine 2.00 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	90.4	87.7	0.2
Atrazine 0.50 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	58.3	54.9	15.7
Atrazine 0.75 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	74.4	71.4	6.7
Atrazine 1.00 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	76.6	73.5	6.1
Atrazine 2.00 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	88.4	86.0	1.1
Weedy check	-	-	17.9

PE: Pre-emergence; PoE: Post-emergence

Table 5. Green fodder yield and economics of fodder maize cultivation

Treatment	Cost of cultivation (× 10^3 `/ha)		Green fodder yield (t/ha)		Transportation and chap cutting cost (x10^3 `)		Net returns (x10^3 `/ha)		Benefit: cost ratio	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
Atrazine 0.50 kg/ha as PE	16.3	18.4	49.3	65.4	9.9	13.2	59.7	98.7	2.2	3.1
Atrazine 0.75 kg/ha as PE	16.3	18.4	51.0	65.6	10.2	13.1	62.2	99.1	2.3	3.1
Atrazine 1.00 kg/ha as PE	16.3	18.4	51.0	65.5	10.2	13.1	62	98.7	2.3	3.1
Atrazine 2.00 kg/ha as PE	16.3	18.4	52.1	65.9	10.4	13.2	63.1	98.7	2.2	2.9
Atrazine 0.50 kg/ha as PoE	16.3	18.4	48.8	64.7	9.8	12.9	58.9	97.6	2.2	3.1
Atrazine 0.75 kg/ha as PoE	16.3	18.4	49.2	65.0	9.8	13.0	59.4	97.9	2.2	3.1
Atrazine 1.00 kg/ha as PoE	16.3	18.4	49.4	65.3	9.9	13.1	59.5	98.3	2.2	3.0
Atrazine 2.00 kg/ha as PoE	16.3	18.4	52.1	66.0	10.4	13.2	63	98.9	2.2	2.9
Weedy check	16.3	18.4	40.8	65.4	8.2	13.1	46.9	99.3	1.9	3.1

Common cost of cultivation in 1st year: ` 16260/ha

(Field preparation {tillage, cost of hiring tractor, field layout, cost of diesel, skilled labourer}: ` 4173/ha, Cost of seed {43 kg/ha} and sowing operation: ` 1909/ha, Cost of fertilizer {NPK ratio12:32:16 and Urea, Dose 80:40:20} and fertilizer application: ` 3373/ha, Cost of irrigation {3 irrigations}: ` 4333/ha, Cost of harvesting operation: ` 2472/ha)

Common cost of cultivation in 2nd year: ` 18439/ha

(Field preparation (tillage, cost of hiring tractor, field layout, cost of diesel, skilled labourer}: ` 4181/ha, Cost of seed {63 kg/ha} and sowing operation through seed drill: ` 3681/ha, Cost of fertilizer {NPK ratio 12:32:16 and Urea, Dose 80:40:20} and fertilizer application: ` 3595/ha, Cost of irrigation {3 irrigations}: ` 4390/ha, Cost of harvesting operation: ` 2592/ha)

Transportation and cost of chap cutting: ` 200/t; Selling price of green fodder: 2000/t)

Table 6. Green fodder yield and economics of double-cut fodder sorghum cultivation

Treatment	Common cost of cultivation (x10^3 `/ha)		Green fodder yield (t/ha)		Transportation and chap cutting cost (x10^3 `)		Net returns (x10^3 `/ha)		Benefit: cost ratio	
	A	B	A	B	A	B	A	B	A	B
Atrazine 0.50 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	39.8	66.6	7.9	13.3	44.9	84.3	1.8	2.6
Atrazine 0.75 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	42.2	70.1	8.4	14.0	48.4	89.6	1.9	2.7
Atrazine 1.00 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	42.6	71.0	8.5	14.2	48.9	90.8	1.9	2.7
Atrazine 2.00 kg/ha as PE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	44.5	73.6	8.9	14.7	51.1	94.2	1.9	2.7
Atrazine 0.50 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	37.6	62.9	7.5	12.6	41.4	78.6	1.7	2.5
Atrazine 0.75 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	41.6	68.1	8.3	13.6	47.5	86.5	1.9	2.6
Atrazine 1.00 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	41.9	69.8	8.4	13.9	47.7	89.0	1.9	2.7
Atrazine 2.00 kg/ha as PoE in 1st cutting *fb* PoE in 2nd cutting	16.4	18.4	44.1	73.1	8.8	14.6	50.5	93.5	1.9	2.7
Weedy check	16.4	18.4	36.6	61.6	7.3	12.3	40.3	77.0	1.7	2.5

A-1st cutting, B-Cumulative of two cuttings

Common cost of cultivation per hectare for 1st cutting: ` 16426/ha,

(Field preparation {tillage, cost of hiring tractor, field layout, cost of diesel, skilled labourer}: ` 4101/ha, Cost of seed {30 kg/ha} and sowing operation: ` 1968/ha, Cost of fertilizer {NPK ratio12:32:16 and Urea, Dose 60:40:20} and fertilizer application: ` 3395/ha, Cost of irrigation {3 irrigations}: ` 4370/ha, Cost of harvesting operation: ` 2592/ha)

Additional common cost of cultivation for 2nd cutting: ` 2020/ha

(Cost of irrigation {one}: ` 1457/ha, Cost of fertilizer {Urea} and fertilizer application: ` 563/ha)

Total common cost of cultivation for two cuttings: ` 18446/ha; Transportation and cost of chap cutting: ` 200/t; Selling price of green fodder ` 1750/t)

other doses of atrazine from 0.75 kg/ha as pre-emergence treatment in 1st cutting followed by atrazine 0.75 kg/ha applied at 7 days after 1st cutting. Pre-emergence treatment of atrazine in 1st cut recorded comparative higher net returns than that of its post-emergence treatment applied at 10 DAS in 1st cut. Cultivation of double cut sorghum showed the benefits in terms of net returns as additional investment of ` 2020/ha after 1st cutting registered the additional net returns of ` 43,100/ha in the treatment comprised by atrazine 2.0 kg/ha applied as pre-emergence followed by application of same dose of atrazine at 7 days after 1st cutting. This result was closely followed by other doses of atrazine from 0.75 kg/ha applied as pre-emergence in 1st cutting followed by atrazine 0.75 kg/ha applied at 7 days after 1st cutting.

Atrazine residue in green fodder of maize and sorghum

Atrazine residues were detected in the green fodder of maize at 60 days after its application *i.e.* at harvesting stage (**Table 7**) and 38 days after application *i.e.* on 2nd cutting in double-cut fodder

Table 7. Residue content of atrazine in maize and sorghum fodder

Pre-emergence treatment	Atrazine residue in maize fodder at 62 DAS (µg/g)	Atrazine residue in sorghum fodder at 45 DAS (µg/g)
Atrazine 0.50 kg/ha	0.008	0.129
Atrazine 0.75 kg/ha	0.014	0.212
Atrazine 1.0 kg/ha	0.181	0.544
Atrazine 2.0 kg/ha	0.531	0.811

Table 8. Maximum residue limit (MRL) of atrazine and simazine in crops and water

Authority	Herbicide (atrazine/ simazine)	MRL in ppm	Crops and water
Food Safety and Standards Authority of India (FSSAI)	Simazine	0.25	Sugarcane
World Health Organization (WHO)	Atrazine	0.002	Water
United States Environment Protection Agency (USEPA)	Atrazine	0.003	Water
The Agricultural and Processed Food Products Export Development Authority (APEDA)	Atrazine	0.10	Fruits
Japan Food Chemical Research Foundation	Atrazine	0.02	Mango

sorghum (**Table 7**) at all the doses of atrazine. Atrazine residues were found from 0.008 to 0.531 µg/g in the green fodder maize at 60 days after application while 0.129 to 0.811 µg/g residues were detected in the green fodder sorghum at 38 days after application.

These results are in agreement with other studies. In a study, in a young corn plants treated with atrazine at a rate similar to those used commercially, atrazine residues were reported to be between 0.003 and 1.23 mg/kg in 30 days forage samples and less than 0.02 mg/kg in silage stage forage and mature fodder (Larson 1993). Residues of chlorometabolites of atrazine were less than 0.02 mg/kg in the 30 day forage. In mature fodder, residues of these metabolites were less than 0.01 mg/kg. The major metabolite of atrazine identified was 2-amino-4-isopropyl-6hydroxy-*s*-triazine, present in amounts of up to 0.27, 0.33, 0.005, and 0.14 mg/kg in 30 days forage, mature fodder, mature grain, and silage stage forage, respectively (Larson 1993). Similarly, in plant foliage collected at harvest traces of atrazine residues were detected in few samples in first year but in the second year residues were not detected (Nag and Das 2009).

It is concluded that atrazine showed selectivity and effectiveness in controlling weeds both in fodder maize and sorghum at the dose of 0.75 kg/ha and above as pre-emergence, however, green fodder contained atrazine residues at harvest in both the fodder crops. Higher seed rate of maize along with the use of ferti-seed-drill was equally effective with weed management by atrazine, providing higher green fodder yield and net returns. Double-cut sorghum recorded more green fodder yield and profit in comparison to single-cut and this indicated the importance of growing multi-cut and perennial fodder crops instead of growing single-cut fodder crops.

ACKNOWLEDGEMENTS

Contribution of ICAR-Indian Veterinary Research Institute (IVRI) for providing necessary facilities and financial assistance in the form of Institute project in duly acknowledged.

REFERENCS

Anonymous. 2013. Demand and supply estimates of dry and green forages (million tonnes). pp 7. In: *ICAR-IGFRI Vision 2050*. ICAR-Indian Grassland and Fodder Research Institute, Jhansi.

Janaki P, Meena S, Chinnusamy C, Arthanari PM and Nalini K. 2012. Field persistence of repeated use of atrazine in sandy clay loam soil under maize. *Madras Agricultural Journal* **99**(7/9): 533–537.

Larson JD. 1993. C-Atrazine: Nature of the residue in sugarcane. In: *Final Report Amendment No. 1*, Hazleton Wisconsin. Incorporated, USA.

Larson JD and Ash SG. 1992. C-atrazine: Nature of the residue in corn and sorghum. In: *Final Report Amendment No. 2*, Hazleton Wisconsin, Incorporated, USA.

Menhi Lal, Tripathi SN, Sinsinwar BS, Niranjan KP, Gupta SD and Arya RL. 1994. Forage production technology, pp 17-24. Indian Grassland and Fodder Research Institute, Jhansi.

Nag SK and Das SK. 2009. Persistence of atrazine in soil under fodder sorghum. *Journal of Crop and Weed* **5**(2): 131–135.

Raju RA. 1997. *Field manual for weed ecology and herbicide research*. Agrotech Publishing Academy, Udaipur, 78p.

Sondhia S. 2001. Determination and assessment of atrazine residues in potato soil. *Geobios* **28**(2/3): 140–142.

Sondhia S. 2002. Studies of herbicides residues in Maize-potato cropping system. Final Report, NRCWS, Jabalpur.

Sunil Kumar, Inder Dev, Agarwal RK, Dixit AK and Ram SN. 2012. Agronomic research on forages in India: An overview. *Indian Journal of Agronomy* (Special Issues) **57**: 101–113.

Wasnik VK, Maity A, Vijay D, Kantwa SR, Gupta CK and Kumar V. 2017. Efficacy of different herbicides on weed flora of berseem (*Trifolium alexandrium* L.). *Range Management and Agroforestry* **38**(2): 221–226.

Yaduraju NT. 2012. Weed management perspective for India in the changing agriculture scenario in the country. *Pakistan Journal of Weed Science* **18**: 703–710.

Yaduraju NT and Mishra JS. 2018. Smart weed management: A small step towards doubling farmers' income. *Indian Journal of Weed Science* **50**(1): 1–5.

Indian Journal of Weed Science **51**(2): 169–172, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Effect of compost extract compost of *Parthenium hysterophorus* on seed germination and growth of mustard, wheat and weeds

Mallik Baby Babita Das* B.D. Acharya, M. Saquib[1] and M.K. Chettri

Botany Department, Amrit Campus, Lainchaur, Tribhuban University, Kathmandu, Nepal

[1]University of Maiduguri, Maiduguri (Borno State), Nigeria, West Africa

**Email: babitamallik@yahoo.com*

Article information

DOI: 10.5958/0974-8164.2019.00036.4

Type of article: Research article

Received : 21 February 2019
Revised : 29 April 2019
Accepted : 1 May 2019

Key words

Allelopathy

Crop

Inhibition

Invasive

Control

ABSTRACT

This study was conducted at Research laboratory, Botany Department Amrit Campus, Kathmandu, Tribhuvan University, Nepal, in the year 2015-2016 to investigate the allelopathic effects of compost extract and soil amended with compost invasive weed *Parthenium weed* on seed germination and seedling growth of two crops *Triticum aestivum*, *Brassica campestris* and some common weeds (*Ageratum conyzoides*, *Bidens pilosa*, *Galinsoga parviflora* and *Cyperus rotundus*). *Parthenium hysterophorus* was collected before flowering and matured seeds of *Bidens pilosa*, *Ageratum conyzoides*, *Galinsoga parviflora* and *Cyperus rotundus* were collected from different sites around Kathmandu valley like Kirtipur and Bhaktapur areas. The compost extract of *Parthenium* of different concentration (control, 1, 2.5, 5 and 10%) and *Parthenium* compost (control, 10, 20, 40 and 50 g compost/kg soil) were used to determine its effect on seed germination, shoot and root length of *T. aestivum* and *B. campestris* and selected common weed seeds under laboratory condition. The compost extracts of *Parthenium* caused significant reduction in seed germination, seedling length (shoot and root length) of selected crops and weeds. The selected common weeds showed more reduction in germination and vegetative shoot and root length in comparison to crop plants (*B. campestris* and *T. aestivum*) in the soil amended with the compost of *Parthenium*.

INTRODUCTION

Parthenium hysterophorus is an invasive weed, commonly known as carrot grass, bitter weed or star weed and belongs to the family Asteraceae. In rainy season, *P. hysterophorus* completes its life cycle within 16-18 weeks (Maharjan *et al*. 2014). *Parthenium* had been ranked top ten among the list of worst weed in the Global Invasive Species Database (Callaway and Ridenour 2004). Ecological impact and economic loss due to rapid expansion of *Parthenium* has become a regional environmental issue of tropical world (Bhowmik *et al*. 2007, Sushilkumar 2014). In Nepal, this species entered probably in 1950s from India. Herbarium specimens of this plant were collected from Trishuli valley of Nuwakot district, a small city north to Kathmandu, in 1967 (Tiwari *et al.* 2005). In Nepal, this plant has already invaded the maize, sugarcane and mustard fields (Shrestha 2014), while in India, this weed has been reported to infest all type of crops and orchards (Sushilkumar 2014).

Singh *et al.* (2003) explored the allelopathic properties of unburnt (UR) and burnt (BR) residues of *P. hysterophorus* on the growth of winter crops, radish and chickpeas. Soil amended with UR and BR extracts, revealed the phytotoxic effects towards test crops, UR crude extracts being more active showed toxic effects on the growth. These effects were attributed to the presence of phenolics (Singh *et al*. 2003). Parthenin has also been reported as a germination and radical growth inhibitor in a different species of dicot and monocot plants (Patel 2011). The present study attempts to find out the allelopathic influences of compost extract and compost of *P. hysterohorus* on some common weeds and winter crops. It is hypothesized that both the compost extract and compost will have inhibitory effects on winter weeds and crops affecting its germination and growth as well.

MATERIALS AND METHODS

Preparation of extract

Parthenium hysterophorus was collected from different selected sites around Kathmandu valley, Nepal, before flowering in May-June, to prepare compost. Mature seeds of *Bidens pilosa*, *Ageratum conyzoides*, *Galinsoga parviflora* and *Cyperus rotundus* were collected from different sites around Kathmandu valley like Kirtipur and Bhaktapur areas in the month of March and April in 2015 for seed germination experiments.

A pit of 2x3x3 feet was prepared at shady place and was filled with layers of *Parthenium* plants altering with soil. It was left for seven months (from March to September, 2015) to become compost. Experiment on compost extract at laboratory was conducted from this compost. To prepare compost extract, compost was air dried then 2 g of compost were soaked in 20 ml distilled water for 24 hours. The extract was filtered using Whatman No.1 filter paper and thus 10% stock solution was prepared. From this stock solution, 1.0, 2.5, 5.0 and 10.0% concentration was prepared. The *Parthenium* compost was also tested by amending 10, 20, 40 and 50 g compost in 1.0 kg soil of Kirtipur and Bhaktapur, separately, in polybag (size 14"x7)

Seed germination

The dominant weed seeds (*A. conyzoides*, *B. pilosa*, *C. rotundus* and *G. parviflora*) and the crop seeds of *B. campestris* and *T. aestivum* were soaked in 2% sodium hypochlorite for 2 minutes separately. The seeds were then washed with distilled water thoroughly. Ten seeds of each species were kept in sterilized Petri-dishes containing control, 1.0, 2.5, 5.0 and 10.0% concentrations of compost extracts for 10 days. For control, seeds were grown in filter paper soaked with 5 ml distilled water. All these experiments were conducted under normal room temperature with five replications. The moisture level in the Petri-dish was maintained by adding distilled water as required.

The seed germination experiment was conducted in polybag by using different concentration of *P. hysterophorus* compost (10, 20, 40 and 50 g/kg soil) in the month of November 2015. The soil for this experiment was sandy loam type having 6.2 pH and humus 0.88%. The nutrients NPK of the soil was recorded 0.14,0, 0028, 0.018% respectively.There were five replications of each treatment (10 seeds of selected seeds of weed and crops were sown separately). The germination and seedling growth was recorded after 40 days. The soil without compost was taken as control.

Statistical analyses were done by using SPSS statistical version 20. The data were subjected to one way ANOVA followed by Duncan's Multiple Range Test

RESULTS AND DISCUSSION

Seed germination, shoot and root length decreased more in the tested weed seeds (*Ageratum conyzoides*, *Bidens pilosa*, *Cyperus rotundus* and *Galinsoga parviflora*) than in selected crops (*Brassica campestris* and *Triticum aestivum*) with an increase in concentration of *Parthenium* compost extract (**Table 1**). *Parthenium* compost extract showed insignificant reduction on seed germination of *B. campestris* with 1.0 and 2.5% , but it was reduced significantly with 5.0%. Seed germination was completely inhibited at 10% *Parthenium* compost extract. Seed germination of *T. aestivum* was enhanced significantly (P=0.05) at 1.0 and 2.5% compost extract treatment, but at higher concentrations (5 and 10%), it reduced significantly. Seed germination of weeds *A. conyzoides* and *G. parviflora* reduced insignificantly up to 5%, but seeds of *Bidens pilosa* showed significant reduction with 2.5 and 5% treatments. Total inhibition of weed was observed at 10%. No seed germination of *Cyperus rotundus* was observed even at lower concentrations of *Parthenium* compost extract (**Table 1**).

The shoot and root length of *B. campestris* reduced significantly with increase in concentration of *Parthenium* compost extract. In *T. aestivum*, the shoot and root length increased significantly at 1% concentration, but reduced significantly at higher concentration (5 and 10%). Shoot and root length of weed seedlings reduced significantly with increasing concentrations of compost extracts (**Table 1**).

Seed germination of crops *B. campestris* and *T. aestivum* increased insignificantly with 10 and 20 g/kg soil treatment with compost of Parthenium, but it reduced significantly with high concentrations in compost amended with soil. Seed germination of *B. campestris* was totally inhibited at 50 g/kg soil treatment (**Table 2**).

Seed germination of weeds *A. conyzoides, B. Pilosa* and *G. parviflora* reduced at 10 and 20 g/kg soil treatment. Seed germination of *Cyperus rotundus* was completely inhibited at all treatments of (**Table 2**).

The shoot and root length of *B. campestris* and *T. aestivum* significantly increased with 10 and 20 g/kg compost, but it reduced significantly with high concentrations (40 g/kg and above) in both crops. The shoot and root length of weed *A. conyzoides* reduced significantly with 10 and 20 g/kg soil treatment, but in case of *B. pilosa* and *G. parviflora* it reduced significantly with 20 g/kg soil treatment only (**Table 2**).

The reduction in seed germination and seedling growth in *B. campestris* was possibly due to presence of significant amount of phenolics the largest group of secondary metabolites in *P. hysterophorus* plant (Singh *et al.* 2005, Safdar *et al.* 2014). Altogether about 47 phytocomponents; 3 terpenoids, 14 fatty acids, 4 hydrocarbons, 7 alcohols, 5 phytosterols, and 14 other metabolites are reported in leaf of *Parthenium* (Ahmed *et al.* 2018).

Lesser detrimental effect of *Parthenium* compost extract was observed in *T. aestivum* than in *B. campestries*. Afridi *et al.* (2015) reported that the effect of allelochemicals on seed germination tested were unfavorable on the seed germination of *T. aestivum* and other species. The insignificant changes in *Triticum* seed germination shoot and root length with lower concentrations may be due to secondary metabolites cysteine rich proteins- defensins present in endosperm of *Triticum* (Freeman and Beattie 2008).

Seed germination of *Brassica* was more or less remained same up to 2.5% compost extract treatment but it was enhanced up to 5% in *T. aestivum*. Similarly, soil amended with *Parthenium* compost also showed insignificantly different seed germination of *Brassica* up to 20 g/kg soil treatment and up to 40 g/kg soil treatment in case of *Triticum*. Seed germination of *T. aestivum* increased slightly at 10 and 20 g/kg treatments. Presence of plenty of micronutrients such as Fe, Zn, Mn and Cu and macro nutrients including NPK in *Parthenium* compost makes it two times richer than farmyard manure (Krishna Murthy *et al.* 2010, Sushilkumar *et al.* 2005), and this possibly might have acted as the promoter for seed germination and seedling growth in low concentrations. But at high concentrations, the allelochemicals found in *Parthenium* might be responsible for the inhibition of cell division, gibberelline and indolacetic acid functions (Tomaszewski and Thimann 1966).

Various types of terpenoids, (9 in roots, 3 in stem and 3 in leaf) are also found in *Parthenium* (Ahmed *et al.* 2018). The noxious behavior of this weed was thought to be due to the sesquiterpene lactone parthenin, which is synthesized by this plant and play a role of allelopathic interference with surrounding plants (Belz 2007). Possibly these terpenoids interfere with enzymatic activity and reduces seed germination of crops as well as weeds at higher concentrations.

Allelochemicals of *P. hysterophorus* severely affected the seed germination, shoot and root length of all tested weeds and crops at higher concentration. The *C. rotundus* was totally inhibited in all tested concentration of *Parthenium* compost extract and compost amended soil. The seed germination of *Brassica* and weeds *A. conyzoides* and *G. parviflora* were fully suppressed at higher concentrations, but the crop *Triticum* could germinate and can survive at higher concentration. The enhancement of seed germination and seedling growth of *Triticum* (up to 40 g compost/kg soil) and *Brassica* (up to 20 g compost/ kg soil) indicate that there is a possibility of using the compost of *Parthenium hysterophorus* to reduce the associated weeds in wheat and mustard fields.

Table 1. Seed germination (% ±SD), shoot and root length (cm ±SD) of selected crop and weed seeds growth on *Parthenium* compost extract (control, 1, 2.5, 5, 10% concentration)

Species		*Parthenium* compost extract (%)				
		0	1	2.5	5	10
Brassica campestris	SG	75±10.00 b	75±5.77 b	70±5.67 b	67.5±5.00 a	NG
	SL	3.25±1.93 d	2.63±1.53 c	1.96±1.22 b	1.46±1.03 a	NG
	RL	3.34±1.96 d	2.68±1.59 c	1.74±1.09 b	1.13±0.84 a	NG
Triticum aestivum	SG	67.5±5.00 b	85±5.77 cd	80.5±0.00 cd	70± 11.54 b	50±21.60 a
	SL	3.92±2.61 b	5.63±2.40 c	4.36±2.38 b	3.65±1.92 b	1.03±1.01 a
	RL	3.76±2.50 b	5.54±2.38 c	4.1±2.24 b	3.46±1.85 b	0.93±0.92 a
Ageratum conyzoides	SG	57.5±5.00 a	52.50±9.57 a	50.00±12.58 a	48±11.57 a	NG
	SL	1.95±1.72 c	0.69±0.68 b	0.69±0.67 b	0.51±0.50 a	NG
	RL	1.27±1.18 c	0.60±0.55 b	0.58±0.57 b	0.44±0.43 a	NG
Bidens pilosa	SG	62.5±5.00 b	65± 12.90 b	52.5±16.32 a	50±14.14.00 a	NG
	SL	2.81±2.09 c	1.69±1.30 b	1.107±1.104 b	0.94±0.86 a	NG
	RL	2.59±1.94 b	1.32±1.13 a	1.04±1.03 a	0.89±0.81 a	NG
Cyperus rotundus	SG	55±5.77	NG	NG	NG	NG
	SL	1.06±1.03	NG	NG	NG	NG
	RL	0.89±0.88	NG	NG	NG	NG
Galinsoga parviflora	SG	55±5.77 a	52.5±5.00 a	50±8.16 a	47.5±9.57 a	NG
	SL	1.90±1.77 b	0.82±0.79 a	0.70±0.68 a	0.43±0.41 a	NG
	RL	1.78±1.66 a	0.73±0.70 b	0.61±0.59 b	0.34±0.33 a	NG

SG-seed germination; SL-Shoot length; RL-Root length; NG- No Germination; Same letters in the same column after Mean ±SD does not differ significantly according to ANOVA followed by Duncan's Multiple Range Test atP=0.05

Table 2. Seed germination (% ±SD), shoot and root length (cm ±SD) of selected crop and weed seeds growth on soil amended with *Parthenium* compost at (0,10,20,40 and 50g compost/kg soil concentration)

Species		Soil amended with Parthenium compost (g/kg)				
		0	10	20	40	50
Brassica campestris	SG	60±14.14 b	65±12.50 b	70±8.16 ab	60±0.00 a	NG
	SL	8.16±7.21 b	12.31±8.84 b	19.9±10.19 b	6.25±5.10 a	NG
	RL	6.44±5.92 b	10.92±7.93 b	10.33±5.87 b	5.14±4.11 a	NG
Triticum aestivum	SG	57.5±5.00 ab	70±11.54 bc	68±14.14 bc	65±5.77 ab	52.5±12.58 a
	SL	9.26±7.73 b	14.64±9.83 c	17.23±11.48 c	9.86±7.72 b	3.68±3.56 a
	RL	7.66±6.47 b	11.71±7.83 c	12.31±9.03 c	8.24±6.42 ab	3.30±3.20 a
Ageratum conyzoides	SG	55±5.77 a	52.5±5.00 a	45±5.00 a	NG	NG
	SL	2.25±2.14 b	1.05±1.02 a	0.90±0.86 a	NG	NG
	RL	1.90±1.76 b	0.96±0.92 a	0.82±0.79 a	NG	NG
Bidens pilosa	SG	55±12.90 b	50±8.16 ab	47.5±9.57 a	NG	NG
	SL	2.27±2.19 b	2.01±1.94 b	1.26±1.21 a	NG	NG
	RL	2.00±1.94 b	1.84±1.79 b	1.04±1.02 a	NG	NG
Cyperus rotundus	SG	52.5±9.57 a	NG	NG	NG	NG
	SL	1.21±1.16 a	NG	NG	NG	NG
	RL	1.09±1.05 a	NG	NG	NG	NG
Galinsog parviflora	SG	55±5.77 a	52.5 ±5.00 a	50±8.16 a	NG	NG
	SL	1.69±1.62 b	1.32±1.27 b	0.71±0.68 a	NG	NG
	RL	1.63±1.54 b	1.24±1.19 b	0.61±0.59 a	NG	NG

SG-seed germination; SL-Shoot length; RL-Root length; NG- No Germination; Same letters in the same column after Mean±SD does not differ significantly according to ANOVA followed byDuncan's Multiple Range Test at P=0.05

ACKNOWLEDGEMENT

The first author is thankful to research grant provided by Professor Emeritus Williams Styan Richards Foundation (PEWSTRIF), Maiduguri, Nigeria for this work and Amrit campus, TU, Nepal for providing laboratory facilities.

REFERENCES

Afridi R and Khan MA. 2015. Comparative effect of water extract of *Parthenium hysterophorus, Datura alba, Phragmites australis* and *Oryza sativa* on weeds and wheat, *Sains Malaysiana* **44**(5): 693–699.

Ahmad J, Bagheri R, Bashir H, Baig MA, Huqail AA, Ibrahim MM and Qureshi MI. 2018. Organ-specific phytochemical profiling and antioxidant analysis of *Parthenium hysterophorus* L., *Hindawi Bio Med Research International* ID 9535232. https://doi.org/10.1155/2018/9535232.

Belz G, Carl F. Reinhard TB, Llewellyn C, Foxcroftc and Karl H. 2007. Residue allelopathy in *Parthenium hysterophorus* L. Does parthenin play a leading role? *Open UP.*

Bhowmik PC, Sarkar D and Yaduraju NT, 2007, The status of *Parthenium hysterophorus* and its potential management, *Ecoprint* **14**: 1–17.

Callaway RM and Ridenour WM. 2004. Novel weapons: Invasive success and the evolution of increased competitive ability. *Frontiers in Ecology and the Environment* **2**(8)*:* 436–443.

Freeman BC and Bettie GA. 2008. An overview of plant defenses against pathogens and herbivores. *The Plant Health Instructor.* DOI*: 10.1094/PHI-I-2008-0226-01*

Krishna Murthy R, Sreenivasa N and Prakash SS. 2010. Chemical and biochemical properties of *Parthenium* and *Choromolaena* compost, *International Journal of Science and Nature,* **1(2)**: 166–171.

Maharjan S, Joshi S, Shrestha BB, Devkota A and Jha PK. 2014. Life history traits and invasion success of *Parthenium hysterophorus* L. in Kathmandu Valley, Nepal. *Journal of Science and Technology* **15**(1): 31–38.

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

Safdar ME, Tanveer A, Khalique A and Naeem M. 2014. Allelopathic action of *Parthenium* and its rhizospheric soil on maize as influenced by growing conditions, *Planta Daninha, Viçosa-MG* **32**(2): 243–253.

Shreshta BB, ShabbirA and Adkins SW. 2014. *Parthenium hysterophorus* in Nepal: a review of its weed status and possibilities for management. *Weed Research* **55**(2): 1132–1140.

Singh HP, Batish DR, Pandher JK, Kohli RK. 2003. Assessment of allelopathic properties of *Parthenium hysterophorus* residues. *Agriculture, Ecosystems and Environment* **9**: 537–541.

Singh, HP. Batish DR, Pandher JK and Kohli RK. 2005. Phytotoxic effects of *Parthenium hysterophorus* residues on three *Brassica* species. *Weed Biology and Management* **5**: 105–109.

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

Sushilkumar, Yaduraju NT, Vishwakarma K and Sondhia S. 2005. Nutrient quality and seed viability of Parthenium compost by NADEP and conventional pit method, pp. 200-203. In: *Proceedings of Second International Conference on Parthenium Management*, December 5-7, 2005, University of Agriculture, Bangalore.

Tiwari S, Adhikari B, Siwakoti M and Subedi K. 2005. *An Inventory And Assessment Of Invasive Alien Plant Species Of Nepal*. IUCN Nepal, Kathmandu.

Tomaszewski M and Thimann KV. 1966, Interactions of phenolic acids metallic ions and chelating agents on auxin induced growth, *Plant Physiology* **41**: 1443–1445.

Indian Journal of Weed Science **51**(2): 173–177, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Pre- and post-emergence herbicidal effect on weeds, fodder yield and quality of berseem in lowland region of Western Himalayas

Mahendra Singh Pal*

GB Pant University of Agriculture & Technology, Pantnagar, Uttarakhand 263 145, India

**Email: drmspal1@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00037.6

Type of article: Research article

Received : 14 March 2019

Revised : 9 May 2019

Accepted : 14 May 2019

Key words

Herbicide

Imazethapyr

L:S ratio

Oxyflourfen

Pendimethalin

Weed control efficiency

ABSTRACT

A field experiment was carried out during winter seasons of 2013-14 and 2014-15 at G.B. Pant University of Agriculture and Technology, Pantnagar to study the effect of pre- and post- emergence herbicides on weeds, fodder yield and quality of berseem (*Trifolium alexandrinum* L.). The experimental results indicated that pre emergence application of pendimethalin (1000 g/ha) followed by imazethapyr (100 g/ha) just after 1st cut produced significantly higher green and dry fodder yields, crude protein and net returns but alone application of pendimethalin at 1000 g/ha had the highest B:C ratio. The pooled values indicated that the lowest weed population was observed at application of pendimethalin + imazethapyr (1666 + 100 g/ha). The fresh and dry weight of weeds were recorded significantly lower under oxyflourfen + imazethapyr at 425 + 100 g/ha (just after 1st cut) in both the years, while pooled weed control efficiency was found significantly highest under oxyflourfen + imazethapyr at 425 + 100 g/ha (just after Ist cut). It is therefore, concluded that the application of pendimethalin + imazethapyr at 1000 + 100 g/ha may be recommended for effective weed control as well as higher fodder yield, its quality and net profit in berseem growing areas of lowland *(Tarai)* region of Western Himalayas.

INTRODUCTION

Berseem (*Trifolium alexandrinum* L.) also known as a Egyptian clover is the most important winter forage crop in north, north-west, and central parts of India under irrigated conditions. The green fodder of berseem is very nutritious with 20-24% crude protein, rich in calcium and phosphorus and 70% digestible dry matter. The quantity and quality of milk is improved by feeding berseem fodder. The weed control is essential in early growth stage of berseem mainly because of slow crop growth and green fodder yield may reduce by 20 to 30% (Joshi and Bhilare 2006, Alfred 2012). The major weed of the berseem namely *Cichorium intybus* (dicot) but other weeds like *Coronopus didymus, Rumex dentatus, Medicago dentriculata, Poa annua, Phalaris minor, Anagalis arvensis, Leudugia octoradosis, Parthenium hysterophorus, Euphorbia geniculata* and *Cyperus rotundus* were dominated and weeds reduce not only the fodder quality (Jain1998) but also compete for light, space and nutrients (Thakur *et al.* 1990).

Normally farmers do not adopt the weed control measures in berseem in *Tarai* region and also hills of Uttarakhand. Some of the progressive farmers apply pre-emergence herbicides like pendimthalinan at 0.5 to 0.75 kg/ha and fluchloralin at 0.60 to 1.20 kg/ha to control the weeds. Recently some post-emergence herbicides were available but their bio-efficacy is yet to be evaluated in berseem. Therefore, the present investigation was carried out to study the effect of pre- and post-emergence herbicides on weeds, fodder yield and quality of berseem in lowland *(Tarai)* region of Western Himalayas.

MATERIALS AND METHODS

A field study was carried out during *Rabi* seasons of 2013-2014 and 2014-2015 at Forage Agronomy block of Instructional Dairy Farm, Nagla, G.B. Pant University of Agriculture and Technology, Pantnagar. The experimental site was silty clay loam having 7.2 pH, 0.86 % organic carbon, 278.48, 27.80 and 232 kg/ha available N, P, and K, respectively. The field experiment consisted of 10 treatments *i.e.* pendimethalin (PE) (1000 g/ha) 2 DAS, pendimethalin (PE) (1333 g/ha) 2 DAS, pendimethalin (PE) (1666 g/ha) 2 DAS, oxyflourfen (PE) (425 g/ha), imazethapyr (POE) (1000 g/ha)(just after 1st and 2nd cut), oxyflourfen + imazethapyr (425 + 1000 g/ha) (just after 1st cut), pendimethalin + imazethapyr (1000 + 1000 g/ha) (just after 1st cut), pendimethalin + imazethapyr (1333 + 1000 g/ha) (just after 1st cut) and pendimethalin + imazethapyr (1666 + 1000 g/ha) (just after 1st cut) was laid out in a completely block design and replicated thrice. The required amount of herbicides was applied using 375 l/ha of water with knap-sack sprayer fitted with a flat-fan nozzle. Berseem variety '*Mescavi*' was sown at 30 kg/ha seed rate in rows spaced at 30 cm apart and fertilized with 30, 26.2 and 33.3 kg/ha nitrogen, phosphorus and potash, respectively at the time of sowing. The first cutting was taken manually with the help of sickle at 55 days after sowing (DAS) followed by subsequent two cuttings at an interval of 30 days. After 3rd cut, the crop was left for seed production. The crop samples were taken from 1.0 m^2 area before each cutting for growth, leaf and stem ratio (L:S), fodder yield and crude protein. The recommended agronomic practices were adopted as and when required for irrigation and plant projection. The growth parameters of berseem were recorded at each cut and then averaged. The weed dry matter was recorded by using a quadrate sampler of 0.5x0.5 m size at the time of each cutting. The weed control efficiency (WCE) was calculated as DMC-DMT/ DMC (Mani *et al.* 1973), where, DMC is dry matter production by weeds in control plot and DMT is dry matter production by weeds in treated plots.

RESULTS AND DISCUSSION

Crop growth attributes

The plant height, L:S ratio of berseem were affected significantly by different pre- and post-herbicides during both the years (**Table 1**). In 2013-14, the tallest plants were recorded with the application of pendimethalin + imazethapyr at 1000 + 1000 g/ha) that was significantly higher with oxyflourfen + imazethapyr at 425 + 1000 g/ha, while in 2014-15, the plant height of berseem was recorded significantly higher under weedy check followed by chemical weed control by pendimethalin (1000 g/ha) and also pendimethalin + imazethapyr (1333 + 1000 g/ha). The pooled values showed the tallest plants under control treatment that remained significantly at par with alone application of pendimethalin (1000 g/ ha) and also pendimethalin + imazethapyr (1333 + 1000 g/ha). The application of pendimethalin at 1666 g/ha had the shortest plants of berseem at harvest for seed yield. It may be due to toxic effect of herbicide on plant growth. It indicated that higher dose of pendimethalin and also oxyflourfen had adverse effect and delayed germination of berseem, hence the early germination of berseem under control contributed higher plant height. The maximum number of plants/m row length in 2013-14 was counted under pendimethalin + imazethapyr (1000 + 1000 g/ha) that had significantly higher values than application of oxyflourfen (425 g/ha), imazethapyr (1000 g/ha) just after 1st and 2nd cut, oxyfluorfen + imazethapyr (425 + 1000 g/ha) and also control. In 2014-15, the number of plants/m row length were found significantly higher at application of pendimethalin (1000 g/ha) followed by pendimethalin + imazethapyr (1333 + 1000 g/ha). The lowest number of plants were found at application of higher dose of pendimethalin (1666 g/ha), pendimethalin + imazethapyr (1333 + 1000 g/ha) as well as application of oxyflourfen (425 g/ha). It was observed that both treatments had adverse effect on germination of both berseem and weeds. Application of herbicides did not have significant effect on straw yield of berseem (after seed yield), however application of pendimethalin + imazethapyrat 1000 + 1000 g/ha just after 1st cut gave maximum values followed by oxyflourfen at 425 g/ha during both years.

Fodder and seed yield

The green and dry fodder yield differed significantly by herbicides during both the years (**Table 1**). Significantly higher green forage yield was recorded under pendimethalin + imazethapyr at 1000 + 1000 g/ha) and remained significantly superior to control, and oxyfluorfen + imazethapyr at 425 + 1000 g/ha during 2013-14 but in 2014-15, significantly higher green fodder yield was achieved at application pendimethalin + imazethapyr of 1333 + 1000 g/ha. It was significantly equal to pendimethalin (1000 g/ha). The dry fodder yield had almost similar trend of green fodder yield during both the years. The lowest green and dry fodder yield were recorded under either alone application of oxyflourfen or combined with imazethapyr during both the years mainly due to poor germination and reduced number of plants/m row length. The higher values attributed to taller plants and more number of plants/ha supported by higher weed control efficiency and better crop growth. Application of imazethapyr at 1000 g/ha just after 1st and 2nd cut produced maximum green and dry fodder yield (Pathan *et al.* 2013). Similarly, Prajapati *et al.* (2015) reported that imazethapyr at 1500 g/ha applied immediate after 1st and 2nd cut gave higher green and dry fodder yield of berseem.

Seed yield was recorded significantly highest with application of pendimethalin + imazethapyr at 1000 + 1000 g/ha during both the years but it remained at par with pendimethalin + imazethapyrat 1333 + 1000 g/ha and alone application of pendimethalin at 1000 g/ha in 2013-14. The seed yield however was very poor in both the years mainly due to poor weather conditions including heavy rainfall during post-flowering that caused lodging of plants and poor seed formation. Pathan *et al.* (2013) reported higher berseem seed yield at application of imazethapyr at 1000 g/ha just after 1st and 2nd cut, while Prajapati *et al.* (2015) found higher seed yield

Table 1. Effect of pre- and post-emergence herbicides on growth, green and dry forage yield, seed yield and straw yield of berseem in 2013-14 and 2014-15

Treatment	Pl height (cm)		No of plants/m row		Green forage yield (t/ha)		Dry forage yield (t/ha)		Seed yield (kg/ha)		Straw yield at harvest (t/ha)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-1.4	2014-15	2013-14	2014-15	2013-14	2014-15
Pendimethalin (PE) (1000g/ha) 2 DAS	39	55	70	86	21.6	46.0	3.00	5.92	52	107	4.06	4.12
Pendimethalin (PE) (1333 g/ha) 2 DAS	38	51	69	73	21.2	43.8	2.90	5.23	42	59	4.18	3.96
Pendimethalin(PE) (1666 g/ha) 2 DAS	39	49	69	67	20.6	38.9	2.80	4.86	40	52	3.95	3.90
Oxyflourfen (PE) (425 g/ha)	36	58	43	67	15.1	39.6	2.10	4.70	40	57	4.22	4.30
Imazethapyr (PoE) (1000 g/ha)(Just after I^st^&II^nd^ cut)	39	54	55	77	20.6	44.2	2.80	5.53	41	73	4.08	4.09
Oxyflourfen + imazethapyr (425 + 1000 g/ha)(Just after I^st^ cut)	34	53	39	74	13.0	42.6	1.80	5.18	41	70	3.87	3.72
Pendimethalin + imazethapyr (1000 + 1000 g/ha) (just after I^st^ cut)	40	52	74	82	22.1	47.4	3.20	6.13	55	133	4.53	4.49
Pendimethalin + imazethapyr (1333 + 1000 g/ha) (just after I^st^ cut)	38	55	70	73	21.8	42.6	3.00	5.38	53	88	4.14	4.11
Pendimethalin + imazethapyr (1666 + 1000g/ha) (just after I^st^ cut)	38	54	68	67	21.4	43.7	3.00	5.48	49	78	4.08	4.08
Weedy check	38	59	66	79	19.8	40.3	2.70	4.86	40	63	3.80	3.92
LSD (p=0.05)	03	06	06	08	1.9	4.8	0.30	0.48	9	18	ns	ns

PE-pre-emergence: PoE-post-emergence; LSD - Least Significant difference at the 5% level of significance: DAS - Days after sowing

under application of oxyflourfen at 425 g/ha followed by imazethapyr immediately after 1st cut. Kauthale *et al.* (2016) reported that combination of oxyflourfen 0.1 kg/ha + imazethapyr 0.1 kg/ha immediately after harvest of first cut produced highest seed and straw yield of berseem. It indicated that oxyflourfen though had negative impact on germination of both crop and weeds but crop grew well in later stages due to poor plant population and resulted into better straw yield.

Fodder quality

The L:S ratio and crude protein are the main indicators of fodder quality. The L:S ratio did not differ significantly by different herbicides during both the years (**Table 2**), however the highest L:S ratio was measured under pendimethalin + imazethapyr at 1666 + 1000 g/ha followed by pendimethalin + imazethapyr at 1333 + 1000 g/ha, pendimethalin + imazethapyr at 1000 + 1000 g/ha) and imazethapyr at 1000 g/ha just after 1st cut and 2nd cut in 2013-14,while in 2014-15, the highest value was recorded under oxyflourfen at 425 g/ha followed by pendimethalin + imazethapyr at 1666 + 1000 g/ha), imazethapyr at 1000 g/ha just after 1st cut and 2nd cut and pendimethalin + imazethapyr at 1000 + 1000 g/ha).

The crude protein was affected significantly by herbicides during both the years (**Table 2**). In 2013-14, it was noticed significantly highest under pendimethalin + imazethapyr at 1000 + 1000 g/ha) that was significantly equal to pendimethalin + imazethapyr at 1333 + 1000 g/ha), pendimethalin + imazethapyr at 1666 + 1000 g/ha) and alone application of pendimethalin at 1000 g/ha. The highest crude protein production was noticed under pendimethalin + imazethapyr at 1000 + 1000 g/ha) (after 1st cut) followed by pendimethalin + imazethapyr at 1000 + 1000 g/ha) (after 1st cut and 2nd cut). The pooled values had the highest crude production pendimethalin + imazethapyr at 1000 + 1000 g/ha) (after 1st cut) followed by pendimethalin at 1000 g/ha. The higher crude protein production is the result of higher dry matter and crude protein percentage. Pathan *et al.* (2013) reported higher crude protein production under oxyflourfen (425 g/ha) followed by imazethapyr (1000 g/ha) just after 1st cut). Kauthale *et al.* (2016) also reported the highest dry matter and crude protein production under combined application of oxyflourfen 0.1 kg/ha + imazethapyr 0.1 kg/ha immediately after the first cut.

Density and biomass

Major weeds like *Cichorium intybus, Coronopus didymus, Rumex dentatus, Medicago dentriculata, Poa annua, Phalaris minor, Anagalis arvensis, Leudugia octoradosis, Parthenium hysterophorus, Euphorbia geniculata* and *Cyperus rotundus* were recorded in per square meter as an index of weed control efficiency of weed management practices. The highest weed population was recorded at weedy check followed by pendimethalinat 1000 g/ha during both the years, while the lowest weed population was counted at oxyflourfen+ imazethapyr (425 + 1000 g/ha) (just after 1st cut) followed by pendimethalin + imazethapyr at 1000 + 1000 g/ha) (just after 1st cut) in 2013-14 but in 2014-15, it was under pendimethalin (1666 g/ha) followed by pendimethalin + imazethapyr at 1666 + 1000 g/ha). The pooled values indicated that pendimethalin + imazethapyr at 1666 + 1000 g/ha) had the lowest weed population followed by oxyflourfen+ imazethapyr (425 + 1000 g/ha) (just after 1st cut) and oxyflourfen (425 g/ha). It indicated that higher dose of pendimethalin and oxyflourfen were very effective in suppressing the weed population, however proved toxic to crop germination. Significantly maximum fresh weed weight was recorded under weedy check during both years. Significantly lowest fresh weed weight was recorded under oxyflourfen+ imazethapyr at 425 + 1000 g/ha (just after 1st cut) in both the years but, it was significantly equal to imazethapyr at 1000 g/ ha (immediate after 1st and 2nd cut), pendimethalin + imazethapyr at 1000 + 1000 g/ha) (after 1st cut), pendimethalin + imazethapyr at 1333 + 1000 g/ha (after 1st cut) in 2014-15. Pathan and Kamble (2012) observed that application of oxyflourfen at 100 g/ha *fb* imazethapyr at 1000 g/ha immediately after 1st cut recorded significantly the lowest total weed count/m^2 and its total dry weight. Jain (1998) and Tamrakar *et al.* (2002) also supported the above findings.

Weed control efficiency (WCE)

The herbicides had significant effect on weed control efficiency during both the years (**Table 2**). In 2013-14, the highest WCE was recorded at application of oxyfluorfen + imazethapyr at 425 + 1000 g/ha (just after 1st cut) followed by pendimethalin + imazethapyr at 1000 + 1000 g/ha) (after 1st cut) and pendimethalin + imazethapyr at 1666 + 1000 g/ha) (after 1st cut). In 2014-15, the highest WCE was recorded under pendimethalin + imazethapyr at 1333 + 1000 g/ha) (after 1st cut) and it was found significantly similar to oxyfluorfen + imazethapyrat 425 + 1000 g/ha (just after 1st cut), pendimethalin + imazethapyr at 1666 + 1000 g/ha) (after 1st cut), pendimethalin + imazethapyr at 1000 + 1000 g/ha)(after 1st cut) and imazethapyr at 1000 g/ha (just after Ist and IInd cut) (**Table 2**). Application of oxyflourfen (PE) was found more toxic not only to berseem but also for weeds, thereby the emergence of weeds and berseem reduced drastically. Application of oxyflourfen followed by POE application of imezathapyr helped to reduce weed population further and improved weed control efficiency. Pathan *et al.* (2013) found similar weed control efficiency in both weed free and oxyflourfen at 425 g/ha *fb* imazethapyr PoE at 1000 g/ha (immediately after 1st cut). Among herbicidal treatments, the weed dry weight was significantly less (48.73 g/0.25m^2) due to application of pendimethalin + imazethapyr at 500 g/ha applied immediate after 1stcut resulting in higher weed control efficiency (43.53%) (Prajapati *et al.* 2015). Among herbicides, imazethapyr at 100 g/ha at 3 weeks after sowing and butachlor 1500 g/ha as pre-emergence were significantly superior in controlling weed flora (weed control efficiency 69.7-77.3 and 68.7-75.8%) and recorded higher green fodder yield (86.0 and 82.1 t/ha) in berseem than other treatments (Priyanka *et al.* 2018).

Economics

Application of pendimethalin + imazethapyr at 1000 + 1000 g/ha) (after 1st cut) had significantly higher gross returns, but was at par with pendimethalin + imazethapyr at 1333 + 1000 g/ha) (after 1stcut) and pendimethalin + imazethapyr at 1666 + 1000 g/ha) (after 1st cut) during 2013-14, but in 2014-15, pendimethalin + imazethapyr at 1333 + 1000 g/ha) (after 1st cut) gave the highest gross returns (**Table 3**), however remained at par with pendimethalin + imazethapyr at 1000 + 1000 g/ha) (immediately after 1st

Table 2. Effect of pre- and post-emergence herbicides on L:S ratio, crude protein and weed population and weed control efficiency of berseem in 2013-14 and 2014-15

Treatment	L:S ratio		Crude protein (yield (t/ha)		No of Weeds/m^2		Fresh weed weight (g/m^2)		Dry weed weight (g/m^2)		Weed control efficiency (%)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Pendimethalin (PE) (1000g/ha) 2 DAS	2.23	2.72	0.58	1.14	595	683	473	297	42.3	48.50	30.07	31.70
Pendimethalin (PE) (1333 g/ha) 2 DAS	2.22	2.49	0.56	1.00	538	398	391	291	43.5	45.17	27.69	36.42
Pendimethalin(PE) (1666 g/ha) 2 DAS	2.30	2.43	0.55	0.96	526	292	365	271	37.7	39.93	33.18	43.89
Oxyflourfen (PE) (425 g/ha)	2.29	3.03	0.41	0.93	336	400	340	259	37.5	37.53	46.17	47.37
Imazethapyr (PoE) (1000 g/ha)(just after Ist&IInd cut)	2.34	2.85	0.55	1.08	448	507	391	242	53.0	25.10	31.11	64.85
Oxyflourfen + imazethapyr (425 + 1000 g/ha)(just after Ist cut)	1.95	2.75	0.34	0.99	212	494	194	235	24.2	22.50	64.31	68.42
Pendimethalin + imazethapy (1000 + 1000 g/ha) (just after Ist cut)	2.50	2.67	0.63	1.20	303	515	267	253	29.0	23.83	50.48	66.53
Pendimethalin + imazethapy (1333 + 1000 g/ha) (just after Ist cut)	2.58	2.42	0.58	1.04	271	469	302	244	45.3	22.47	44.79	69.26
Pendimethalin + imazethapy (1666 + 1000g/ha) (just afterIst cut)	2.89	2.99	0.58	1.06	331	329	283	262	46.7	23.73	47.37	66.65
Weedy check	2.01	2.57	0.54	0.95	651	709	565	389	58.8	71.20	-	-
LSD (p=0.05)	ns	ns	0.07	-	-	-	63	54	09	5.81	6.67	8.34

PE-pre-emergence: PoE-post-emergence; LSD - Least Significant difference at the 5% level of significance: DAS - Days after sowing

Table 3. Effect of pre- and post-emergence herbicides on economics of berseem in 2013-14 and 2014-15

Treatment	Gross returns ($x10^3$ `/ha)		Net returns ($x10^3$ `/ha)		B:C ratio	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Pendimethalin (PE) (1000g/ha) 2 DAS	45.16	108.46	31.76	93.46	2.37	6.23
Pendimethalin (PE) (1333 g/ha) 2 DAS	43.81	103.45	30.31	88.25	2.25	5.80
Pendimethalin(PE) (1666 g/ha) 2 DAS	41.89	93.36	28.29	77.97	2.08	5.06
Oxyflourfen (PE) (425 g/ha)	37.63	95.52	24.28	80.42	1.82	5.32
Imazethapyr (PoE) (1000 g/ha)(just after Ist&IInd cut)	42.62	104.82	29.37	89.82	2.22	5.98
Oxyflourfen + imazethapyr (425 + 1000 g/ha)(just after Ist cut)	34.22	100.51	20.62	85.11	1.52	5.52
Pendimethalin + imazethapy (1000 + 1000 g/ha) (just after Ist cut)	47.87	112.86	33.87	96.86	2.42	6.05
Pendimethalin + imazethapy (1333 + 1000 g/ha) (just after Ist cut)	45.79	101.64	31.94	86.00	2.31	5.49
Pendimethalin + imazethapy (1666 + 1000g/ha) (just afterIst cut)	44.56	103.83	30.66	88.08	2.21	5.59
Weedy check	40.56	96.29	27.71	81.79	2.16	5.64
LSD (p=0.05)	3.64	8.39*	3.64	8.39*	0.27	0.55*

PE-pre-emergence; PoE-post-emergence application; LSD - Least Significant difference at the 5% level of significance: DAS - Days after sowing; Rates (`/q): Green forage yield= ` 100/-, Berseem seed=14000/-straw= 400/-

and 2nd cut). Application of oxyflourfen at 425 g/ha and pendimethalin + imazethapyr at 1666 + 1000 g/ha) (after 1st cut) had phytotoxic effect on both weeds and crop, therefore the plant population of berseem reduced and finally produced lower green fodder yield. Kauthale *et al.* (2016) also found the highest net returns with combined application of oxyflourfen 0.1 kg/ha + imazethapyr 0.1 kg/ha immediately after harvest of first cut.

The net returns was recorded significantly higher at pendimethalin + imazethapyr at 1000 + 1000 g/ha) (after 1st cut) that remained equal to pendimethalin (1000 g/ha), pendimethalin + imazethapyr at 1333 + 1000 g/ha) (after 1st cut) and pendimethalin + imazethapyr at 1666 + 1000 g/ha) (after 1stcut) in 2013-14, while in 2014-15, it was significantly higher under pendimethalin + imazethapyrat 1333 + 1000 g/ha (after 1st cut) and remained at par with pendimethalin + imazethapyr at 1000 + 1000 g/ha) (immediate after 1st and 2nd cut). Similarly, the B:C ratio was also observed significantly higher at pendimethalin at 0.3 kg/ha + imazethapyr at 0.1 kg/ha (after 1st cut) that was significantly superior to pendimethalin at 0.5 kg/ha and oxyflourfen at 0.1 kg/ha in 2013-14 but in 2014-15, the highest B:C ratio was found at application of pendimethalin at 0.3 kg/ha that was significantly similar to pendimethalin at 0.4 kg/ha) and also pendimethalin at 0.3 kg/ha + imazethapyr at 0.1 kg/ha after 1st cut. The higher B:C ratio was the result of higher number of plants/ha, green and forage yield, seed yield and weed control efficiency (**Table 3**).

The experimental results indicated clearly that application of pendimethalin + imethapyr at 1000 + 1000 g/ha (just after 1st cut) and alone pre-emergence application of pendimethalin at 1000 g/ha gave higher green and dry fodder yield, seed yield, L:S ratio, crude protein, gross returns, net returns and B:C ratio mainly because of reduced weed population and higher weed control efficiency, Therefore, application of pendimethalin + imethapyr at 1000 + 1000 g/ha (just after 1st cut) or alone pendimethalin at 1000 g/ha may be recommended for weed control in berseem cultivation in *Tarai* region of Western Himalayas.

ACKNOWLEDGEMENT

The field experiment was conducted under All India Coordinated Research Project on Forage Crops & Utilization funded by Indian Council of Agricultural Research, New Delhi.

REFERENCES

Alfred S. 2012. *Evaluation of Herbicides for Weed Management in Berseem*. M.Sc. Thesis submitted to G.B. Pant University of Agriculture and Technology, Pantnagar. 98p.

Jain KK. 1998. Floristic composition of berseem–weed ecosystem on weed dynamics. *World Weeds* **5**:37–39.

Joshi YP and Bhilare RL. 2006. Weed management in berseem. *Pantnagar Journal Research* **4**:15–17.

Kauthale VK, Takawale, PS and Patil, SD. 2016. Weed control in berseem. *Indian Journal of Weed Science* **48**(3): 300–306.

Mani VS, Pandita ML, Gautam KC and Das B. 1973.Weed killing chemicals in potato cultivation. *PANS* **23**: 17–18.

Pathan SH. and Kamble AB. 2012. Chemical weed management in berseem. *Forage Research* **38**(3): 138–143.

Pathan SH, Kamble AB and Gavit MG. 2013. Integrated weed management in berseem. *Indian Journal of Weed Science* **45**: 148–150.

Prajapati B, Singh TC, Giri P and Kewalanand. 2015. Efficacy of herbicides for weed management in berseem. *The Bioscan* **10**: 347–350.

Priyank, Sheoran, RS, Punia, SS and Singh, S. 2018. Studies on chemical weed control in berseem (*Trifolium alexandrinum* L.). *International Journal of Current Microbiology and Applied Sciences* **7**(1): 2669–2673.

Thakur GS, Dubey RK and Tripathi AK. 1990. Evaluation of herbicides for weed management in berseem, pp. 55. *In: Biennial Conference of Indian Society of Weed Sciences.* 4-5 March 1990. JNKVV, Jabalpur.

Tamrakar MK, Kewat ML, Agrawal SB and Shukla VK. 2002. Efficacy of herbicides against *Cichorium intybus* in berseem. *Indian Journal of Weed Science* **34**:333–334.

Indian Journal of Weed Science **51**(2): 178–182, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Indian Journal of Weed Science

In vitro evaluation of low dosages of 2,4-D on germination and seedling growth of wheat and associated weeds

Avneet Kaur* and Navjyot Kaur

Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab 141 004, India

**Email: avneetatwal1995@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00038.8

Type of article: Research article

Received : 2 April 2019
Revised : 19 June 2019
Accepted : 21 June 2019

Key words

2,4-D

Germination

Hormesis

Low doses

Weeds

ABSTRACT

Hormesis is a biphasic dose response to an environmental agent characterized by low dose stimulation and high dose inhibitory or toxic effect. In order to develop an effective weed management system, the stimulatory and/or inhibitory response of low doses of herbicides on germination and growth of weeds should be considered. Thus, a laboratory study was conducted to test the effect of low dosages of 2,4-D on wheat (*Triticum aestivum* L.) and associated dicotyledonous weeds. Low dosages of 2,4-D (0, 5, 10, 20, 40 and 50 g/ha) failed to accelerate either seed germination or seedling growth of *T. aestivum* and tested four weed species –*Phalaris minor* Retz., *Avena ludoviciana* Durieu., *Medicago denticulata* Willd. and *Rumex dentatus* L. under *in vitro* conditions in Petri-dishes. The application of 2,4-D inhibited the seed germination and seedling growth of these weeds in a dose dependent manner with higher concentrations being more inhibitory. The sodium formulation of 2,4-D more adversely affected the germination of *P. minor* and *A. ludoviciana* as compared to its ethyl ester formulation. The results indicated that 2,4-D when used as a post-emergence herbicide in wheat fields can delay the emergence of new flushes of weeds like *P. minor*, *A. ludoviciana*, *M. denticulata* and *R. dentatus* due to its inhibitory effect on their germination. It could be concluded that low doses of 2,4-D did not enhance germination/ seedling growth of wheat and associated weeds.

INTRODUCTION

In the North Western states of India, wheat production is under a severe threat due to the increasing infestation of weeds in the crop. Herbicides are the most effective, practical and economical means for weed management. But improper use of herbicides can do harm rather than benefitting the productivity. The selection of best herbicide, proper time and proper dose of herbicide application are important factors for achieving good herbicide efficacy. Wheat fields are infested with many monocotyledonous and dicotyledonous weeds which may cause the yield loss of 7 to 50% based on the kind of weed flora and their intensity (Chhokar *et al*. 2012). The major weeds prevalent in the wheat fields of Punjab are *Phalaris minor*, *Medicago denticulata*, *Rumex dentatus*, *Avena ludoviciana*, *Chenopodium album*, *Fumaria parviflora*, *Cirsium arvensis*, *Anagallis arvensis*, *Melilotus indica* and *Lathyrus aphaca*. Among these, *Medicago denticulata* and *Rumex dentatus* are the major dicotyledonous weeds and *Phalaris minor* and *A. ludoviciana* are the major monocotyledonous weeds in irrigated wheat under the rice-wheat cropping system in India (Chhokar *et al*. 2006).

Hormesis refers to biphasic dose response to an environmental agent characterized by low dose stimulation or beneficial effect and a high dose inhibitory or toxic effect (Mattson 2008). Some patches of crop and weeds may receive very low doses of herbicides due to herbicide drift, incorrect methods or improper time of herbicide application or herbicide dilution in the soil due to the degradation and immobilization. Herbicides can also be applied at sub-lethal rates due to lateral and vertical movements of the nozzle boom, weed coverage by the crop plants or mulches, leaf contact of treated and untreated plants and herbicide resistance. Rainfall and dew drops may also dilute the herbicide concentration (Souza *et al.* 2007). The low doses of herbicides may exert stimulatory effect on crops and weeds boosting their growth and seed production potential. Hormetic effect of herbicides depends on many factors such as type of herbicide, herbicide dose, time of application, type of crop or weeds species, light, nutrients, temperature, carbon dioxide, and many other management practices (Belz *et al.* 2008). The growth stimulation due to herbicides under uncontrolled field conditions is generally unpredictable (Belz *et* *al*.2011). Hormetic responses have been demonstrated in response to many herbicides like glyphosate in *Cicer arietinum* L. (chickpea) and *Vicia faba* (faba bean) (Abbas *et al*. 2015, El- Shahawy and Sharara 2011); fenoxaprop-p-ethyl in *Phalaris minor* (littleseed canarygrass) and *Avena fatua* (wild oats) (Abbas *et al*. 2016). 2,4-D at very low concentration (0.1 kg/ha) has been reported to enhance seed production ability of *Chenopodium album* (Hume and Shirriff 1989).

The stimulatory response of plants at very low doses of herbicides have been reported for different physiological and biochemical parameters such as gene expression, enzyme activity, growth, biomass, protein content and chlorophyll content (Duke *et al*. 2006). Low doses of herbicides have been reported to stimulate growth in various crop species under field as well as controlled conditions (Cedergreen *et al*. 2007, Velini *et al*. 2008). Growth stimulation due to low herbicide doses to the extent of 20-30% and 10-15% has been reported under controlled and field conditions, respectively (Cedergreen *et al*. 2005, 2007, 2009). Nadeem *et al.* (2016) reported that sub-lethal doses of glyphosate solution in the range of 65–250 g/ha promoted the seed germination and seedling growth of four broad-leaved weeds–*C. didymus*, *C. album*, *R. dentatus* and *L. aphaca*. However, at high concentration (500 g/ha) inhibition of germination and seedling growth was reported. When crops are influenced by the hormetic effects, farmers may occasionally benefit from this phenomenon. But, it may intervene in the weed management or decline the crop production if hormetic phenomenon is produced in weeds (Velini *et al*. 2010).

2,4-D (2,4-dichlorophenoxyacetic acid) is an effective herbicide against dicotyledonous weeds, which is a synthetic auxin and effective plant growth regulator but limited studies have been undertaken on hormetic effect of 2,4-D in wheat crop and weed flora associated with this crop. It was hypothesized that sub-toxic concentrations of 2,4-D may affect germination and seedling growth of weeds that can influence the crop-weed competition. So, the present study was conducted to study the hormetic effect of low doses of 2,4-D on germination and seedling growth of wheat and four major weeds associated with wheat- *P. minor*, *A. ludoviciana*, *M. denticulata* and *R. dentatus.*

MATERIALS AND METHODS

Four annual winter season weeds (*P. minor*, *A. ludoviciana*, *M. denticulata* and *R. dentatus*) were selected to test the hormetic effects of 2,4-D. The seeds of these species were collected from wheat fields of Punjab Agricultural University, Ludhiana. 2,4-D ethyl ester 38% EC and 2,4-D sodium salt 80% WP were used as source of 2,4-D. The seeds of wheat cv. '*PBW 677*' were procured from Punjab Agricultural University, Ludhiana.

Germination protocol

Uniform sized seeds of *T. aestivum*, *M. denticulata*, *R. dentatus*, *P. minor* and *A. ludoviciana* were surface sterilized with 0.1% mercuric chloride for two minutes.Seeds were then washed several times with distilled water to avoid any fungal infection. The seeds of each species were kept for germination separately in Petri-dishes lined with Whatman No. 1 filter paper. The germination ability of seeds under different concentrations of 2,4-D (5, 10, 20, 40, 50 and 500 g/ha) was examined. At the beginning of the experiment, 5 ml of treatment solution was added in Petri-dishes. Petri-dishes were then kept at 20°C in an environmental chamber (Model MAC MSW-127, Delhi, India). The seeds germinated using distilled water served as control. Each treatment was replicated thrice and experiment was repeated three times.

Observations recorded

Germination counts were daily made for 15 days after initiation of the experiment. The visible protrusion of the radicle was regarded as the germination criteria. Germination percentage was calculated as:

Germination (%) = (no. of seeds germinated / total no.of seeds) x 100

Speed of germination (germination index) was computed as described by the Association of Official Seed Analysts (1983) using the following formula.

$$\text{GI} = \frac{\text{No. of germinated seeds}}{\text{Days of first count}} + - - + \frac{\text{No. of germinated seeds}}{\text{Days of final count}}$$

Mean germination time (MGT) was calculated according to the following equation of Ellis and Roberts (1981):

$$\text{MGT} = \Sigma\,(Dn) / \Sigma\, n$$

Where n is the number of seeds that had germinated on day D and D is the number of days counted from the initiation of germination.

Seedling vigour index (SVI) was calculated using the following formula (Abdul-Baki and Anderson 1973):

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

Statistical analysis

All the experiments were repeated three times in a completely randomized design (CRD) using three replicates, and data were analyzed by analysis of variance (ANOVA) using statistical analysis software version 9.2 (SAS 2009). Means were separated at $\sqrt{x+0.5}$ using Fisher's Protected Least Significant Difference (LSD) test (Cochran and Cox 1957).

RESULTS AND DISCUSSION

Effect of 2,4-D on germination and seedling growth of *P. minor*

When ethyl ester formulation was used, 2,4-D concentrations higher than 10 g/ha significantly reduced the germination (%) and germination speed with concomitant increase in mean germination time. Abnormal germination was observed at 40 and 50 g/ha 2,4-D with emergence of only plumule and radicle failed to emerge at these concentrations **(Table 1)**. *P. minor* seeds possessed the ability to germinate upto 50 g/ha 2,4-D with complete inhibition at 500 g/ha 2,4-D. Increasing concentration of 2,4-D from 0 to 50 g/ha caused significant decrease in seedling growth and vigour **(Table 2)**. Significant reduction in germination of seeds was observed at and above 5 g/ha2,4-D sodium salt formulation and no germination was recorded at 500 g/ha2,4-D. Mean germination time was increased with concomitant decrease in germination speed with increase in 2,4-D concentration. Radicle emergence of *P. minor* was completely inhibited in the presence of 2,4-D sodium salt concentrations higher than 10 g/ha in the germination medium.

Effect of 2,4-D on germination and seedling growth of *Avena ludoviciana*

The increase in 2,4-D concentration (ethyl ester formulation) from 5 to 500 g/ha significantly decreased seed germination of *A. ludoviciana*; and germination was found to be abnormal at highest dose (500 g/ha 2,4-D) where radicle failed to emerge and only shoot emergence was observed **(Table 1)**. Seeds germinated at 2,4-D concentration of 500 g/ha took maximum time to start germination along with reduced speed of germination and increased mean germination time. Increasing concentration of 2,4-D ethyl ester from 5 to 500 g/ha significantly decreased the growth of *A. ludoviciana* seedlings with a more pronounced effect on root length. There was 64.9% reduction in vigour index I at 2,4-D concentration of 5 g/ha in comparison to control. Sodium formulation of 2,4-D more adversely affected seed germination and abnormal germination was observed when 2,4-D concentration was increased above 5 g/ha in the germination media. Germination was completely inhibited in the presence of 500 g/ha concentration of 2,4-D sodium. Even the lowest dose of 2,4-D sodium (5 g/ha) caused significant decline in growth and vigour of *A. ludoviciana* seedlings **(Table 2).**

Effect of 2,4-D on germination and seedling growth of *Medicago denticulata* Willd

Ethyl ester and sodium formulations of 2,4-D exhibited similar effects on germination and seedling growth of *M. denticulata* at similar concentrations. Either ethyl ester or sodium formulation at concentration 5 g/ha 2,4-D caused no significant effect on germination of *M. denticulata* seeds but germination observed was abnormal as there was only emergence of plumule and radicle failed to emerge. Germination of *M. denticulata* was completely inhibited at and above 10 g/ha 2,4-D concentrations**.** Application of 5 g/ha 2,4-D (ethyl ester formulation) recorded 2.1 fold reduction in germination index and 2.3 times increase in mean germination time in comparison to control **(Tables 1 and 2)**.

Effect of 2,4-D on germination and seedling growth of *R. dentatus*

The seeds exhibited significant reduction in germination at and above 5 g/ha 2,4-D concentrations (ethyl ester formulation). However, germination observed even in the presence of sub-lethal doses of 2,4-D ranging from 5-50 g/ha was abnormal with only emergence of plumule and radicle failed to emerge at these herbicide concentrations. Germination was completely inhibited at 500 g/ha concentration of 2,4-D **(Table 1)**. At 50 g/ha2,4-D concentration, germination speed was decreased by about 2.6 times and mean germination time was enhanced by about 1.5 times than control. Seedling vigour index was reduced by about 93.4% as compared to control when seedlings were grown in the presence of 50 g/ha 2,4-D **(Table 2)**. Sodium formulation of 2,4-D exhibited effects similar to its ethyl ester formulation at different concentrations.

Effect of 2,4-D on germination and seedling growth of *Triticum aestivum*

2,4-D ethyl ester at 5 g/ha caused no significant effect on percent germination, speed of germination and mean germination time. However, significant reduction in germination of *T. aestivum* seeds was observed with 2,4-D concentrations higher than 5 g/ha while the germination of seeds was completely inhibited at 500 g/ha 2,4-D concentration. Increasing 2,4-D sodium salt concentration from 0 to 40 g/ha caused no significant effect on germination of *T. aestivum* seeds. 2,4-D concentrations higher than 40 g/ha caused significant decline in germination of *T. aestivum* seeds. Abnormal germination was observed in the presence of 40 and 50 g/ha concentrations of 2,4-D (ethyl ester and sodium salt) where only plumule was able to emerge and radicle exhibited complete failure to emerge **(Table 1)**. At 50 g/ha

Table 1. Effect of 2,4-D on germination and speed of germination of *P. minor*, *A. ludoviciana*, *M. denticulata*, *R. dentatus* and *T. aestivum*

2,4-D concentration (g/ha)	Germination (%)					Speed of germination				
	P. minor	*A. ludoviciana*	*M. denticulata*	*R. dentatus*	*T. aestivum*	*P. minor*	*A. ludoviciana*	*M. denticulata*	*R. dentatus*	*T. aestivum*
2,4-D ethyl ester formulation										
0 (Control)	100.0±0.00	96.1±2.00	91.0±4.04	88.33±1.67	100.0±0.00	6.45±0.01	3.15±0.14	3.98±0.25	2.85±0.12	9.61±0.24
5	95.0±1.44	83.8±2.32	86.3*±6.17	80.00*±2.89	96.7±1.67	5.96±0.13	1.49±0.02	1.85±0.07	1.98±0.15	9.12±0.15
10	94.2±1.67	81.3±1.53	NG	75.00*±2.89	93.3±3.33	5.21±0.00	1.59±0.07	-	1.87±0.08	8.93±0.29
20	72.5±1.44	78.3±2.54	NG	71.67*±1.67	88.3±1.67	2.94±0.05	1.31±0.07	-	1.41±0.04	8.19±0.28
40	60.0*±4.33	78.9±1.67	NG	63.33*±1.67	85.0*±2.89	2.38±0.10	1.22±0.01	-	1.36±0.04	7.56±0.25
50	45.8*±0.83	83.9±1.67	NG	46.67*±1.67	78.3*±1.67	1.31±0.03	1.28±0.06	-	1.09±0.06	6.51±0.16
500	NG	42.2*±4.84	NG	NG	NG	-	0.57±0.05	-	-	-
LSD (p=0.05)	5.89	7.88	8.46	6.04	6.04	0.21	0.22	0.29	0.26	0.66
2,4-D sodium salt formulation										
0 (Control)	100.0±0.00	90.0±0.00	88.66±4.67	90.0±2.89	100.0±0.00	6.28±0.10	2.16±0.07	3.65±0.20	2.64±0.05	9.47±0.27
5	86.7±1.67	63.3±3.33	86.33*±6.17	73.3*±7.27	93.3±4.41	5.67±0.13	0.94±0.07	1.81±0.15	1.56±0.18	8.74±0.46
10	88.3±1.67	66.7*±6.67	NG	73.3*±4.41	90.0±5.00	5.64±0.06	0.91±0.12	-	1.52±0.09	8.65±0.40
20	71.7*±1.67	43.3*±3.33	NG	71.7*±1.67	90.0±2.89	4.48±0.12	0.61±0.02	-	1.36±0.06	8.22±0.23
40	65.0*±5.77	50.0*±5.77	NG	58.3*±4.41	90.0*±5.00	3.81±0.16	0.60±0.07	-	1.27±0.06	8.22±0.66
50	71.7*±1.67	46.7*±3.33	NG	45.0*±2.89	83.3*±3.33	3.75±0.31	0.52±0.06	-	1.00±0.02	6.82±0.43
500	NG	NG	NG	NG	NG	-	-	-	-	-
LSD (p=0.05)	7.64	12.08	8.87	12.08	10.81	0.46	0.21	0.28	0.25	1.21

Data are mean ± standard error; *abnormal germination with only emergence of plumule; NG: No germination

concentration of 2,4-D sodium salt, speed of germination was decreased by about 1.4 times and mean germination time was increased by about 1.4 times than control **(Table 2)**.

Unlike many studies which indicate hormetic effect of herbicides namely glyphosate and fenoxaprop-p-ethyl at low doses (Velini *et al.* 2008, Abbas *et al.* 2016, Nadeem *et al.* 2016), the results of present investigation demonstrate that low concentrations of 2,4-D have failed to stimulate either germination or seedling growth of *T. aestivum* and tested four weed species – *P. minor*, *A. ludoviciana*, *M. denticulata* and *R. dentatus*. The application of 2,4-D herbicide inhibited the seed germination and seedling growth of these weeds in a dose dependent manner with higher concentrations being more inhibitory. The sodium formulation of 2,4-D adversely affected the germination of *P. minor* and *A. ludoviciana*as compared to its ethyl ester formulation. 2,4-D sodium salt at 500 g/ha concentration completely inhibited the germination of *A. ludoviciana* while germination was drastically reduced (56.1%) by 500 g/ha concentration of ethyl ester formulation of 2,4-D. Radicle emergence of *A. ludoviciana* was observed in the presence of 5-50 g/ha concentrations of 2,4-D ethyl ester. However, radicle emergence was completely inhibited in the presence of 10-50 g/ha 2,4-D sodium salt in the germination medium. 2,4-D herbicide possessed the ability to reduce seed germination and seedling growth of *R. dentatus* even at very low doses ranging from 5-50 g/ha. In case of *M. denticulata*, the inhibition in germination was more pronounced as there was no emergence of radicle even at the lowest concentration of 2,4-D (5 g/ha). Low doses of 2,4-D in the range of 5-20 g/ha did not significantly reduce germination of *T. aestivum*. Radicle emergence of *T. aestivum* was completely inhibited in the presence of 2,4-D concentrations equal to 40 g/ha 2,4-D sodium or higher concentrations. Even at lowest dose of 2,4-D *i.e.* 5 g/ha, root and shoot length were reduced by 80.6 and 43.8% as compared to control. Similar to our study, Khan and Aslam (2006) also reported the inhibitory effect of 2,4-D sodium at different concentrations (0.01% , 0.1% , 1.0%) on germination and seedling growth of *Triticum aestivum* and *Phalaris minor* with higher suppression of germination in *P. minor* than *T. aestivum*. Shoot and root length were reduced with the increase in dose of herbicide and radicle was more severely affected than coleoptile. In wheat, the swelling of hypocotyl was observed due to endogenous production of ethylene.

The results of present study reflected that different concentrations of 2,4-D used were toxic to all the five species as germination and seedling growth were declined as compared to control. The results indicate the possibility that 2,4-D when used as a post-emergence herbicide in wheat fields can delay the emergence of new flushes of weeds like *P. minor*, *A. ludoviciana*, *M. denticulata* and *R. dentatus* due to its inhibitory effect on their germination. However, unlike herbicides glyphosate and fenoxaprop-P-ethyl (Abbas *et al.* 2015, 2016), sub-lethal concentrations of 2,4-D failed to exhibit any hormetic effect in terms of enhanced germination/seedling growth of *P. minor*, *A. ludoviciana*, *M. denticulata* and *R. dentatus*.

The results indicated inhibitory effect of low doses of 2,4-D under *in vitro* conditions in the

Table 2. Effect of 2,4-D on mean germination time (MGT) and seedling vigour index I *P. minor*, *A. ludoviciana*, *M. denticulata*, *R. dentatus* and *T. aestivum*

2,4-D concentration (g/ha)	MGT(days)					Seedling vigour index I				
	P. minor	*A. ludoviciana*	*M. denticulata*	*R. dentatus*	*T. aestivum*	*P. minor*	*A. ludoviciana*	*M. denticulata*	*R. dentatus*	*T. aestivum*
2,4-D ethyl ester formulation										
0 (Control)	3.22±0.02	4.43±0.33	3.53±0.25	7.03±0.38	2.13±0.09	1133±55.62	1389±69.74	409±16.93	334±16.88	1584±9.40
5	3.37±0.17	7.87±0.30	8.03±0.58	8.64±0.27	2.24±0.07	443±10.29	487±94.93	74±7.37	113±5.20	661 ±20.48
10	4.19±0.09	6.93±0.22	-	8.66±0.11	2.18±0.03	321±28.38	503±18.80	-	79±4.35	520±46.76
20	6.15±0.14	8.19±0.28	-	10.09±0.38	2.36±0.10	148±8.62	448±32.67	-	59±4.75	339±23.99
40	6.20±0.61	7.85±0.22	-	10.74±0.10	2.47±0.10	90±8.34	387±20.49	-	38±3.00	197±6.76
50	7.65±0.90	8.25±0.46	-	10.85±0.31	2.82±0.12	94±3.36	370±37.85	-	22±1.63	158±17.41
500	-	9.51±0.51	-	-	-	-	143±8.88	-	-	-
LSD (p=0.05)	1.28	1.06	0.73	0.79	0.25	73.93	150.47	21.00	21.91	68.97
2,4-D sodium salt formulation										
0 (Control)	3.30±0.08	4.96±0.26	3.76±0.10	8.19±0.46	2.17±0.09	1478±38.89	667±83.85	451±45.41	285±34.35	1480±129.91
5	3.08±0.02	7.07±0.38	7.84±0.13	9.52±0.16	2.27±0.06	440±17.61	109±48.76	73±11.02	71±7.74	545±22.97
10	3.20±0.04	8.29±0.44	-	9.74±0.12	2.16±0.04	319±12.61	203±38.97	-	53±1.91	388±40.98
20	3.30±0.08	8.46±0.03	-	9.25±0.50	2.40±0.12	271±41.42	184±47.84	-	48±3.07	281±10.03
40	3.62±0.28	8.95±0.33	-	10.44±0.44	2.44±0.10	173±45.36	237±18.95	-	39±3.05	181±25.40
50	4.27±0.51	9.67±0.44	-	11.26±0.54	2.94±0.36	172±18.76	99±30.69	-	21±2.26	113±18.71
500	-	-	-	-	-	-	-	-	-	-
LSD (p=0.05)	0.68	0.96	0.19	1.13	0.46	89.59	138.12	53.57	40.81	162.85

Data are mean ± standard error

laboratory on germination and seedling growth of *T. aestivum* and tested four weed species – *P. minor*, *A. ludoviciana*, *M. denticulata* and *R. dentatus*. The low doses of 2,4-D did not enhance germination/seedling growth of wheat and associated weeds.

REFERENCES

Abbas T, Nadeem MA, Tanveer A and Zohaib A. 2016. Low doses of fenoxaprop-p-ethyl cause hormesis in littleseed canarygrass and wild oat. *Planta Daninha* **34**: 527–533.

Abbas T, Nadeem MA, Tanveer A, Zohaib A and Rasool T. 2015. Glyphosate hormesis increases growth and yield of chickpea (*Cicer arietinum* L.). *Pakistan Journal of Weed Science Research* **21**: 533–542.

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

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

Belz RG, Cedergreen N and Duke SO. 2011. Herbicide hormesis - can it be useful in crop production? *Weed Research* **51**: 321–332.

Belz RG, Cedergreen N and Sorensen H. 2008. Hormesis in mixtures-can it be predicted? *Science of the Total Environment* **404**: 7–87.

Cedergreen N, Felby C, Porter JR and Streibig JC. 2009. Chemical stress can increase crop yield. *Field Crops Research* **114**: 54–57.

Cedergreen N, Ritz C and Streibig JC. 2005. Improved empirical models describing hormesis. *Environmental Toxicology and Chemistry* **24**: 3166–3172.

Cedergreen N, Streibig JC, Kudsk P, Mathiassen SK and Duke SO. 2007. The occurrence of hormesis in plants and algae. *Dose-Response* **5**: 150–162.

Chhokar RS, Sharma RK and Sharma I. 2012. Weed management strategies in wheat-a review. *Journal of Wheat Research* **4**: 1–21.

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.

Cochran WG and Cox GM. 1957. *Experimental Designs.* John Wiley, New York.

Duke SO, Cedergreen N, Velini ED and Belz RG. 2006. Hormesis: is it an important factor in herbicide use and allelopathy? *Outlooks on Pest Management* **17**: 29–33.

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

El-Shahawy TA and Sharara FAA. 2011. Hormesis influence of glyphosate in between increasing growth, yield and controlling weeds in faba bean. *Journal of American Science* **7**: 139–144.

Hume L and Shirriff S. 1989. The effect of 2,4-D on growth and germination of lamb's-quarters (*Chenopodium album* L.) plants having different degrees of tolerance. *Canadian Journal of Plant Science* **69**: 897–902.

Khan MR and Aslam KM. 2006. Effect of 2,4-D on seedling physiology and cytogenetical studies in *Triticum aestivum* and *Phalaris minor*. *Acta Botanica Yunnanica* **28**: 394–398.

Mattson MP. 2008. Hormesis Defined. *Ageing Research Reviews* **7**: 1–7.

Nadeem MA, Abbas T, Tanveer A, Maqbool R, Zohaib A and Shehzad MA. 2016. Glyphosate hormesis in broad-leaved weeds: a challenge for weed management. *Archives of Agronomy and Soil Science* **63**: 344–351.

SAS 2009. SAS User's Guide. SAS Institute, Cary, NC, USA.

Souza RT, Velini ED and Palladini LA. 2007. Methodological aspects for spray deposit analysis by punctual deposit determination. *Planta Daninha* **25**: 195–202.

Velini ED, Alves E, Godoy MC, Meschede DK, Souza RT and Duke SO. 2008. Glyphosate applied at low doses can stimulate plant growth. *Pest Management Science* **64**: 489–496.

Velini ED, Trindade MLB, Barberis LRM and Duke SO.2010. Growth regulation and other secondary effects of herbicides. *Weed Science* **58**: 351–354.

Indian Journal of Weed Science **51**(2): 183–187, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Aquatic weeds management through chemical and manual integration to reduce cost by manual removal alone and its effect on water quality

Adikant Pradhan* and Shushil Kumar[1]

S.G. College of Agriculture & Research Station, IGKV, Jagdalpur, Chhattisgarh 494 005, India

[1]ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482 004, India

**Email: adi19agro@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00039.X

Type of article: Research article

Received : 15 February 2019
Revised : 29 April 2019
Accepted : 4 May 2019

Key words

Aquatic weeds

Alligator weed

Chemical control

Integrated Management

Lotus

Mechanical control

Water hyacinth

Weed management

ABSTRACT

Dlapat sagar reservoir is one of the prominent aquatic bodies in Jagdalpur of Bastar region of Chhattisgarh state in India. The reservoir was severely infested by aquatic weeds for last many years. An experiment was done to evaluate the integration of herbicides and manual/mechanical approaches to reduce the cost in comparison to manual removal alone. The experiment comprised of 8 treatments, *viz.* glyphosate 2.0 and 1.0 kg/ha (41 SL), paraquat 2.0 and 1.0 kg/ha (24 SL) and 2,4-D (amine salt 58% SL) 2.0 and 1.0 kg/ha dissolving in 500 litre water, manual removal and control was laid out in randomized block design with three replications at reservoir located at $19^0$5'41"N and $82^0$0'43"E with elevation of 563 m MSL during 2016 and 2017. The aquatic body was covered with thick mat of different weeds entangled with each other. Herbicides were sprayed to loosen the entangled weed biomass followed by manual and mechanical removal after 25 to 30 days. Glyphostae, 2,4-D and paraquat were mixed with sticker (Latron AG-98) and were sprayed in three replications by power spray machine (1HP HTP MAK ASPEE) mounted on the boat. The pH of water was gradually increased from 6.79 to 7.09 while EC and TDS from 0.33 to 0.30 (mS/cm^2) and 101 to 207 (mg/l), respectively. The minimum density and dry matter was recorded with manual/mechanical removal followed by application of glyphosate 2.0 kg/ha, which was significantly superior over control and lower dose of other two herbicides and found statistically at par with 2,4-D amine salt 58% SL and applied at higher dose (2.0 kg/ha) during both the years. Glyphosate (2.0 kg/ha) was found effective in controlling weeds with the cost of ` 19,660/- and ` 18080 per hectare during 2016 and 2017, respectively with weed control efficiency of 86.4, 84.3; 79.1, 82.2 and 83.8, 88.3 % for water hyacinth, lotus and alligator weeds during 2016 and 2017, respectively.

INTRODUCTION

Aquatic weeds are those unwanted plants, growing in water and complete at least a part of their life cycle in water. Aquatic weeds can be classified as submerged weeds, emerged weeds and dispersed weeds, shoreline and ditch weeds, bank weeds, marshland and swamp weeds. (Gupta 1987). Out of about 140 aquatic weeds, following weeds are of primary concern in India: *Alternanthera philoxeroides, Chara* spp., *Ipomoea* spp. *Eichhornia crassipes, Hydrilla verticillata, Nelumbo nucifera, Nitella* spp. *Nymphaea stellata, Salvinia molesta, Typha angustata, Vallisnaria* spp. (Labrada 1996, Gopal and Sharma 1981). Among these, *Eichhornia crassipes*, alligator weed and lotus are of primary concern in India and world over. In general, it is estimated that 20-25% of the total utilizable water in India is currently infested with *Eichhornia crassipes* (water hyacinth), while in the state of Assam, Kerala, West Bengal, Orissa and Bihar, more than 40% water bodies are infested with water hyacinth (Sushilkumar 2011, Sushilkumar and Pradhan 2018). In Kuttanad region of Kerala, water hyacinth problem has taken a serious view, which has compelled Kerala Government to take immediate action to manage it, but problem still persists. By 1980, alligator weed (*Alternanthera philoxeroides*) was not considered a problem in India, but now it has become growing menace in water bodies, which necessitated to find out its management through various approaches including chemical management (Sushilkumar 2003). Holm *et al.* (1991) reported that in India under Chambal Project, submerged aquatic weeds had cut the flow of water by 80% in the canals. Likewise, lotus has also become a nuisance in many aquatic bodies in India and many other countries (Sushilkumar 2003, 2011). In lack of suitable biological control options for alligator and lotus weed and high cost of labour involved in manual removal, attempts were made to manage aquatic weeds in severely infested water bodies, first through herbicide application over the weed mat to get it loosened and thereafter to remove them manually and mechanically.

Dalpatsagar Reservoir in Jagdalpur city of Bastar district in Chhattisgarh state of India is one of the prominent big reservoirs spreading over 137.77 ha (340.44 acres). It was constructed by King Dalpat Deo Kakatiya over 400 years ago with the objective of harvesting rain water, but off late it became famous for its fishing and livelihood related activities for the inhabitants. Mild infestation of aquatic plants like water hyacinth, lotus and alligator weeds was started in 2005 and gradually spread in whole water body over the years due to draining of city sewage into reservoir, which favoured severe growth of aquatic weeds especially water hyacinth, lotus and alligator weed. By 2016, more than 80% surface water turned as green carpet and caused big challenge for fishing, navigation and other vital use. This compelled local administration to manage the weeds for the benefit of residents for their livelihood. In view of densely interlocked weed mat over the water surface, manual removal was experienced difficult and costly. Biological control option was available only for water hyacinth, but it was considered time taking method while other weeds would not be controlled. Therefore, it was thought to loosen the weed mat by using herbicides followed by manual and mechanical removal to reduce the cost of operation by manual method alone. Looking to the importance, an experiment was conducted to find out the suitability of the method for controlling the weeds in Dalpat sagar reservoir.

MATARIALS AND METHODS

Dalpat sagar reservoir situated at northern side of Jagdalpur city in Chhattisgarh state, India coordinating 19°5'413 N 82°0'433 E with elevation of 563 m MSL was severely infested with many type of aquatic weeds. Weed were collected and identified before applying treatments. The experiment was conducted during 2016 and 2017 at infested locations of reservoir comprising of 8 treatments namely glyphosate 41 SL at 2.0 and 1.0 kg/ha, paraquat 24 SL at 2.0 and 1.0 kg/ha, 2, 4-D (amine salt 58%) at 2.0 and 1.0 kg/ha, manual removal and control under randomized block design with three replications. Manual/mechanical removal was done by cutting of weed mat and dragging the weeds manually by boats to the bank side and from there to remove and upload on tractor trolley by JCB machine. Spraying of herbicides was done over weed mat dissolving into 500 litre water and adding with sticker 20 ml (Latron AG-98). The chemical spray was done with power spray machine (1HP HTP MAK ASPEE) mounted on the boat. The experimental area was equally divided into 24 plots of 10 x 10 m by piling bamboo poles at corners of each plot and separated by net. The gap between two plots was kept 10 meter. Herbicide spraying was done on 15th and 17th June, 2016 and 2017, respectively. After spray of herbicides, weed biomass was loosened and upper leaves were dried, but weed mat was still interlocked, which was cut and dragged manually upto bank side by the labours using the boats, ropes and bamboos. Likewise, untreated weed mat was also cut, dragged and removed using labours and machine only.

Water samples of Dalapat sagar reservoir were collected before spraying and at 10 days interval after spraying upto 30 days from each plot under different treatments. The samples were analysed for physio-chemical properties such as pH, EC and TDS using standard procedure (Jackson 1967).

Different types of aquatic weeds were collected and identified. Weed counts (no./m^2) was recorded by placing a quadrate (1.0 m^2) at three random spots in each plot before and after 25 days after spray (DAS). Roots were separated from aerial portion for taking dry weight of weed. Dry weight (g/m^2) was recorded after oven drying at 60±5^{o}C for 72 hours and weed control efficiency was calculated following the standard method. Economics of each treatment was calculated taking into consideration the cost of hiring the boat, machine and labours. Data on density and dry weight of weeds were transformed using square root transformation ($\sqrt{x+0.5}$) before statistical analysis as suggested by Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

Weed flora

Major aquatic weeds of Dalpat sagar reservoir were *Eichhornia crassipes* (Mart.) Solms, *Echinodorus grisebachii* Small, *Nymphaea alba* L., *Nelumbo nucifera* Gaertn., *Nymphaea rubra* Roxb. ex Andrews, *Nymphaea indica* (L.) Kuntz, *Cyperus javanicus* Houtt. Houttuyn, *Oxalis corniculata* L., *Ipomoea aquatica* Forssk, *Ipomoea carnea* Jace., *Oryza nivara* S.D. Sharma & Shastry, *Alternanthera philoxeroides* R.Br.exDC, *Potamogeton crispus* L., *Lemna minor* L., *Potamegaton amplifolius* Tuckerman and *Ceratophyllum demersum* L. Among these aquatic flora, *Eichhornia crassipes, Alternanthera philoxeroides and Nelumbo nucifera* were prominent weeds and most of the water surface was covered with these flora.

Physio-chemical properties of water body

The pH of the reservoir was influenced by weed management practices. In general, there was no difference in pH until the chemicals were applied and weeds were removed, but it increased gradually from 10 to 30 DAS during both the years. In two years of experimentation, pH was higher in the year 2017 as compared to 2016; TDS and EC were increased during 2016 than 2017 (**Table 1**). Among weed management treatments, pH in glyphosate 2.0 kg/ha (6.67, 6.97, 6.85 and 6.75 7.05, 7.01 at 10, 20 and 30 DAS in 2016 and 2017, respectively) treated plots were found significantly higher than remaining treatments except 2,4-D amine salt 2.0 kg/ha, which was at par with glyphosate 1.0 kg/ha at 10, 20 and 30 DAS (**Table 1**). The lowest TDS (105 mg/l) was noticed in control before spray during 2016, which increased at 10, 20 and 30 days after herbicide spray, while in glyphosate 1.0 kg/ha treated plots it was at par with 2,4-D 1.0 kg/ha. TDS increased gradually from 10 to 30 DAS corresponding to the deterioration of weeds. The significant differences of EC were not observed among the treatments at 10 days after spray. Significantly higher EC was observed in application of glyphosate 2.0 kg/ha (0.33, 0.30, 0.26 and 0.35,0.27, 0.24 (mS/cm^2) at 10 20 and 30 DAS during 2016 and 2017, respectively), which was at par with 2,4-D 1.0 kg/ha (0.28, 0.35, 0.29 and 0.27, 0.22, 0.28 at 10, 20 and 30 DAS during 2016 and 2017, respectively) whereas in rest of treatments, EC was found less (**Table 1**). Similar finding was reported by Kannan and Karthiresan (2002) for effective control of water hyacinth with glyphosate 2.20 kg/ha without much reduction of water quality in term of pH. Glyphosate and 2,4-D ethyl-ester 2.0 kg/ha were found effective to control lotus in a pond at Jabalpur with no mortality of fish (Sushilkumar *et al.* 2003). However, they observed decrease in pH and dissolve oxygen after 15 days of herbicide spray on lotus and interpreted this decrease with the decomposing of leaves of lotus due to action of chemicals. In the present study also, no fish mortality was observed after herbicide spray. This might be happened because all the herbicides fell down on dense mat of weeds and therefore there was no direct mixing of herbicide with the water.

Effect of herbicides on density of weeds

The maximum density was recorded with alligator weed followed by water hyacinth and lotus. In control, no significant difference was observed in density of weeds before imposing treatments, but significant changed was recorded in the treated plots after 25 DAS (days after spray). The density of water hyacinth in control varied from 8.98 to 9.51 and 5.76 and 6.37 per m^2 during 2016 and 2017, respectively. The lotus density in control was recorded 2.37 to 2.62 m^2 and 1.44 to 1.67 m^2 during 2016 and 2017, respectively. The alligator density in control varied from 9.97 to 10.03 and 6.4 to 7.04 m^2 during 2016 and 2017, respectively. The overall density in all the treatments was found reduced in 2017 in control, which reflected that control action taken during 2016

Table1. Physio-chemical properties of Dalpatsagar reservoir

Treatment	Year	pH				TDS(mg/litre)				EC (mS/cm^2)			
		Before spray	10 DAS	20 DAS	30 DAS	Before spray	10 DAS	20 DAS	30 DAS	Before spray	10 DAS	20 DAS	30 DAS
Glyphosate 41 SL 2.0 litre/ha	2016	6.09	6.65	6.97	6.85	102	143	193	204	0.31	0.33	0.3	0.26
	2017	6.23	6.75	7.05	7.01	112	139	189	199	0.28	0.35	0.27	0.24
Glyphosate 41 SL1.0 litre/ha	2016	6.1	5.98	6.19	6.37	110	129	174	183	0.3	0.29	0.2	0.23
	2017	5.44	6.02	6.08	5.98	115	124	165	178	0.29	0.29	0.24	0.20
Paraquat 24 SL 2.0 litre/ha	2016	5.95	5.73	5.94	6.11	105	123	166	176	0.28	0.28	0.26	0.21
	2017	6.02	5.79	6.01	6.18	106	124	168	178	0.28	0.28	0.26	0.21
Paraquat 24 SL 1.0 litre/ha	2016	5.81	5.5	5.7	6.86	101	128	160	169	0.29	0.26	0.25	0.21
	2017	5.98	5.86	6.01	6.25	113	126	165	171	0.31	0.34	0.31	0.24
2,4-D Amine Salt 58% SL 2.0 kg/ha	2016	6.07	6.73	6.89	7.09	104	145	195	207	0.3	0.32	0.3	0.23
	2017	6.80	7.54	7.72	7.94	116	132	218	232	0.34	0.36	0.34	0.26
2,4-D Amine Salt 58% SL 1.0 kg/ha	2016	6.08	6.05	6.27	7.18	111	130	176	186	0.3	0.29	0.23	0.22
	2017	6.83	6.81	6.78	6.91	118	137	186	201	0.34	0.32	0.29	0.26
Manual removal	2016	6.00	5.89	6.01	7.19	106	125	168	178	0.29	0.28	0.24	0.21
	2017	6.12	6.02	6.17	7.21	112	131	172	182	0.32	0.31	0.25	0.24
Control	2016	5.98	5.87	5.77	5.63	105	117	122	171	0.28	0.27	0.25	0.28
	2017	6.64	5.89	6.01	6.09	117	118	110	190	0.32	0.35	0.28	0.32
LSD (p=0.05)	2016	NS	0.67	0.73	0.72	NS	19.5	14.4	12.3	NS	0.03	0.03	0.02
	2017	NS	0.76	0.86	0.76	NS	20.1	15.2	13.8	NS	0.03	0.04	0.02

DAS=Days after spray; mS/cm =millisiemens per centimeter caused reduction in density in aquatic weeds in 2017. The severe reduction in density of water hyacinth was observed with spraying of glyphosate 2.0 kg/ha followed by 2,4-D amine salt 2.0 kg/ha and paraquat 2.0 kg/ha (**Table 2**). Lower doses of tested herbicides were not significantly effective with each other. Manual/mechanical removal was significantly superior in reduction of density over the rest of treatments. Density of all three type of weeds were found significantly increased in control than the herbicidal and manual control treatment. Aquatic weeds were effectively controlled by manual and mechanical removal, but it was costlier than the chemicals (Bhan and Sushilkumar 1996). Glyphosate at 2.0 kg/ha was found superior in controlling weeds than other herbicidal treatments except higher dose (2.0 kg/ha) of 2,4-D amine salt, which were at par with glyphosate 2.0 kg/ha (**Table 2**). Similar finding was of glyphosate quoted by Muniyappa *et al.* (1995) at 2 ml per litre of glyphosate for alligator weed in reduction of density. Obyleye *et al.* (1993) obtained most effective and economic method of control for *E. crassipes* by application of 2,4-D amine salt and fish species composition also improved qualitatively and quantitatively.

Weed control efficiency (WCE)

The weed control efficiency was significantly highest under manual and mechanical removal than other treatments except glyphosate 2.0 kg/ha, which was at par with this treatment. 2,4-D 2.0 kg/ha was the second most effective herbicides to loosen the compact weed mat and was at par with glyphosate 2.0 kg/ha. In paraquat treatment, upper leaves started to dry by 24 hours after spray and it appeared that it will quickly control the weeds, but within a week, leaves gradually started to regain its green colour from the lower side of the plant. Higher WCE was recorded during 2017 in comparison to 2016 (**Table 3**), which might be due to the past experience of labour in applying of herbicides followed by cutting and dragging of weed biomass to the bank side. Raju and Reddy (1988) suggested that lowest WCE was noticed when 2,4-D amine salt 58% SL was applied at 0.5 kg/ha due to more reduction of dry matter, which led to higher WCE. Sushilkumar (2011) recorded

Table 2. Effect of weed control treatments on density (no./m^2) of the aquatic weeds

Treatment	Water hyacinth				Lotus				Alligator weed			
	2016		2017		2016		2017		2016		2017	
	Before spray	25 DAS	Before spray	25 DAS	Before spray	25 DAS	Before spray	25 DAS	Before spray	25 DAS	Before spray	25 DAS
Glyphosate 41 SL 2.0 kg/ha	9.93	4.25	6.37	2.46	2.62	1.46	1.67	0.94	11.03	4.19	7.04	2.69
	(98.09)	(19.73)	(61.25)	(10.57)	(6.35)	(1.62)	(4.08)	(1.05)	(121.09)	(17.05)	(76.12)	(10.92)
Glyphosate 41 SL1.0 kg/ha	8.98	5.09	5.76	3.27	2.25	1.73	1.44	1.11	9.97	5.18	6.40	3.32
	(80.06)	(25.43)	(45.21)	(14.25)	(4.55)	(2.50)	(2.91)	(1.61)	(98.83)	(26.31)	(62.13)	(16.87)
Paraquat 24 SL 2.0 kg/ha	9.08	5.67	5.82	3.35	2.29	1.76	1.47	1.13	10.08	5.41	6.46	3.71
	(81.93)	(26.78)	(51.27)	(17.18)	(4.74)	(2.61)	(3.05)	(1.66)	(101.15)	(27.70)	(64.89)	(17.78)
Paraquat 24 SL 1.0 kg/ha	9.18	5.88	5.78	3.64	2.33	1.97	1.50	1.26	10.20	5.79	6.54	3.39
	(83.85)	(26.56)	(53.79)	(16.79)	(4.93)	(3.38)	(3.16)	(2.16)	(103.51)	(27.48)	(65.44)	(17.62)
2,4-D Amine Salt 58% SL 2.0 kg/ha	9.29	4.12	5.89	2.89	2.37	1.56	1.51	1.00	10.32	4.57	6.62	2.91
	(85.81)	(16.48)	(54.23)	(11.25)	(5.13)	(1.94)	(3.28)	(1.23)	(105.94)	(20.41)	(66.96)	(13.10)
2,4-D Amine Salt 58% SL 1.0 kg/ha	9.40	5.91	6.03	3.79	2.41	1.77	1.55	1.14	10.44	6.01	6.70	3.86
	(87.82)	(34.42)	(55.62)	(20.91)	(5.33)	(2.63)	(3.41)	(1.69)	(108.42)	(35.61)	(69.75)	(22.83)
Manual removal	9.51	3.10	6.10	1.99	2.46	1.18	1.58	0.78	10.56	3.02	6.77	2.03
	(89.88)	(9.09)	(56.47)	(5.80)	(5.53)	(0.89)	(3.55)	(0.57)	(110.95)	(9.40)	(72.15)	(6.03)
Control	9.41	10.40	6.04	6.64	2.42	3.32	1.55	2.13	10.84	10.63	6.95	6.81
	(87.98)	(107.64)	(55.46)	(68.95)	(5.34)	(10.51)	(3.43)	(6.74)	(116.95)	(112.58)	(74.56)	(71.25)
LSD (p=0.05)	NS	1.40	NS	0.81	NS	0.14	NS	0.19	NS	1.17	NS	0.95

Table 3. Effect of weed control treatments on weed control efficiency and economics

Treatment	Weed control efficiency (%)						Cost of control (x10^3 `/ha)	
	Water hyacinth		Lotus		Alligator weed			
	2016	2017	2016	2017	2016	2017	2016	2017
Glyphosate 41 SL 2.0 litre/ha	86.4	84.2	79.1	82.2	83.7	88.3	19.66	18.08
Glyphosate 41 SL1.0 litre/ha	81.7	81.1	74.9	79.2	80.5	82.3	20.41	19.10
Paraquat 24 SL 2.0 litre/ha	68.0	62.2	61.3	60.3	66.1	67.2	24.12	24.57
Paraquat 24 SL 1.0 litre/ha	62.1	61.3	56.0	54.7	62.6	65.6	22.26	22.31
2,4-D Amine Salt 58% SL 2.0 kg/ha	81.7	78.3	67.7	78.2	74.9	82.6	21.33	20.41
2,4-D Amine Salt 58% SL 1.0 kg/ha	75.3	74.0	66.2	71.2	73.8	79.2	20.78	19.40
Manual removal	91.6	90.1	88.4	91.2	91.0	92.3	59.36	57.52
Control	0	0	0	0	0	0	0	0
LSD (p=0.05)	8.1	6.1	7.5	14.0	16.0	10.6	1.87	2.08

highest weed control of water hyacinth by 2,4-D 2.kg/ha (82.8%) followed by glyphosate 2.0 kg/ha (75.4%) and by paraquat (75.6%) at 21 days after herbicide spray, however they observed highest regrowth of water hyacinth in paraquat treatment after 3 months of spray followed by 2,4-D and glyphosate. Sushilkumar *et al.* (2003) also recorded higher weed control of lotus by glyphosate 2.0 kg/ha (82.7%) followed by 2,4-D (ethyl ester) 2.0 kg/ha (77.5%). Sushilkumar *et al.* (2008) recorded that 2,4-D (1.5 kg/ha) and glyphosate (2.0 kg/ha) caused almost 100% superficial killing of terrestrial form of alligator weed at 15 DAS, however, regrowth occurred after 60 days. They observed that repeat application of same herbicides after 90 days of first application revealed no significant difference in regrowth at 30 DAA, however significant difference appeared at 60 and 90 DAS.

Economics

The maximum cost of weed control was associated with manual-cum-mechanical removal because of engagement of labours with highest WCE (91.56, 90.15,88.45 and 81.25, 91.04, 92.35% for water hyacinth, lotus and alligator weeds during 2016 and 2017, respectively). Glyphosate (2.0 kg/ha) was found most effective with cost of ` 19660 and ` 18080 per hectare with WCE of 86.4 and 84.3% for water hyacinth during 2016 and 2017, respectively (**Table 3**). Paraquat 24 SL and 2,4-D amine salt 58% SL were less costlier than glyphosate applied at higher dose, but weed control efficiency was not parallel to glyphosate. Lower dose of glyphosate was effective than lower dose of paraquat and 2,4-D in context to weed control efficiency, which were 76.4,80.2, 67.7 and 71.2, 74.9, 79.5% for water hyacinth, lotus and alligator weeds during 2016 and 201. The cost of treatments *of* 2,4-D amine salt at 1.0 kg/ha and paraquat 1.0 kg/ha for controlling weeds was found to be ` 20780 and 19400 and ` 22260 and 22310 per hectare during 2016 and 2017, respectively, which was about 61% lower than that of manual removal cost of ` 59360 and 57520 per hectare during 2016 and 2017, respectively. Reduction in cost in second year was possible due to experience gained during previous year to spray the chemical and to remove the weed subsequently. Sharma *et al*. (1989) obtained that an expenditure of ` 30324.00 was incurred in manual removal of *E. crassipes* from four experimental ponds, which had an area of 18.18 hectare after the removal of *E. crassipes* mechanically over manual control. In our experiment, we removed aquatic weeds after loosening the weed mat using both manual and mechanical approaches due to which cost of removal has come down appreciably than the manual approach alone.

It was concluded that in case of sever infestation of complex of aquatic weeds, we can reduce the cost of manual or mechanical removal appreciably without disturbing water quality by first employing the herbicide over the weed mat to loosen the entangled weed biomass and thereafter to remove them manually/mechanically after a gap of 25 to 30 days.

REFERENCES

Jackson ML.1967. *Soil Chemical Analysis*. Prentice hall of India Pvt. Ltd., New Delhi 498p.

Bhan VM and Sushilkumar. 1996. Eco-friendly approaches in aquatic weed management. Pp. 191–201. In: *Proceedings of Workshop on "Aquatic Weeds- Problems and Management"* (Ed. Varma CVJ). held at Bangalore (Karnataka), 5-7 June 1996.

Gopal B and Sharma KP. 1981. *Water Hyacinth (Eichhornia Crassipes) the Most Troublesome Weeds of the World*. Hindasia Publisher, New Delhi, 129 p.

Gupta, O.P. 1987. *Aquatic Weed Management: A Text Book and Manual*. Today and Tomorrow's Printers and Publishers, New Delhi

Holm LG, Plucknett DL PanchoJV and Herberger JP. 1991. The *World's Worst Weeds, Distribution And Biology*, Krieger Publishing Company, Malabar, Florida, USA.

Kannan C and Kathiresan RM. 2002. Herbicidal control of water hyacinth and its impact of fish growth and water quality. *Indian Journal of Weed Science* **34**(1&2): 92–95.

Labrada R. 1996. *Status of Water Hyacinth In Developing Countries*. Food and Agriculture organization of the United States (FAO), Rome Italy.

Muniyappa TV, Manjunatha V and Sureshbabu V. 1995. Efficacy of post emergent herbicides on control of water hyacinth and their effect on fishes. *World Weeds* **2**: 117–121.

Raju RA and Reddy MN. 1988. Control of water hyacinth through herbicides. *Indian Farming* **38**(3): 19–21.

Sharma RC, Gupta DK and Sharma VP. 1989. Control of water hyacinth in the ponds of Kheda district, Gujarat, A cost: benefit analysis. *Indian Journal of Weed Science* **21**(3&4): 19–24.

Sushilkumar. 2011. Biological based chemical integration for early control of water hyacinth. *Indian Journal of Weed Science* **43** (3&4): 211–214.

Sushilkumar, Sondhia S and Vishwakarma K. 2004. Role of insects in suppression of problematic alligator weed (*Alternanthera philoxeroides*) and testing of herbicides for its integrated management. *Final Report of ICAR Adhoc Project* (1.9.2000 to 31.8 2003), 39 p

Sushilkumar, Sondhia Shobha and Vishwakarma K. 2008. Evaluation of herbicides in context to regrowth against terrestrial form of alligator weed. *Indian Journal of Weed Science* **40** (3&4): 180–187.

Sushilkumar, Vishwakarma K and Yaduraju NT.2005. Chemical control of lotus (*Nelumbo nucifera* Gaertn) in fish culture pond and its impact on water quality. Indian Journal of Weed Science, **37** (3 & 4) :293- 295. SushilkKumar and Pradhan Adikant. 2018. Aquatic weeds problems in India-Challenge for management. *Indian Farming* **68**(11): 42–45.

Indian Journal of Weed Science **51**(2): 188–197, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Suppression of seed setting and viability in phytoplasma-infected *Parthenium* weed in nature through differential gene expression

Neeraj Kumar Dubey, Pawan Yadav, Nisha Gupta, Kapil Gupta, Jogeswar Panigrahi, Aditya Kumar Gupta*

Department of Biotechnology, School of Life Sciences, Central University of Rajasthan, Ajmer, Rajasthan 305 817, India

**Email: guptaditya1954@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00040.6

Type of article: Research article

Received : 24 August March 2018
Revised : 27 April 2019
Accepted : 2 May 2019

Key words

APETALA-1
DA1
Parthenium
PhATL80
Phytoplasma
Witches' broom

ABSTRACT

The phytoplasma-mediated witches' broom disease in *Parthenium hysterophorus* L., a notorious weed, inhibits flower formation and percentage of seed setting. Even the seeds produced from infected plants showed poor viability and reduced rate of germination. Expression analysis of three orthologous genes in *P. hysterophorus*, namely, *APETALA-1* (*PhAP1*), ubiquitin binding protein (*PhDA1*), and RING-type E3 ubiquitin ligase (*PhATL80*) showed significant variation in their transcription levels. Expression of *PhAP1*, *PhDA1*, and *PhATL80* was higher in apical shoot bud and inflorescence than in other studied tissues. Infected plants showed suppressed expression of *PhAP1* and *PhATL80* in the inflorescences while no significant variation was observed in *PhDA1* expression. This resulted in floral to vegetative transition, causing phyllody and virescence, and lesser seed setting. These findings suggest that in naturally phytoplasma-infected *P. hysterophorus*, expression of gene(s) participating in floral development as well as seed setting at onset of the reproductive phase is suppressed.

INTRODUCTION

Weeds are serious problem for agriculture production (Chauhan *et al.* 2012, Aly and Dubey 2014). *Parthenium hysterophorus* L., belonging to family Asteraceae, is a devastating weed, which causes extensive losses in crop yield besides affecting biodiversity and environment in tropical and subtropical regions of the world (Adkins and Shabbir, 2012, Sushilkumar 2014)). It is difficult to control this weed in its habitat due to high seed setting as well as seed dormancy. This plant also contains allergenic growth inhibitors which cause respiratory problems, contact dermatitis, and so on in humans and livestock (Patel 2011, Sushilkumar 2005). It is also an alternative host for the sap-sucking insects like mealy bugs, leafhoppers and aphids. Currently, *P. hysterophorus* population is controlled by either conventional methods (hand pulling, crop rotation, mulching) or herbicides (2,4-D, Atrazine, metribuzin, Glyphosate, *etc*). Mexican beetle *Zygogramma bicolorata* has emerged most effective biological control agent to suppress Parthenium during rainy season (Sushilkumar 2009). Controlling this weed through conventional methods or the use of herbicides is not only cumbersome and expensive, the latter also pose a threat to the environment.

Life cycle of this weed starts with seed germination and proceeds through rosette formation, flowering, and seed setting and ends with seed dispersion. Thus, flower development, seed setting, and seed germination are considered as critical steps in the perpetuation of this weed. Several genes like *APETALA 1* (*AP1*), *LEAFY*, *DA1*, *ATATL80* (*RING-type E3 ubiquitin ligase*), *PTB1* (*POLLEN TUBE BLOCKED*), and so on play a significant role in inflorescence development and seed setting in model plants like *Arabidopsis thaliana* and *Oryza sativa* (Mandel *et al.* 1992, Gustafson-Brown *et al.* 1994, Wagner *et al.* 1999, William *et al.* 2004, Li *et al.* 2008, Benlloch *et al.* 2011, Li *et al.* 2013). The expression of *AP1* gene is up regulated during initiation of flowering, transition from vegetative to flowering stage and floral whorl development (Mandel *et al.* 1992, Gustafson-Brown *et al.* 1994, Benlloch *et al.* 2011). Mutants with pseudo-*AP1* showed secondary shoot and shoot-like development of flowers (Liljegren *et al.* 1999), and induced expression of *AP1* has been reported to convert shoot meristem into floral meristem in *A. thaliana* (Mandel and Yanofsky 1995). Seed development is a coordinated process following pollination and fertilization, and it involves development of the embryo, endosperm, and maternal tissues (Adamski *et al.* 2009). The genes like *AUXIN RESPONSE FACTOR2*, *APETALA2*, and Arabidopsis *DA1* (*AtDA1*) play a key role in seed setting (Adamski *et al.* 2009). Among these, *AtDA1* (which codes ubiquitin binding receptor proteins) is involved in final seed setting and also determines the seed size (Fang *et al.* 2012, Xia *et al.* 2013, Li *et al.* 2008). It works with other ubiquitin-related proteins *DA2*, *EOD1*, and *UBP15* (Du *et al.* 2014). Another member of RING-type E3 ubiquitin ligase gene family like *POLLEN TUBE BLOCKED 1* (*PTB1*-a) of rice and *ATATL80* of *Arabidopsis thaliana* also play a similar role in regulation of seed setting (Suh and Kim 2015, Li *et al.* 2013).

Phytoplasma is a phloem-restricted phytopathogenic bacteria, which causes witches' broom disease in several crops with symptoms like sepal hypertrophy, bigger buds, phyllody, excessive proliferation of shoots, inflorescence clustering, virescence, and development of small leaves (Bertaccini 2007, Yadav *et al.* 2015a). The phytoplasma are transmitted through insects, and at the onset of invasion, the host's morphology and life cycle are so modified to be conducive both for vector activity (Sugio *et al.* 2011) and bacterial colonization (MacLean *et al.* 2014, Su *et al.* 2011). Being obligate parasitic bacteria, these phytoplasma are restricted to the phloem sieve tubes and induce witches' broom disease in *Parthenium* species by altering floral development (Li *et al.* 2011, Bertaccini 2007, MacLean *et al.* 2014, Pracros *et al.* 2007). During reversal of flowering to vegetative phases in the infected host plants, phytoplasma induces transcriptional reprogramming of flowering-related genes. In tomato, phytoplasma induce the expression of *LEAFY* ortholog (*FA*) and suppress the *APETALA3* (*SlDEF*) and *AGAMOUS* (*TAG1*) (Pracros *et al.* 2006, Pracros *et al.* 2007). Hypermethylation-mediated transcriptional reprogramming and inhibition in expression of *SlDEF* (*APETALA3*) in tomato and *APETALA3* and *AGAMOUS* in *A. thaliana s* have also been observed (Pracros *et al.* 2007, Finnegan *et al.* 1996). Further phytoplasma produced a novel effector protein (SAP54), which interacts with MADS-domain transcription factor (*MTF*) and degrades it with the help of *RADIATION SENSITIVE23* (*RAD23*) genes associated with proteasomes (MacLean *et al.* 2014). Degradation of *MTF*, a key regulator of flower development, led to differential expression of *SEPALLATA3* and *APETALA1* in *Arabidopsis* and thus modifies floral development (MacLean *et al.* 2014). Similarly, suppression of *CrSEP3*, a *SEPALLALA3* ortholog, and *Chalcone synthase*, and the loss of floral pigmentation in *Catharanthus roseus* have also been observed during phytoplasma infection (Su *et al.* 2011).

Phytoplasma infection also causes differential expression of genes related to photosynthesis and elevated expression of Sucrose Synthase and Alcohol Dehydrogenase-I in *Vitis vinifera* (Bertamini and Nedunchezhian 2001, Hren *et al.* 2009). Alteration in the fate of inflorescence, flowering, fertilization, flower fertility, and seed setting have been observed in different species (Mathur 1989, Keshwal 1982).

Thus, understanding the molecular mechanism for inhibition of fertilization and seed setting in naturally phytoplasma-infected *P. hysterophorus* would be useful in developing a new strategy to control this weed. This study reports on differential expression of three orthologous candidate genes, regulating flower development in naturally phytoplasma-infected *P. hysterophorus* plants. Further, the effect of natural phytoplasma infection on seed setting, seed viability, and rate of seed germination in *P. hysterophorus* are also reported.

MATERIALS AND METHODS

The *P. hysterophorus* plants with symptoms of witches' broom disease were identified in the nursery of the Central University of Rajasthan, India, and tagged. Sepal hypertrophy, big buds, phyllody, excessive proliferation of shoots, inflorescence clustering, virescence, and development of small leaves were used to confirm the disease. Further, the presence of phytoplasma on the plants was affirmed by amplification of 16S rRNA using primers (Forward 5'GACTGCTAAGACTGGATAGG 3' and Reverse 5' CGAACGTATTCACCGCGAC 3', **Table 1**) and sequencing of the 16S rRNA clones (Xcelris Labs Ltd). About 100 mature flowers of healthy and infected plants were collected and used in the assessment of seed setting, seed viability (Verma and Majee 2013) and germination test. For germination assay, the seeds were kept on distilled water-soaked blotting paper (Axiva, India) for eight to ten days, and the number of seeds that germinated was observed. This experiment was performed with three biological replicates, and the experiment was repeated twice. Student 'T' test was used to analyse the result.

Total RNA was isolated from different plant parts of infected and healthy plants using total RNA purification kit (Jena Biosciences, Germany) followed by cDNA preparation with Verso cDNA

Table 1. List of primer sequences used in study

Genes	Forward primer (5’ - 3’)	Reverse primer (5’ - 3’)
Used in amplification/cloning		
16S rRNA	GACTGCTAAGACTGGATAGG	CGAACGTATTCACCGCGAC
PhAP1	GCTCTAGAATCTTCACCCATATAGTGC	CGGGATCCTTAGGAGGATAGAGAACAAG
PhDA1	GCTCTAGATCTGATCACGAGTTCTCCATGTC	CGGGATCCGGTTCACCTTCCATGGCTTC
PhATL80	GCTCTAGATCCGATTTCGTCGTCATCC	CGGGATCCCGGAAACTCGCCGCACTTC
Used in qRT-PCR analysis		
PhAP1	TCACCCATATAGTGCCTGTGA	GGAGCGATATGAGCGATATTC
PhDA1	TCCATGTCTGACAACCGTCC	ACAGCTGCAACATCTAGGAG
PhATL80	ACGGATCAACCACCAATTGC	GTGTCAACGCACGTGACATG
Actin	GAAGAGAACCTCAGGGCAAC	CGAGCAAGAGCTTGAGACTG

synthesis kit (Thermo Scientific, USA). The phytoplasma infestations of infected plants were affirmed by reverse transcriptase (RT) PCR analysis of phytoplasma 16S rRNA (Li *et al.* 2011) using synthesized primers (**Table 1**).

Since a complete decoded genome sequence or transcriptome of *P. hysterophorus* is lacking, the sequence of corresponding genes from *Arabidopsis thaliana* (TAIR database) were used as query nucleotide for BLAST analysis with EST sequence of *Parthenium argentatum* (http://comp genomics. ucdavis.edu /cgp_wd_assemblies.php#4232) and *Dahlia trinity* using BioEdit software (**Supple mentary file S1**). The conserved regions were identified by aligning the retrieved EST sequences with those of other members of *Compositae* family (http://www.genome.jp/tools/ clustalw/). The primers were designed from the most conserved region for cloning and expression analysis (**Table 1**).

The cDNAs amplified from healthy plants were directly cloned into TA cloning vector (T-Vector pMD20, Takara) and validated by re-sequencing of the clones. These partially cloned EST sequences were deposited at NCBI with accession number KY745903 (*PhAP1*), KY745904 (*PhDA1*), and KY745905 (*PhATL80*). These sequences showed significant similarity with their corresponding genes obtained from *P. argentatum* and *D. trinity*, respectively (**Supplementary file S2-4**).

Expression of orthologous genes of *P. hysterophorus*, namely, *APETALA-1* (*PhAP*1), Ubiquitin binding protein (*PhDA1*), and *RING-type E3 ubiquitin ligase* (*PhATL80*), was studied in healthy plants during developmental stages and in the shoot bud, leaf, and inflorescence of phytoplasma-infected plants. qRT-PCR of these genes was performed in biological triplicate and experimental duplicate condition by using diluted cDNA products (fivefold with deionized water) as a template. Each qRT-PCR reaction was performed at Roche Real-Time PCR Detection System (Roche, Light Cycler® 96) by using the DyNamoColorFlash SYBR Green qPCR kit (Thermo Scientific Cat No. F-416L) as prescribed in the manufacturer’s manual. Each reaction mixture (10 µL) was prepared by adding 5 µL of 2X SYBR Green PCR Master mix, 1 µL (10 pmol) of forward and reverse primers, and 1 µL of diluted cDNA. The amplification condition was as follows: 95°C for 7 min followed by 45 cycles of 95°C for 10s, 60°C for 15s and 72°C for 15s. Expressions of the three genes were normalized with an internal reference gene *Parthenium argentatum* Actin (>Contig12870). Results of qRT-PCR were analysed by the ‘$2^{-\Delta\Delta Ct}$’ method (Livak and Schmittgen 2001).

RESULTS AND DISCUSSION

In the present study, the incidence of phytoplasma in *P. hysterophorus* was affirmed by morphological symptoms of witches’ broom, such as phyllody and virescence (**Figure 1a**). These findings were corroborated with earlier observations (Li *et al.* 2011) that altered distribution of phytohormones and repression of genes related to floral development (Tan and Whitelow 2001, Sugio *et al.* 2011, Su *et al.* 2011) could cause the observed symptoms.

Further, the presence of phytoplasma in plant tissue was validated by the amplification of 16S rRNA unique to this phytopathogen group (**Figure 1b**). The 16S rRNA sequence of the phytoplasma strain obtained in the present study revealed more than 99% similarity with that of phytoplasma strain *YJJ2*, which belongs to phytoplasma 16SrII-A group (**Supplementary file S5**) and causes witches’ broom disease in *P. hysterophorus* (Gene ID.EU779826.1; Li *et al.* 2011). Further, phylogenetic analysis of 40 reported 16S rRNA sequences along the present one showed its clustering with the phytoplasma sequences belonging to 16SrII group (**Figure 1c**), and most of them cause witches’ broom disease in different species, including *Hibiscus* sp., bamboo, cactus, and peanut (Montano

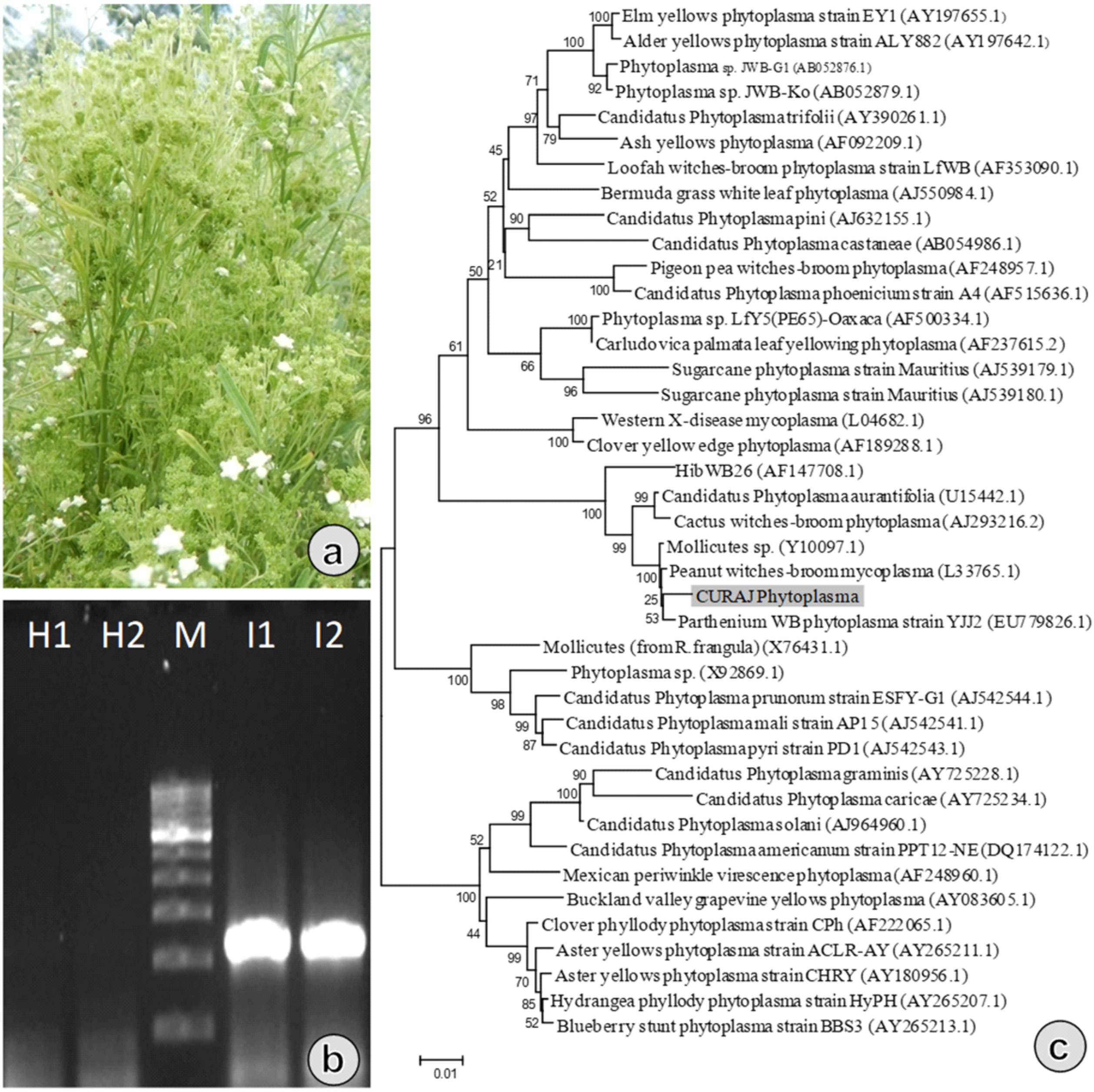


Figure 1. Identification and confirmation of witches' broom disease in *P. hysterophorus* L. through infective phytoplasma (a) Photography of infected plants, (b) Confirmation of phytoplasma infection by RT-PCR analysis 16S rRNA, and (c) Phylogenetic map of phytoplasma's 16S rRNA sequences with available sequence of the other strain (Alignments were made using CLUSTAL Omega multiple sequence alignment tool. The phylogenetic tree was constructed by the neighbourjoining approach using the MEGA5.10 program with default settings. CURAJ_Phytoplasma is shown in the yellow bracket. Numbers at the branch points indicate bootstrap values based on 1000 bootstrap replicate)

et al. 2001, Yadav *et al.* 2015b, Li *et al.* 2012, Chung *et al.* 2013). Phytoplasma-infected plants of *P. hysterophorus* showed about ten-fold reduction in number of seeds per inflorescence compared to healthy plants (**Figure 2a-e**) as reported earlier in this species (Taye *et al.* 2002). The seeds of infected plants appeared mottled black whereas those of healthy plants were dark black in appearance (**Figure 2g-h**). The viability assessment revealed that less number of viable seeds were produced in the infected plants as compared to healthy plants (**Figure 2f**), and the seed viability ratio of healthy plants was more than 80% in comparison to about 12% in infected plants. Delayed response to seed germination and lowered rate of seed germinations were noticed for the seeds of infected plants, the latter being about five fold lower (**Figure 2i-k**).

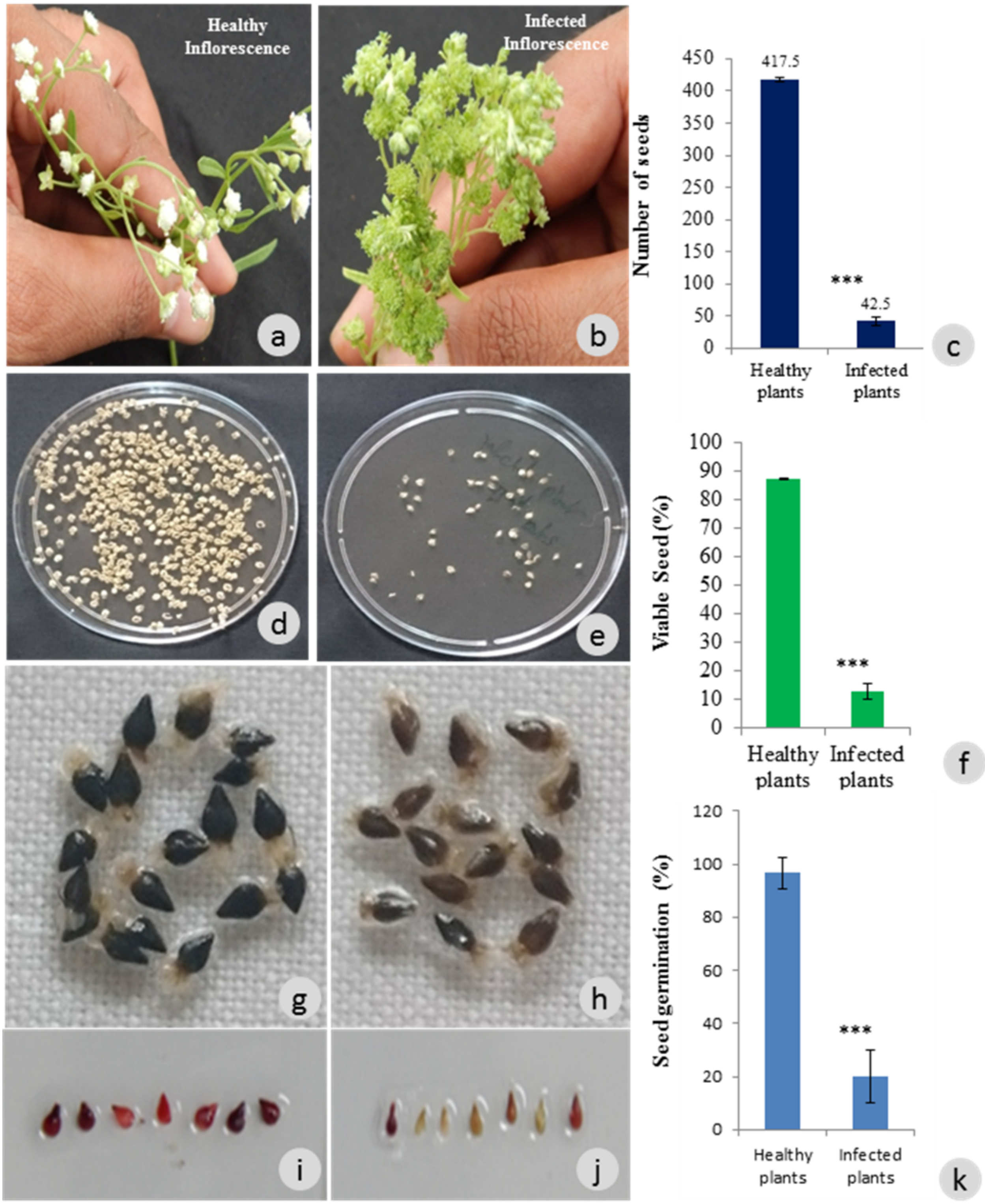


Figure 2. Effect of phytoplasma infection on seed settings, viability, and germination rate in *P.hysterophorus* L. plants (a–b) Photograph of inflorescence of healthy and infected plants, (c–e) Differences in seed setting,(f–j)Nature and viability of sets seeds in healthy and infected plant, and (k) Seed germination percentage in healthy and infected plants; hundreds of inflorescences of healthy and infected plants were collected for the experiment. Mean ± SE were obtained from three independent plants. Bars labelled with stars indicate the significant differences as determined by Student T-Test (P ≤ 0.001)

In this study, the expression of putative orthologous genes related to flower development, *PhAP1*, and seed setting, *PhDA1* and *PhATL80*, varied in at different stages of growth and development in healthy plants. Expression of *PhAP1* was maximum in inflorescence (139-fold), followed by apical bud (34-fold) than in seedling leaves (**Figure 3a**). Expression of *PhDA1* was significant and induced more than two fold in buds and inflorescence than in other part like seedling leaf and leaves of vegetative and flowering stages (**Figure 3b**). The expression of *PhATL80* was found significantly induced in all the tissues tested in the study compared to seedling leaves (**Figure 3c**). The maximum expression of *PhATL80* was in apical bud (55-fold) followed by inflorescence (38-fold) compared to seedling leaves (**Figure 3c**). Among the three selected genes, the expression of *PhAP1* was maximum in inflorescence whereas the expression of *PhATL80* and *PhDA1* were also augmented at onset of the reproductive phases. Their expression profiles suggest their role in flowering and development of *P. hysterophorus* as reported earlier in various species (Mandel *et al.* 1992, Gustafson-Brown *et al.* 1994, Li *et al.* 2008, Benlloch *et al.* 2011, Li *et al.* 2013, Fang *et al.* 2012, Xia *et al.* 2013, Suh and Kim 2015).

The expressions of these three genes (*PhAP1*, *PhDA1* and *PhATL80*) were tested in leaves, apical buds, and inflorescences of infected plants along with

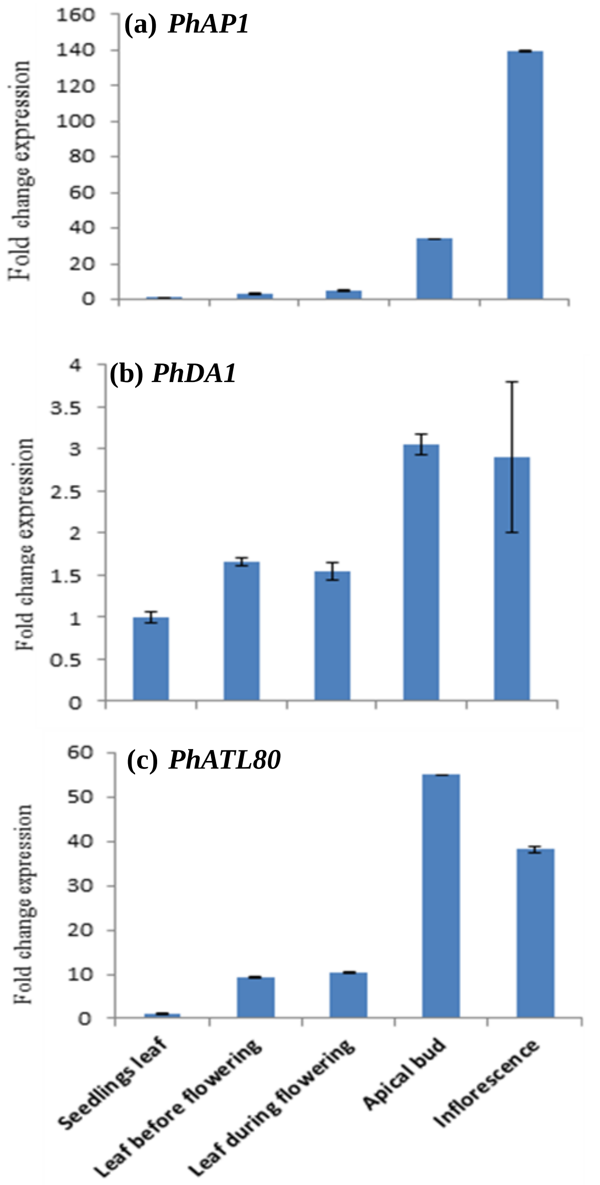


Figure 3. Expression pattern of *PhAP1*, *PhDA1*, and *PhATL80* genes at different stages and tissues of *P. hysterophorus* L. plant; expression of (a) *PhAP1*, (b) *PhDA1*, and (c) *PhATL80* in seedling leaves, leaf before flowering, leaf during flowering, apical bud, and inflorescence

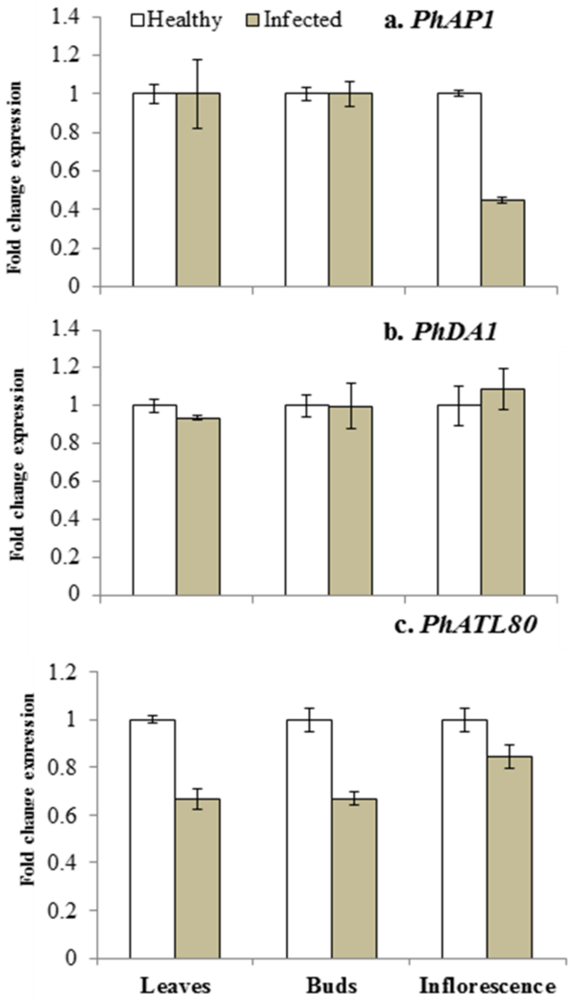


Figure 4. Expression pattern of *PhAP1*, *PhDA1*,and *PhATL80* genes in different tissues of phytoplasma-infected *P. hysterophorus* L. plant. Expression of (a) *PhAP1*, (b) *PhDA1*, and *PhATL80* (c) in buds, leaf, and inflorescence of infected and healthy plants

healthy plants. The expression of *PhAP1* was significantly suppressed in the inflorescences of infected plants and remained unchanged in buds and leaves during reproductive phases (**Figure 4a**). In contrast to *PhAP1*, the expression of *PhDA1* in buds, leaves, and inflorescences of the infected plants remained equivalent to that in healthy ones **(Figure 4b).** Like *PhAP1*, expression of *PhATL80* was significantly suppressed in buds, leaves, and inflorescence, but the suppression level was less than that of *PhAP1* (**Figure 4c**).

Zhang *et al.* (2015) have shown that *Arabidopsis DA1* is a negative regulator in seed size development, and its mutant produces larger seeds than the wild type. However, the over expression of *GsoDA1* gene did not affect seed size in *Glycine soja* and was associated with salinity resistance, which suggests its diverse function across the species (Zhao *et al.* 2015). The role of *DA1*in endo-re-duplication with cell and organ growth during leaf development has also been provided (Peng *et al.* 2015). In the present study, expression of *PhDA1* was almost unaffected in infected leaves, buds, and flowers of *P. hysterophorus*, showing that phytoplasma infection is unable to modulate expression of this gene and causes no alteration in seed size. Transcription factor like *AP1* regulate the flower formation along with *LFY* and mutation of these genes causes conversion of flower into shoot (Weigel *et al.* 1992, Riechmann *et al.* 1996, Parcy *et al.* 1998). In the present study, the expression *PhAP1* was significantly suppressed in the inflorescences of infected plants, which could putatively be associated with the reversal of flowering to vegetative phase causing phyllody. *ATATL80* (AT1G20823.1) are plasma membrane (PM)-localized ubiquitin (Ub) ligase and are involved in maintaining the phosphorus content as well as seed yield and biomass in *Arabidopsis* (Suh and Kim 2015). As expected, the expression of *PhATL80* was also significantly suppressed in buds, leaves, and inflorescences of the infected *P. hysterophorus* plants causing reduction in seed yield. The mutant line of *Arabidopsis* for this gene *ATATL80* showed earlier bolting than wild type, and overexpression of this gene resulted in late flowering and lower seed yield (Suh and Kim 2015). This implies the important role that *ATATL80* gene plays in flowering as well as seed setting in *Arabidopsis*. In *P. hysterophorus*, in contrast to *Arabidopsis*, phytoplasma infestation causes suppression of *PhATL80* gene resulting in floral to vegetative transition, causing phyllody and virescence, and lesser seed setting (Suh and Kim 2015).

Supplementary file S1. Systemic representation of different steps in isolation and fetching of candidate genes of *Arabidopsis thaliana* from Compositae EST database (http:// compgenomics. ucdavis. edu/ cgp_ wd_assemblies. php# 4232).

(1) Selection and isolation of candidate gene sequences from TAIR (e.g. AP1 (AT1G69120.1), DA1 (AT1G19270.1), ATATL80 (AT1G20823.1) gene sequences were isolated from TAIR website (https://www.arabidopsis.org))

⇩

(2) Selection and isolation of EST sequence of *Parthenium argentatum* and *Dahlia trinity* from Compositae Genome database (http:// compgenomics. ucdavis. edu/ cgp_ wd_assemblies. php# 4232) and creation of local nucleotide data base file with BioEdit software (http://www.mbio.ncsu.edu/bioedit/bioedit.html) and considering them as source file.

⇩

(3) Nucleotide BLAST analysis with *A. thaliana*'s selected sequences (as query sequences) and *P. argentatum* and *Dahlia trinity* EST Library (as source file) with the help of BioEdit software (http:// www.mbio.ncsu.edu/bioedit/bioedit.html) with filteration of maximum percentages of similarity.

⇩

(4) Fetching of corresponding EST sequence of *Parthenium argentatum* and *Dahlia trinity* from Compositae Genome database (e.g. *AtAP1* - matched with corresponding contig >1078 of *P. argentatum AtDA1* - matched with corresponding contig >guayule_c124924 *P. argentatum*, and *ATATL80* matched with Dahlia.faS >comp1908_c0_seq3 of *Dahlia trinity*)

⇩

(5) Further to get the conserved region and designing of primers for cloning, the corresponding retrieved sequences were separately aligned with other members of compositae family's 454 derived EST sequences (http://www.genome.jp/tools/clustalw/).

Supplementary file S2. Alignment of the selected nucleotide sequence of the *P. argentatum* contigs1078 (Pag1078) with cloned sequence from *Parthenium hysterophorus* (*PhAP1*);analysis was performed with BioEdit software (http://www.mbio.ncsu.edu/bioedit/ bioedit.html);underlined, coloured letters show the primer regions of the selected sequences for cloning.

```
PhAP1 1 atcttcacccatatagtgcctgtgatttctttgtaaaagctcagcccttgatttaagttt 60
        ||||||||||||||||||||||||||| |||||||||||||||||||| |||||||| ||
Pag1078 381 atcttcacccatatagtgcctgtgattcctttgtaaaagctcagccctagatttaagctt 440

PhAP1 61 gttgtactcaagggtccaacttcttggagtagcatcagcggcaactagctgtctctcggt 120
        ||| |||||||||||||||||||| |||||||||||||||||||||||||||||||| ||
Pag1078 441 gttatactcaagggtccaacttctcggagtagcatcagcggcaactagctgtctctcagt 500

PhAP1 121 ataagaatatcgctcatatcgctccaagatgctgtccatgcaagagtcagtagaaaactc 180
        ||||||||||||||||||||||||||| ||||||||||||||||||||||| ||||||||
Pag1078 501 ataagaatatcgctcatatcgctccaatatgctgtccatgcaagagtcagttgaaaactc 560

PhAP1 181 aaagagttttcctttgttggagaagacaattaaggcaacttcagcatcacaaagaacaga 240
        ||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||
Pag1078 561 aaagagttttcctttgttggagaagacaattaaggcaacttcagcatcacaaagaacaga 620

PhAP1 241 aatttcatgggctttcttcaataagccacctcttctcttggagaaagtaacttgcctgtt 300
        ||||||||||||||||||||||||||||||||| ||||||||||||||||||||||||||
Pag1078 621 aatttcatgggctttcttcaataagccacctctcctcttggagaaagtaacttgcctgtt 680

PhAP1 301 gatcttgttctctatcctcctaag 324
        ||||||||||||||||||||||||
Pag1078 681 gatcttgttctctatcctcctaag 704
```

Score = 486 bits (306),
Expect = e-141
Identities = 315/324 (97%)
Strand = Plus / Plus

Supplementary file S3. Alignment of the selected nucleotide sequence of the *P. argentatum*guayule_c124924 (Pagc124924) with cloned sequence from *Parthenium hysterophorus* (*PhDA1*);analysis was performed with BioEdit software (http://www.mbio.ncsu.edu/bioedit/bioedit.html); underlined coloured letters show the primer regions of the selected sequences for cloning

```
PhDA1 1 atcacgagttctccatgtctgacaaccgtcccttccacaagtcatgctataaagaacacc 60
 |||||||||||||||||||||| ||||| |  || ||||| || ||||||||||||||||
Pagc124924 35 atcacgagttctccatgtctgaaaaccgccagtttcacaaatcgtgctataaagaacacc 94

PhDA1 61 atcacccgaaatgtgatgtttgcaagaactttataccaacaaatagaggcggtctgattg 120
 ||||||||| ||||||||| |||||||||||||| |||||||||  ||  ||| |||| |
Pagc124924 95 atcacccgagatgtgatgtctgcaagaactttattccaacaaatgcagctggtttgatcg 154

PhDA1 121 aataccgggcccatccattttggctacaaaagtattgccctgccctcgagcatgatggaa 180
 ||||| |||| ||||| ||||||| ||| || || |||||  | | ||||||||| || |
Pagc124924 155 aatacagggcgcatccgttttggcaacagaaatactgcccgtcacacgagcatgacggga 214

PhDA1 181 ctcctagatgttgcagctgtgaaagaatggaacctaggtacacaagatacttattgctag 240
 | ||  ||||||||||||||||| |||||||| |  || |||||| ||| || || ||||
Pagc124924 215 ccccacgatgttgcagctgtgaacgaatggaagcacgggacacaaaatatttgttactag 274

PhDA1 241 atgacggttggaagctatgcctgcaatgttttgtctttgcaataatggatactcatgaat 300
 |||| ||| ||||  |||||||| | ||||| | || |||||| ||||| ||||||||||
Pagc124924 275 atgatggtaggaaattatgcctggagtgtttggactctgcaattatggacactcatgaat 334

PhDA1 301 gtcaacctctttatcttgaaattcaggattttatgaaggattaaatatgaaaattgagc 360
 | ||||| || || ||||||||||| ||||||||||||||||||| |||||||||||||
Pagc124924 335 gccaaccactgtaccttgaaattcaagattttatgaaggattaaacatgaaaattgagc 394

PhDA1 361 aacaagttccaatgttattggttgagagacaagccgtaaatgaatccatggaagg 415
 |||| || ||| ||||  ||||||||||||||||  |||||||| ||||||||||
Pagc124924 395 aacaggtaccattgttgctggttgagagacaagctctaaatgaagccatggaagg 449
```

Score = 446 bits (281),
Expect = e-129
Identities = 348/415 (83%)
Strand = Plus / Plus

Supplementary file S4. Alignment of the selected nucleotide sequence of the *Dahlia trinity* comp1908_c0_seq3 (Dtcomp1908) with cloned sequence from *Parthenium hysterophorus* (*PhATL80*); analysis was performed with http://www.ebi.ac.uk/Tools/msa/clustalw2/; underlined coloured letters show the primer regions of selected sequences for cloning

```
Dtcomp1908 tccgatttcgtcgtcatcctggcggcactcctctgcgctttgatttgcgtcctaggcctg
PhATL80 tccgatttcgtcgtcatcctcgccgccttcatatgcgccttaatctgcgtactgggtctc
 ******************** ** ** ** * ***** ** ** ***** ** ** **

Dtcomp1908 atcgcagtagctcgctgcgcgtggctccgacgcggatctacctccgacggtcg------c
PhATL80 atagccatcgctcgttgcacctggctccggcgactctccggcgtgatcatcaccggcggc
 ** ** * ***** *** * ******** ** ** * * *

Dtcomp1908 cggaaccctagcctgccggcggcggctaataaaggaatgaagaagaaggtagttgagtcg
PhATL80 cgtacggatcaaccaccaattgccgccaataaaggggttagaaaaaaggtgttgaagact
 ** * * * ** ** ** ******** * * ** ***** * ** *

Dtcomp1908 attccgaagttcgtttatgattcaggtaaggatttagaagtggagctgtcttccggtgag
PhATL80 ctaccgaagctgacgtattcattggaaa---------caagtgaggaaagggtctctgaa
 * ****** * *** * * * * *** * ***

Dtcomp1908 tgcgcgatctgtttatcggaatattccgacggcgatgagatccgtgttctgccgcagtgt
PhATL80 tgtgttatatgtttgacggaatttaggtccggtgatgagataagggtgttgccccagtgt
 ** * ** ***** ****** * *** ******** * ** **** ******

Dtcomp1908 gggcacgggttccacgtcggatgtattgatgtgtggttaggatcgcattcttcgtgtccg
PhATL80 gggcatgggtttcatgtcacgtgcgttgacacgtggtttgggtcccactcgtcgtgcccg
 ***** ***** ** *** ** **** ****** ** ** ** ** ***** ***

Dtcomp1908 tcgtgtaggcagatattggtgatgacga------ggtgccggaagtgcggcgagtttccg
PhATL80 tcttgtcggatggttttggtcgcggggccgccgcggtgtaggaagtgcggcgagtttccg
 ** *** ** * * ***** * * **** *******************
```

Supplementary file S5. Alignment of the selected nucleotide sequence of the phytoplasma (EU779826.1_CoWBP) and clones 16S rRNA of phytoplasma (CURAJ Phytoplasma);analysis was performed with BioEdit software (http://www.mbio.ncsu.edu/bioedit/bioedit.html); underlined coloured letters shows the primers region of selected sequences for cloning

```
CURAJ_CoWBP TTGACTGCTAAGACTGGATAGGAAGATAAAAGGCATCTTTTATCTTTTAAAAGACCTA-G

EU779826.1_CoWBP ACGACTGCTAAGACTGGATAGGAAGATAAAAGGCATCTTGTATCTTTTAAAAGACCTAGT
 ************************************** ******************

CURAJ_CoWBP TAATAGGTATGCTTTAGGAGGGGCTTGCGCCATATTAGTTAGTTGGTAGGGTAATGGCCT
EU779826.1_CoWBP TAATAGGTATGCTTTAGGAGGGGCTTGCGCCATATTAGTTAGTTGGTAGGGTAATGGCCT
 ************************************************************

CURAJ_CoWBP ACCAAGACGATGATGTGTAGCTGGACTGAGAGGTTGAACAGCCACATTGGGACTGAGACA
EU779826.1_CoWBP ACCAAGACGATGATGTGTAGCTGGACTGAGAGGTTGAACAGCCACATTGGGACTGAGACA
 ************************************************************

CURAJ_CoWBP CGGCCCAAACTCCTACGGGAGGCAGCAGTAGGGAATTTTCGGCAATGGAGGAAACTCTGA
EU779826.1_CoWBP CGGCCCAAACTCCTACGGGAGGCAGCAGTAGGGAATTTTCGGCAATGGAGGAAACTCTGA
 ************************************************************

CURAJ_CoWBP CCGAGCAACGCCGCGTGAATGACGAAGTACTTCGGTATGTAAAGTTCTTTTATCAAGGAA
EU779826.1_CoWBP CCGAGCAACGCCGCGTGAATGACGAAGTACTTCGGTATGTAAAGTTCTTTTATCGAGGAA
 ****************************************************** *****

CURAJ_CoWBP GAAAAGCAAATGGCGAACCATTTGTTTGCCGGTACTTGATGAATAAGCCCCGGCTAATTA
EU779826.1_CoWBP GAAAAGCAAATGGCGAACCATTTGTTTGCCGGTACTTGATGAATAAGCCCCGGCTAATTA
 ************************************************************

CURAJ_CoWBP TGTGCCAGCAGCCGCGGTAAGACATAAGGGGCAAGTGTTATCCGGAATTATTGGGCGTAA
EU779826.1_CoWBP TGTGCCAGCAGCCGCGGTAAGACATAAGGGGCAAGTGTTATCCGGAATTATTGGGCGTAA
 ************************************************************

CURAJ_CoWBP AGGGTGCGTAGGCGGTCTAGTAAGTCAGTGGTGTAATGGCAACGCTTAACGTTGTCCGGC
EU779826.1_CoWBP AGAGTGCGTAGGCGGTCTAGTAAGTCAGTGGTGTAATGGCAACGCTTAACGTTGTCCGGC
 ** *********************************************************

CURAJ_CoWBP TGTTGAAACTGCTAAACTTGAGTTAGATAGAGGCGAGTGGAATTCCATGTGTAGCGGTAA
EU779826.1_CoWBP TATTGAAACTGCTAAACTTGAGTTAGATAGAGGCGAGTGGAATTCCATGTGTAGCGGTAA
 * **********************************************************

CURAJ_CoWBP AATGCGTAAATATATGGGGGAACACCAGAGGCGTAGGCGGCTCGCTGGGTCTTAACTGAC
EU779826.1_CoWBP AATGCGTAAATATATGGAGGAACACCAGAGGCGTAGGCGGCTCGCTGGGTCTTAACTGAC
 ***************** ******************************************

CURAJ_CoWBP GCTGAGGCACGAAAGCGTGGGGAGCAAACAGGATTAGATACCCTGGTAGTCCACGCCGTA
EU779826.1_CoWBP GCTGAGGCACGAAAGCGTGGGGAGCAAACAGGATTAGATACCCTGGTAGTCCACGCCGTA
 ************************************************************

CURAJ_CoWBP AACGATGAGTACTAAGTGTCGGGTTAAACCGGTACTGAAGTTAACACATTAAGTACTCCG
EU779826.1_CoWBP AACGATGAGTACTAAGTGTCGGGTTAAACCGGTACTGAAGTTAACACATTAAGTACTCCG
 ************************************************************

CURAJ_CoWBP CCTGAGTAGTACGTACGCAAGTATGAAACTTAAAGGAATTGACGGGACTCCGCACAAGCG
EU779826.1_CoWBP CCTGAGTAGTACGTACGCAAGTATGAAACTTAAAGGAATTGACGGGACTCCGCACAAGCG
 ************************************************************

CURAJ_CoWBP GTGGATCATGTTGTTTAATTCGAAGATACCCGAAAAACCTTACCAGGTCTTGACATGTTT
EU779826.1_CoWBP GTGGATCATGTTGTTTAATTCGAAGATACCCGAAAAACCTTACCAGGTCTTGACATGTTT
 ************************************************************

CURAJ_CoWBP TTGCAAAATGATAGTAATATCGTGGAGGTTACCAGAAACACAGGTGGTGCATGGTTGTCG
EU779826.1_CoWBP TTGCAAAATGATAGTAATATCGTGGAGGTTACCAGAAACACAGGTGGTGCATGGTTGTCG
 ************************************************************

CURAJ_CoWBP TCAGCTCGTGTCGTGAGATGTTAGGTTAAGTCCTAAAACGAGCGAAACCCTTATCGTTAG
EU779826.1_CoWBP TCAGCTCGTGTCGTGAGATGTTAGGTTAAGTCCTAAAACGAGCGAAACCCTTATCGTTAG
 ************************************************************

CURAJ_CoWBP TTGCCAGCACGTTATGGTGGGGACTTTAACGAGACTGCCAATGATAAATTGGAGGAAGGT
EU779826.1_CoWBP TTGCCAGCACGTTATGGTGGGGACTTTAACGAGACTGCCAATGATAAATTGGAGGAAGGT
 ************************************************************

CURAJ_CoWBP GAGGATCACGTCAAATCAGCATGCCCCTTATGACCTGGGCTACAAACGTGATACAATGGC
EU779826.1_CoWBP GAGGATCACGTCAAATCAGCATGCCCCTTATGACCTGGGCTACAAACGTGATACAATGGC
 ************************************************************

CURAJ_CoWBP TGTTACAAAGGGTAGCTGAAACGCAAGTTCTTGGCCAATCCCCAAAAACAGTCCCAGTCC
EU779826.1_CoWBP TGTTACAAAGGGTAGCTGAAACGCAAGTTCTTGGCCAATCCCCAAAAACAGTCCCAGTCC
 ************************************************************

CURAJ_CoWBP GGATTGAAGTCTGCAACTCGACTTCATGAAGTTGGAATCGCTAGTAATCGCGAATCAGCA
EU779826.1_CoWBP GGATTGAGGTCTGCAACTCGACTTCATGAAGTTGGAATCGCTAGTAATCGCGAATCAGCA
 ******* ****************************************************

CURAJ_CoWBP TGTCGCGGTGAATACGTTCGAATCGGTCCCCCGGACCCC
EU779826.1_CoWBP TGTCGCGGTGAATACGTTCGCGGGGTTTGTACACACCGC
 ******************** * * * *** *
```

Score = 2351 bits (1186),
Expect = 0.0
Identities = 1211/1218 (99%),
Strand = Plus / Plus

In conclusion, these findings suggest that in naturally phytoplasma-infected *P. hysterophorus*, expression of gene(s) participating in floral development as well as seed setting at onset of the reproductive phase is suppressed. Further, we also suggest that a chemically or biologically active compound which can suppress the expression of these genes could be used to control seed setting and spreading of *P. hysterophorus*.

ACKNOWLEDGEMENTS

The authors NKD, NG and KG are grateful to the University Grant Commission (UGC), Govt. of India for providing financial assistance through Dr DS Kothari Postdoc fellowship. Authors are also thankful to Mr Vikas Kumar Singh for his kind help in photography. The author AKG is grateful to Department of Biotechnology (Government of India) for financial support in this study.

REFERENCES

Adamski NM, Anastasiou E, Eriksson S, O'neill CM, Lenhard M. 2009. Local maternal control of seed size by KLUH/ CYP78A5-dependent growth signaling. *Proceedings of the National Academy of Sciences* **106**: 20115–20120. doi: 10.1073/pnas.0907024106.

Adkins SW and Shabbir A. 2014. Biology, ecology and management of the invasive Parthenium weed (Parthenium hysterophorus L.). *Pest Management Science* **70**: 1023–1029.

Aly R, Dubey NK. 2014. Weed Management for parasitic weeds. pp. 315-345. In: *Recent Advances in Weed Management*). Springer, New York, NY.

Benlloch R, Kim MC, Sayou C, Thévenon E, Parcy F, Nilsson O. 2011. Integrating long day flowering signals: a LEAFY binding site is essential for proper photoperiodic activation of APETALA1. *The Plant Journal* **l67**: 1094-1102. doi:10.1111/j.1365-313X.2011.04660.x

Bertaccini A. 2007. Phytoplasmas: diversity, taxonomy, and epidemiology. *Frontieres in Bioscience* **12**: 673–689. http:/ /dx.doi.org/10.2741/2092

Bertamini M, Nedunchezhian N. 2001. Effect of phytoplasma, stolbur-subgroup (Bois noir-BN)] of photosynthetic pigments, saccarides, ribulose-1,5-bisphosphate carboxylase, nitrate and nitrite reductases and photosynthetic activities in field-grow grapevine (*Vitis vinifera* L. cv Chardonnay) leaves. *Photosynthetica* **39**: 119–122. doi: 10.1023/A:1012412406727

Chauhan BS, Mahajan G, Sardana V, Timsina J and Jat ML. 2012. Productivity and sustainability of the rice–wheat cropping system in the Indo- Gangetic Plains of the Indian subcontinent: problems, opportunities, and strategies. *Advances in Agronomy* 117: 315–369.

Chung WC, Chen, LL, Lo WS, Lin CP, Kuo CH. 2013. Comparative analysis of the peanut witches'-broom phytoplasma genome reveals horizontal transfer of potential mobile units and effectors. *PLoS One* **8**(4): e62770. doi:10.1371/journal.pone.0062770

Du L, Li N, Chen L, Xu Y, Li Y, Zhang Y, Li C, Li Y. 2014. The ubiquitin receptor DA1 regulates seed and organ size by modulating the stability of the ubiquitin-specific protease UBP15/SOD2 in Arabidopsis. *The Plant Cell* **26**: 665-677. doi: http:/ / dx. doi. org/ 10. 1105/ tpc. 114. 122663.

Fang W, Wang Z, Cui R, Li J, Li Y. 2012. Maternal control of seed size by EOD3/CYP78A6 in *Arabidopsis thaliana*. *The Plant Journal* **70**: 929-939. doi: 10.1111/j.1365-313X.2012.04907.x.

Finnegan EJ, Peacock WJ, Dennis ES. 1996. Reduced DNA methylation in *Arabidopsis thaliana* results in abnormal plant development. *Proceedings of the National Academy of Sciences* **16**: 8449-8454.

Gustafson-brown C, Savidge B, Yanofsky MF. 1994. Regulation of the Arabidopsis floral homeotic gene APETALA1. *Cell* **76**: 131–143. doi:10.1016/0092-8674(94)90178-3.

Hren M, Ravnikar M, Brzin J, Ermacora P, Carraro L, Bianco PA, Casati P, Borgo M, Angelini E, Rotter A, Gruden K. 2009. Induced expression of sucrose synthase and alcohol dehydrogenase I genes in phytoplasma infected grapevine plants grown in the field. *Plant Pathology* **58**: 170–80. doi: 10.1111/j.1365-3059.2008.01904.x.

Keshwal RL. 1982. Spread of Parthenium phyllody under field condition. *Indian Journal of . Weed Science* **14**: 34-36.

Li ZN, Zhang L, Liu P, Bai YB, Yang XG, Wu YF. 2012. Detection and molecular characterization of cactus witches'-broom disease associated with a group 16SrII phytoplasma in northern areas of China. *Tropical Plant Pathology* **37**: 210-214. http://dx.doi.org/10.1590/S1982-56762012000300008.

Li S, Li W, Huang B, Cao X, Zhou X, Ye S, Li C, Gao F, Zou T, Xie K, Ren Y. 2013. Natural variation in PTB1 regulates rice seed setting rate by controlling pollen tube growth. *Nature communications* **4**: 1-13. doi:10.1038/ncomms3793

Li Y, Zheng L, Corke F, Smith C, Bevan MW. 2008. Control of final seed and organ size by the DA1 gene family in *Arabidopsis thaliana*. *Genes & Development* **22**: 1331-1336. doi: 10.1101/gad.463608.

Li Z, Zhang L, Che H, Liu H, Chi M, Luo D, Li Y, Chen W, Wu Y. 2011. A disease associated with phytoplasma in *Parthenium hysterophorus*. *Phytoparasitica* **39**: 407–410. doi 10.1007/s12600-011-0160-x.

Liljegren SJ, Gustafson-brown C, Pinyopich A, Ditta GS, Yanofsky MF. 1999. Interactions among APETALA1, LEAFY, and TERMINAL FLOWER1 specify meristem fate. *The Plant Cell* **11**: 1007-1018.

Livak KJ, Schmittgen TD. 2001. Analysis of relative gene expression data using real-time quantitative PCR and the 2-[Delta][Delta] CT method. *Methods* **25**: 402–408. doi: 10.1006/meth.2001.1262.

Maclean AM, Orlovskis Z, Kowitwanich K, Zdziarska AM, Angenent GC. 2014. Phytoplasma Effector SAP54 Hijacks Plant reproduction by degrading MADS-box proteins and promotes insect colonization in a RAD23-dependent manner. *PLoS Biol* **12**(4): e1001835. doi:10.1371/ journal.pbio.1001835.

Mandel MA, Gustafson-brown C, Savidge B, Yanofsky MF. 1992. Molecular characterization of the *Arabidopsis* floral homeotic gene APETALA1. *Nature* **360**: 273–277.

Mandel MA, Yanofsky MF. 1995. A gene triggering flower formation in *Arabidopsis*. *Nature* **377**: 522-524

Mathur SK. 1989. *Studies on Parthenium Phyllody*. M.Sc. (Agric.) Thesis University of Agricultural Sciences, Bangalore, India.

Montano HG, Davis RE, Dally EL, Hogenhout S, Pimentel JP, Brioso PS. 2001. '*Candidatus Phytoplasma* brasiliense', a new phytoplasma taxon associated with hibiscus witches' broom disease. *International Journal of Systematic and Evolutionary Microbiology* **51**: 1109-1118. DOI: 10.1099/00207713-51-3-1109.

Parcy F, Nilsson O, Busch MA, Lee I, Weigel DA. 1998. Genetic framework for floral patterning. *Nature* **395**: 561–566. doi:10.1038/26903.

Patel S. 2011. Harmful and beneficial aspects of *Parthenium hysterophorus*: an update. *3 Biotech* **1**: 1-9. doi: 10.1007/s13205-011-0007-7.

Peng Y, Chen L, Lu Y, Wu Y, Dumenil J, Zhu Z, Bevan MW, Li Y. 2015. The ubiquitin receptors DA1, DAR1, and DAR2 redundantly regulate endoreduplication by modulating the stability of TCP14/15 in *Arabidopsis*. *The Plant Cell* **27**: 649-662. doi: 10.1105/tpc.114.132274.

Pracros P, Hernould M, Teyssier E, Eveillard S, Renaudin J. 2007. Stolburphytoplasma-infected tomato showed alteration of SlDEF methylation status and deregulation of methyltransferase genes expression. *Bulletin of Insectology* **60**: 221-222.

Pracros P, Renaudin J, Eveillard S, Mouras A, Hernould M. 2006. Tomato flower abnormalities induced by stolburphytoplasma infection are associated with changes of expression of floral development genes. *Molecular Plant-Microbe Interactions* **19**: 62–68. DOI: 10.1094/MPMI-19-0062.

Riechmann JL, Krizek BA, Meyerowitz EM 1996. Dimerization specificity of *Arabidopsis* MADS domain homeotic proteins APETALA1, APETALA3, PISTILLATA, and AGAMOUS. *Proceedings of the National Academy of Science. USA*. **93**: 4793–4798.

Su YT, Chen JC, Lin CP. 2011. Phytoplasma-induced floral abnormalities in *Catharanthus roseus* are associated with phytoplasma accumulation and transcript repression of floral organ identity genes. *Molecular plant-microbe interactions* **24**: 1502–1512. doi: 10.1094/MPMI-06-11-0176.

Sugio A, Maclean AM, Grieve VM, Hogenhout SA. 2011. Phytoplasma protein effector SAP11 enhances insect vector reproduction by manipulating plant development and defense hormone biosynthesis. *Proceedings of the National Academy of Sciences* **108:** E1254-E1263. doi: 10.1073/pnas.1105664108.

Suh JY, Kim WT. 2015. Arabidopsis RING E3 ubiquitin ligase AtATL80 is negatively involved in phosphate mobilization and cold stress response in sufficient phosphate growth conditions. *Biochemical and Biophysical Research Communications* **463**: 793-799. doi: 10.1016/j.bbrc.2015.06.015.

Sushilkumar. 2005. Biological Control of Parthenium Through *Zygogramma Bicolorata*. National Research Centre for Weed Science, Jabalpur, India: 88 p.

Sushilkumar. 2009. Biological control of Parthenium 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.

Tan PY, Whitlow T. 2001. Physiological responses of *Catharanthus roseus* (periwinkle) to ash yellows phytoplasmal infection. *New Phytol* **150**: 757-769. doi: 10.1046/j.1469-8137.2001.00121.x.

Taye T, Gossmann M, Einhorn G, Büttner C, Metz R, Abate D. 2002. The potential of pathogens as biological control of parthenium weed (*Parthenium hysterophorus* L.) in Ethiopia. Meded Rijksuniv Gent Fak Landbouwkd Toegep. *Biol Wet* **67**: 409–20.

Verma P, Majee. 2013. Seed Germination and viability test in tetrazolium (TZ) Assay. *Bio-protocol* **3**: 1–4. doi.org/10.21769/BioProtoc.884.

Wagner D, Sablowski RW, Meyerowitz EM. 1999. Transcriptional activation of APETALA1 by LEAFY. *Science* **285**: 582–584. doi: 10.1126/science.285.5427.582

Weigel D, Alvarez J, Smyth DR, Yanofsky MF, Meyerowitz EM. 1992. LEAFY controls floral meristem identity in *Arabidopsis*. *Cell* **69**: 843–859.

William DA, Su Y, Smith MR, Lu M, Baldwin DA, Wagner D. 2004. Genomic identification of direct target genes of LEAFY. *Proceedings of the National Academy of Sciences i. USA* **101**: 1775–1780. doi: 10.1073/pnas.0307842100.

Xia T, Li N, Dumenil J, Li J, Kamenski A, Bevan MW, Gao F, Li Y. 2013. The ubiquitin receptor DA1 interacts with the E3 ubiquitin ligase DA2 to regulate seed and organ size in Arabidopsis. *The Plant Cell* **25**: 3347–3359. doi: http:/ / dx.doi.org/10. 1105/ tpc. 113. 115063.

Yadav A, Thorat V, Bhale U, Shouche Y. 2015a. Association of 16SrII-C and 16SrII-D subgroup phytoplasma strains with witches' broom disease of *Parthenium hysterophorus* and insect vector *Orosiusa lbicinctus* in India. *Australasian Plant Disease Notes* **10**: 31. DOI: 10.1007/s13314-015-0181-2.

Yadav A, Thorat V, Shouche Y. 2015b. *Candidatus Phytoplasma* aurantifolia (16SrII Group) Associated with Witches' Broom Disease of Bamboo (*Dendrocalamus strictus*) in India. *Plant Disease* **100**: 209. http://dx.doi.org/10.1094/PDIS-05-15-0534-PDN.

Zhang Y, Du L, Xu R, Cui R, Hao J, Sun C, Li Y. 2015. Transcription factors SOD7/NGAL2 and DPA4/NGAL3 act redundantly to regulate seed size by directly repressing KLU expression in *Arabidopsis thaliana*. *The Plant Cell* **27**: 620–632. doi: 10.1105/tpc.114.135368.

Zhao M, Gu Y, He L, Chen Q, He C. 2015. Sequence and expression variations suggest an adaptive role for the DA1-like gene family in the evolution of soybeans. *BMC plant biology* **15**: 1–12. doi: 10.1186/s12870-015-0519-0.

Indian Journal of Weed Science **51**(2): 198–202, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Rice cultivation using plastic mulch under saturated moisture regime and its implications on weed management, water saving, productivity and profitability

B. Gangaiah[1]*, M.B.B. Prasad babu, P.C. Latha, T.Vidhan Singh and P. Raghuveer Rao

Directorate of Rice Research, Rajendra Nagar, Hyderabad, Telangana 500 030, India

[1]Head, Division of Natural Resource Management, ICAR-Central Island Agricultural Research Institute, Port Blair, 744 101, Andaman & Nicobar Islands, India

**Email: bandlagangaiah1167@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00041.8

Type of article: Research note

Received : 1 May 2019
Revised : 21 June 2019
Accepted : 25 June 2019

Key words

Plastic mulches

Saturation moisture

Standing water

Transplanted rice

Water saving

Weeds

ABSTRACT

A *Rabi* season (2012-13) field investigation was carried out at Directorate of Rice Research, Hyderabad to assess the impact of saturated moisture regime (SMR) with and without plastic mulching (black and transparent) in transplanted rice (TPR) on weed menace, water saving, productivity and economics as compared to 5 cm standing water regime (SWR) rice in RBD with six replications. Results revealed that no-mulch SMR rice has 37.3 and 80.2% higher weed count and thus 26.8 and 114.1% lower weed control efficiency than SWR rice culture at 20 and 40 days after transplanting. Plastic mulching (PM) with SMR has reduced the weed count and weed biomass in rice by over 90% as compared to no-mulch-SWR rice. Labour days required for weeding were enhanced by 50% under SMR (30 man days) as compared SWR (20 man days). SMR had 35% irrigation water (IW) economy but with 7.1% grain yield penalty (0.34 t/ha) as compared to SWR (100 cm IW use and 4.79 t/ha grain yield). When SMR was combined with plastic mulching (PM), there was aless yield depression (0.10-0.18 t/ha) when compared to SWR. SWR has more net returns (` 42,160/ha) than SMR (` 30,750). High cost of PM (` 23,000/ha) with SMR has masked gains in IW, weeding costs saving and higher yields. SMR can be adopted without any challenges but weed management through PM is desired with added advantage of water economy. Reducing cost of plastic mulches and evolving biodegradable plastics may make SMR rice culture a reality.

Rice (*Oryza sativa* L.) is the most important staple crop of India cultivated on 43.79 mha with a production of 168.5 million tonnes of un-milled rice in 2017 (FAOSTAT 2019). About 60.1% of the rice crop's total area in 2014-15 was under irrigation (Anonymous 2017) and thus is the highest water consumer in the country with an estimated water foot print of 432.9 billion m^3 including percolation losses during 2000-2004 (Chapagain and Hoekstra 2011). However, over time, on account of rising population, the per capita water availability in the country has got reduced from safe limit of 1700 m^3 in 2001 (1820 m^3) to 1545 m^3 by 2011 and is slated to reach 1140 m^3 by 2030 (Sengupta 2018) and country becomes water stressed. Accordingly, the share of water for agriculture (GOI 2009) is declining from 88 (2000) to anticipated level of 72% by 2050. These reduced water supplies call for rational use of water by all sectors in general and crops like rice in particular. Post-monsoon rice accounting for 13.1% of total rice production during 2017-18 (DOES, 2018) relies heavily on conserved waters (stored and ground water). In this context, water efficient rice production technologies *i.e.* (i) saturated soil culture through system of rice intensification, alternate wetting and drying (Peng *et al.* 2006); (ii) aerobic rice culture with irrigation at critical stages (Boumann *et al.* 2002) and (iii) ground cover rice production systems (GCRPS) involving mulches (Tao *et al.* 2006) and drip irrigation (Haibing He *et al.*2013) need focussed attention. Studies have indicated the utility of GCPRS in weed management too by thermal regulation (Kasirajan and Ngouajio 2012) and physical exclusion. In India, studies pertaining to GCPRS are yet to be made. The contributions of GCPRS to weed management needs to be weighed from contributions of standing water of TPR to reduced weed pressures (Kent and Johnson 2001). Keeping the dearth of information on GCPRS to weed management, a field study was carried out during *Rabi* season of 2012-13 (December-April) to assess the utility of plastic film mulch cultivation of rice with saturation moisture regime when compared to standing water TPR culture on weed menace, crop productivity and profitability.

Field studies were conducted during *Rabi* season of December 2012- April, 2013 at Directorate of Rice Research, Rajendranagar, Hyderabad, located at 19^0 N latitude and 74^0E longitude at an altitude of 700 m above mean sea level.The experimental region had a semi-arid climate.A rainfall of 32.2 mm in 4 rainy days (a day with >2.5 mm rain/day) was received and mean maximum and minimum temperature during crop life (January- 20th April) was 31.9 and 16.8^0C.The experimental clay loam soil (Vertisols; Typic Pellustert) with a 7.8 pH at the start of study in December, 2012 in its top 20 cm layer soil was collected and analysed as per Jackson (1973) contained 0.67% organic carbon and was rated low for available nitrogen (268.1kg/ha $KMnO_4$ extractable N), medium for available phosphorus (18.2 kg/ha 0.5 M $NaHCO_3$ extractable P) and potassium (379.8 kg/ ha NH_4OAC extractable K). The soil with a bulk density of 1.40 g/cc had a field capacity (FC) and permanent wilting point (PWP) moisture of 23 and 13%. Four mulching and moisture regime treatments were evaluated in randomized complete block design with six replications per treatment in transplanted rice. The treatments were (i)no mulch-5 cm standing water rice (SWR), (ii) no mulch-saturation moisture rice (SMR), (iii) black polythene mulch (BPM) - SMR and (iv) transparent (TPM)-SMR. In a well prepared land by 3 times ploughing and puddling followed by levelling, present experiment was laid out. Plastic film mulches (1.4 m width, 15 m length and 25 gsm thickness) as per treatment were spread on the field with inward folding of plastic sheet into the soil and placing of wet soil on all sides to form a bund of 15 cm height with a channel following the plot of 15 m length on all sides. A wooden marker with pegs at 20 cm distance apart having 6 pegs was prepared and pressed into the PM sheets at 10 cm spacing (to maintain 20 x 10 cm planting geometry). Into these holes, twenty-five day old '*MTU-1010*' rice seedlings were manually transplanted on 30th December, 2012. Phosphorus (26.4 kg/ha P) and potassium (36 kg/ haK) fertilizers were applied through single super phosphate and muriate of potash in last puddling uniformly to all treatments. Nitrogen as prilled urea (150 kg/ha) was broadcast applied on 5, 30 and 45 days after transplanting (DAT) in unmulched rice crop. In mulched treatments, 100 kg N was applied as basal along with P and K. Remaining N was mixed with irrigation water at water delivery point of each plot at 16.7 kg/ha on 30, 40 and 50 DAT. Two manual weeding were done on 20 and 40 DAT. Weed count in 0.5 m^2 quadrate at two locations/plot was recorded (same quadrats data recorded each time) prior to weeding and weeds were removed along with their roots. Root portion of weeds was cut and above ground portion of weeds was oven dried at 60^0 C for 48 hours to attain a constant weight and weight was recorded expressed as g/m^2. At harvest also, crop was harvested carefully leaving the weeds intact and their count and weight (above ground) was recorded as above. Weeds were not separated into grass, broad-leaved weed and sedges treatment wise. However, weed flora of SWR and SMR was enlisted separately. Weed Control Efficiency (WCE) in per cent (%) was worked out as per Ahlawat *et al.* (2005); WCE (%) = {Weed dry weight (g) in no mulch standing water rice - weed dry weight in no mulch/mulch rice- with saturation moisture/weed dry weight in no mulch standing water rice} x 100. As weed count and dry weight data have zero values, the data was subjected to square root transformation ($\sqrt{x+0.5}$) prior to statistical analysis.For manual weeding, 20,30 and 2 man days were used for SWR, SMR and PM + SMR treatments and a labour cost of ` 300/day was used for economic calculations.

Water was applied to each plot through PVC pipes of 10 cm diameter to maintain SMR in mulched treatments and SWR (5 cm) was maintained from 3 DAT onwards. Irrigation water (IW) of bore well lifted by electrical pump set was applied after measurement. Saturation moisture regime was maintained by alternate day irrigation. In SWR, water was let in whenever water depth was coming below 4 cm depth at bench mark point kept in each plot. Irrigation was stopped from 5th April onwards. Benefit-Cost (BC) ratio was worked out as ratio of gross income (net income + cost of cultivation) to cost of cultivation (`/ha). Growth was recorded in non-destructive way through recording plant height and tiller numbers in treatments (data not given).Yield attributes (data not given) from ten randomly selected hills and yield (straw and grain) from net plot (kg/ha) were recorded post-harvest. Crop was harvested at physiological maturity on 20th April. In the calculation of economics, minimum support price of rice grain (` 14,500/ tonne) and market price of straw (` 2,500/ tonne) were used. For plastic mulch treatment imposition in field, 10-man days (` 3,000) and plastic cost of ` 20,000/ha were used. Need based plant protection measures were taken for successful cultivation of crop without any yield penalties. For SMR irrigation, 7-man days were used. Economics was worked out with no cost of irrigation water. The analysis of variance (ANOVA) was done in randomized complete block design. The significance of treatment differences was compared by critical difference (CD) at 5% level of significance (p=0.05) and statistical interpretation of treatments was done as per Gomez and Gomez (1984).

Weather was highly congenial for rice cultivation. During the rice growing period, 32.2 mm rainfall was received and crop was raised on bore well water irrigation and faced no stress. The mean minimum temperatures ranged from 10.1-28.0 ^{0}C and the maximum temperature from 20.0-40.0 ^{0}C. Near absence of rains during study period has enabled in effective implementation of soil moisture regimes and mulching treatments and any differences in crop performance were ascribed to treatments under study only.

Weed flora

No mulch- standing water rice: The weed flora of no mulch-SWR treatment at 20 and 40 DAT consisted of 15 weeds (grasses, sedges and broad-leaved weeds). Weed species (relative value index) include: *Echinochloa colona* (24.3%), *Cyperus* spp. (20.3%), *Commelina benghalensis* (10.2%), *Ammania baccifera* (8.8%) and *Scripus* (6.1%) that together accounted for 69.7% of weed counts. *Aeschynomene indica* (5.4%), *Monochoria vaginallis* (4.2%) and *Bulbostylis barbata* (3.7%) were the other important weeds that accounted for 13.3% of total weed count. Rest 17% weed count was accounted by other 7 weeds *Fimbristylis miliaceae Alternanthera sessilis, Caesulia axillaris, Eclipta alba, Ludwigia parviflora, Marselia quadrifolia* and *Sphenoclea zeylanica.*

No mulch-saturation moisture rice: The weed flora of no mulch-SMR treatment was 1.3 times more diverse (20 weed species) than SWR rice. Weed species (relative value index) include: *Cyperus* spp. (21.5%), *E. colona* (19.8%), *C. benghalensis* (8.9%), *A. baccifera* (6.5%) and *Scripus* (4.9%) that together accounted for 61.6% of weed counts. *A. indica* (4.9%), *M. vaginallis* (1.5%) and *B. barbata* (2.0) were the other important weeds that accounted for 8.4% of weed count. Rest 30% weed count was accounted by other 11 weeds *i.e. F. miliaceae, A. sessilis, C. axillaris, E. alba, L. parviflora, M. quadrifolia* and *S. zeylanica, D. sanguinalis. D. retroflexa, D. aegyptium, L. chinensis* and *E. crus-galli*.

Plastic mulch-saturation moisture rice: The weed flora of plastic mulch- SMR was confined to 3-5 grassy weeds only. These weeds looking similar to rice might have been transplanted along with rice seedlings. *E. colona* (40.8%), *Cyperus* spp. (38.5%), *F. miliaceae* (10.9%), *E. indica* (6.5%) and *D. sanguinalis* (3.3%).

Weed count and weed biomass

Weed count and weed biomass of transplanted rice varied greatly among mulching and moisture regimes (**Table 1**). Plastic mulching almost excluded the weed pressure on rice crop irrespective of its colour (black/transparent) by acting as physical barrier between emerging weeds and sun light. Weeds that germinated below the mulch died quickly on account of lack of sunlight for photosynthesis. Only the weeds emerged from within the rice hill from the holes of plastic survived and that were very few. Thus a weed count reduction of 91, 90.5 and 100% at 20, 40 DAT and at harvest stages have effected a concomitant reduction in weed biomass by 94.5, 95.5 and 100%, respectively in plastic mulched rice with SMR. The reductions in weed biomass due to plastic mulching of current study were corroborated by the findings of Aimrun Wayayok *et al.* (2014) on system of rice intensification farming with mulches. Manual removal of weeds at 20 and 40 DAT resulted in zero weed counts and biomass at harvest stage. With age (maximum tillering stage), plastic holes were filled up with the rice tillers and no scope lied for further emergence of weeds. No mulch-SMR rice proved congenial for emergence of 1.8 times more number of weeds than the SWR without mulch. Accordingly,

Table 1. Weed biomass and weeding labour requirements of rice as affected by mulching and moisture regime

Treatment	Weed count/m^2			Weed biomass (g/m^2)		
	20 DAT	40 DAT	At harvest	20 DAT	40 DAT	At harvest
No mulch and saturation moisture (SM)	10.23 (103.4)	6.40 (66.5)	3.30 (20.4)	10.48 (109.3)	9.18 (83.7)	6.37 (40.1)
Black polythene mulch and SM	2.65 (6.5)	2.00 (3.5)	0.71 (0.0)	2.24 (4.5)	1.14 (1.5)	0.71 (0.0)
Transparent polythene mulch and SM	2.74 (7.0)	2.00 (3.5)	0.71 (0.0)	2.35 (5.0)	1.58 (2.0)	0.71(0.0)
No mulch and 5 cm standing water (SW)	6.31 (75.3)	4.73 (36.9)	2.79 (14.3)	9.31 (86.2)	6.29 (39.1)	4.69 (21.5)
LSD (p=0.05)	0.38	0.22	0.18	0.33	0.27	0.49

Original values in parentheses were subjected to square root $\sqrt{x+0.5}$ transformation.

no mulch-SMR rice had 37.3 (26.8), 80.2 (114.1) and 42.7% (86.5) higher weed count (weed biomass) at 20, 40 DAT and harvest stage than the SWR rice. In 5 cm standing water,water loving weeds only emerged, but SMR favoured germination of both water loving and aerobic conditions requiring weeds equally and thus higher weed count and biomass was recorded than SWR crop. A similar difference in weed flora and weed biomass of transplanted rice due to standing water depth reported by Kent and Johnson (2001), Haefele *et al.* (2004) and Duttarganvi *et al.* (2016) supports the current findings.

Weed control efficiency

Weed biomass differences have been reflected in weed control efficiency (WCE) and labour required for weeding (**Table 2**). The increases in weed biomass in no mulch-SMR over no mulch-SWR have been translated into reduced weed control efficiencies. Thus no mulch- SMR had negative (-) WCE values as weed biomass increased over bench mark (SWR). It ranged from -26.8, -114.1 and -86.5% at 20, 40 DAT and harvest stages, respectively. The decreasing WCE values with age of rice crop in SMR-no mulch rice was ascribed to the fact that at 20 DAT weeds were small and had low biomass despite of higher weed count. At 40 DAT and harvest stage, higher weed count was reflected in higher weed biomass also. A complete weed control achieved with polythene mulching in tomato by Anzalone *et al.* (2010) corroborates the current research findings.

Labour requirement for weeding

On account of higher weed count and weed biomass, 50% additional man days were required for two hand weedings in no mulch-SMR than no mulch-SWR rice (20 man days) (**Table 2**). Mulched treatments have little weed pressure as evident from the weed count and weed biomass (**Table 1**). On account of reduced weed count and weed biomass of mulched-SMR treatments, manual labour required for weeding was reduced by 15 times (2 labourers/ha).

Yield and water economy

Saturation moisture regime without mulching has resulted in significant reduction in grain yield (7.1%) as compared to SWR (4.79 t/ha) that were brought to statistically at par level with plastic mulching (**Table 3**). Same was the trend for straw yield also. Saturation moisture rice without mulch has resulted into 35% water savings over no mulch-SWR culture (**Table 3**). An additional 30% savings in irrigation water (15 cm) were brought up by plastic mulching with SMR as compared to SMR alone. Thus water productivity of SWR (47.9 kg/ha-cm) was enhanced by 43% with shifting to SMR. Further, SMR water productivity (68.5 kg/ha-cm) was enhanced by 35.8% with plastic mulching (93 kg/ha-cm). Savings of water due to reduced weed count and biomass was not assessed in the study. However, the savings in water due to mulching were due to combined effect of reduced evaporation and transpiration from weeds. They need to be partitioned through separate studies.

Economics

Economics of rice cultivation was assessed from enhanced yield, reduced water consumption, additional costs from plastic mulch and labour inputs for weeding/irrigation (**Table 4**). Cost of cultivation of transplanted rice with 5 cm SWR was ` 45000/ha. In SMR, additional costs for weeding (10 man days) and

Table 2. Weed control efficiency and labour requirements for weeding of rice as affected by mulching and moisture regime

Treatment	Weed control efficiency (%)			Labour requirement and their cost of weeding	
	20 DAT	40 DAT	At harvest	Man days	Cost (`/ha)
No mulch and saturation moisture rice (SMR)	-26.8	-114.1	-86.5	30	9000
Black polythene mulch and SMR	94.8	96.2	100.0	2	600
Transparent polythene mulch and SMR	94.2	94.9	100.0	2	600
No mulch and 5 cm standing water rice (SWR)	-	-	-	20	6000

Table 3. Water savings in rice as affected by plastic mulching and moisture regime

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Mean water use (cm)*	Water productivity (kg/ha-cm)
No mulch and saturation moisture (SM)	4.45	6.52	65	68.5
Black polythene mulch and SM	4.61	6.70	50	92.2
Transparent polythene mulch and SM	4.69	6.88	50	93.8
No mulch and 5 cm standing water (SW)	4.79	7.08	100	47.9
LSD (p=0.05)	0.190	0.312	10.3	4.29

*From transplanting to – harvest

Table 4. Economics of rice cultivation as affected by mulching and moisture regime

Treatment	Cost of cultivation (x10^3 `/ha)	Gross returns (x10^3 `/ha)	Net returns (x10^3 `/ha)	B -C ratio
No mulch and saturation moisture rice (SMR)	50.10	80.83	30.73	1.61
Black polythene mulch and SMR	64.10	83.60	19.50	1.30
Transparent polythene mulch and SMR	64.10	85.21	21.11	1.33
No mulch and 5 cm standing water rice (SWR)	45.00	87.16	42.16	1.94
LSD (p=0.05)	-	-	5.02	0.25

irrigations (7 man days) were incurred which increased cost of cultivation by ` 5100/ha over SWR. In plastic mulching-SMR treatments, additional cost of plastics (` 20,000/ha) and labour for its laying/careful planting (15 man days) were incurred while labour for weeding were reduced by 18 man days as compared to SWR rice and thus had ` 19,100/ha higher cultivation cost. Net income and benefit-cost (BC) ratio were highest with 5 cm SWR rice cultivation. Plastic mulching remained least profitable as compared to no mulch SWR and SMR treatments. The low income in plastic mulching was ascribed to higher costs incurred for plastics. In the current study, life of plastics was taken as one season. If we take higher life period for plastics (2-4 seasons), then their cost would decrease and could become more profitable.

Saturation moisture regime rice without polythene mulch saved water considerably with higher water productivity compared to 5 standing water rice but it encountered more weed pressure and yield penalities making it less profitable. Plastic mulching could contribute to the success of saturation moisture rice cultivation a possibility in future but its cost, durability and safer disposal at the end of day are causes of major concern. In organic farms, plastic mulches preferably bio-degradable may be more acceptable than herbicides. There is a need to reduce cost of plastics for use in rice culture and also need to evolve biodegradable plastics that makes their use more economical and ecologically benign. Use of plastic mulches would become profitable preposition, if irrigation water is priced that is most likely in near future and plastics would become handy in reducing evaporation water losses and weed loads.

REFERENCES

Anonymous. 2017. Government of India Ministry of Agriculture & Farmers Welfare Department of Agriculture, Cooperation & Farmers Welfare Directorate of Economics and Statistics: www.agricoop.nic.in & http:// eands.dacnet.nic.in. 511 p.

Ahlawat IPS, Gautam RC, Sharma AR, GajendraGiri, Ranbir Singh, Sharma SN, Rana KS and Gangaiah B. 2005.*A Practical Manual of Crop Production*. Division of Agronomy, IARI, New Delhi, 116 p.

AimrunWayayok, Mohd Amin MohdSoom, KhalinaAbdan and Umar Mohammed. 2014. Impact of mulch on weed infestation in System of Rice Intensification (SRI) farming. *Agriculture and Agricultural Science Procedia* **2**: 353–360.

Anzalone A, Cirujeda A, Aibar J, Pardo G and Zaragoza C. 2010. Effect of biodegradable mulch materials on weed control in processing tomatoes. *Weed Technology* **24**(3): 369–377.

Boumann BAM, Yang XG and Wang HQ. 2002. Aerobic rice (Han Dao): a new way of growing rice in water-short areas 12th ISCO Conference. Beijing, China.

Chapagain AK and Hoekstra AY. 2011.The blue, green and grey water footprint of rice from production and consumption perspectives. *Ecological Economics* **70** (4): 749-758.

DOES. 2018. Second Advance *Estimates of Food Grains, Oil Seeds and Other Commercial Crops 2018-19*. Directorate of Economics & Statistics Department of Agriculture, Cooperation and Farmers Welfare, 28-02-2019.

Duttarganvi Shantappa, Mahender Kumar, Desai BK, Pujari BT,Tirupataiah K, Koppalkar BG, Umesh MR, Naik MK and Yella Reddy K. 2016. Influence of establishment methods, irrigation water levels and weed management practices on growth and yield of rice (*Oryza sativa*). *Indian Journal of Agronomy* **61**(2): 174–178.

FAOSTAT. 2019. Crops. http://www.fao.org/faostat/en/?#data/ QC accessed on 02-05-2019. Food and Agriculture Organization of United Nations.

GOI (Government of India). 2009. *Background note for consultation meeting with Policy makers on review of National Water Policy*. Ministry of Water Resources. 50 p.

Gomez KA and Gomez AA. 1984. *Statistical Procedures for Agricultural Research*. John Wiley and Sons, Inc. London, UK, 2nd Edition.

Haefele SM, Woperies MCS, Ndiaye MK, BarroSF and Ouldisseelmou M. 2004. Internal nutrient efficiencies, fertilizer recovery rates and indigenous nutrient supply of irrigated lowland rice in sahelian West Africa. *Field Crops Research* **80**: 19–32.

Haibing He, Fuyu Ma mail, Ru Yang, Lin Chen, Biao Jia, Jing Cui, Hua Fan, Xin Wang and Li Li. 2013. Rice performance and water use efficiency under plastic mulching with drip irrigation. *Plos One* **8**(12): e83103. doi: 10.1371/ journal.pone.0083103.

Jackson ML. 1973. *Soil Chemical Analysis*, Prentice Hall Publication, New Delhi, p.184.

Kasirajan S and Ngouajio M. 2012. Polyethylene and biodegradable mulches for agricultural applications: a review. *Agronomy for Sustainable Development* **32**: 501–529.

Kent RJ and Johnson DE. 2001. Influence of flood depth and duration on growth of lowland rice weeds, Coˆte d'Ivoire. *Crop Protection* **20**(8): 691–694.

Peng SB, Bouman, BAM and Visperas RM. 2006. Comparison between aerobic and flooded rice in the tropics: agronomic performance in an eight-season experiment. *Field Crops Research* **96**: 252–259.

Sengupta Ahona. 2018. India already water stressed, Sees falling per capita capacity. *News 18*, March 6, 2018.

Indian Journal of Weed Science **51**(2): 203–205, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Sequential application of herbicides for weed management in rainfed lowland rice

G. Gangireddy, D. Subramanyam*, S. Hemalatha and B. Ramana Murthy
Department of Agronomy, S.V. Agricultural College, Tirupati, Andhra Pradesh 517 502, India
**Email: subbuagro37@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00042.X

Type of article: Research note

Received : 1 May 2019
Revised : 22 June 2019
Accepted : 25 June 2019

Key words
Rainfed lowland rice, Sequential application, Weed growth, Yield

ABSTRACT

A field experiment was conducted during rainy season of *(Kharif)* 2018 at Tirupati, Andhra Pradesh to find out the effect of sequential application of pre- and post-emergence herbicides on weed growth and yield of rainfed lowland rice. The present study has revealed that pre-emergence application of pendimethalin 1000 g/ha *fb* florpyrauxifen-benzyl 25 g/ha or halosulfuron-methyl 65.7 g/ha applied at 20 DAS resulted in the highest grain yield and economic returns as well as broad-spectrum weed control in rainfed lowland rice.

Rice (*Oryza sativa* L.) is an important food crop of India contributing 45% of the total food grain production. Transplanting in puddled soils with continuous land submergence is the most common method of rice crop establishment. Puddling causes clogging of macropores, breakage of soil aggregates and formation of subsurface shallow hardpans along with effective weed control due to standing water in the field. But, this technique is very laborious, cumbersome, expensive and time consuming. In this context, to overcome the problems associated with traditional rice cultivation, direct seeding of rice seems to be the viable alternative. Weeds are the major yield-limiting constraint in direct-seeded rice due to simultaneous germination of weeds and crop. The risk of yield loss from weeds in direct-seeded rice is greater than transplanted rice. Singh *et al.* (2005) reported that uncontrolled weed growth in direct-seeded rice, wet-seeded rice and transplanted rice reduced the grain yield by 75.8, 70.6 and 62.6%, respectively. Pre-emergence application of pendimethalin is recommended to control weeds in direct-seeded rice, but it does not control *Cyperus rotundus* and some of the broad-leaved weeds. Heavy weed infestation in direct-seeded rice from sowing to harvesting of rice crop leads to severe competition offered by weeds and sometimes complete crop failure. Hence, there is a need to evaluate sequential application of pre- and post-emergence herbicides for broad-spectrum weed control in direct-seeded rice with special reference to perennial sedge, *Cyperus rotundus*. Hence, the present investigation was carried out to evaluate the relative efficacy of some of the newly developed post-emergence herbicides for control of weeds in direct-seeded rice.

The field experiment was conducted duringrainy season of *(Kharif)* 2018 at wetland farm of S.V. Agricultural College, Acharya N. G. Ranga Agricultural University, Tirupati, Andhra Pradesh in rainfed lowland rice. The soil was sandy clay loam in texture having low organic carbon, slightly alkaline in reaction with low available nitrogen and medium in available phosphorus and potassium. The rice variety '*MTU-1010*'is a semi dwarf variety suitable for both aerobic and lowland conditions and matures within 120 days. It was sown at a spacing of 20 x 10 cm on 13August, 2018 with seed rate of 35 kg/ha by giving pre-sowing irrigation and it was grown under aerobic condition upto 40 DAS and then converted to lowland submergence for better growth and development. The crop was harvested on 14 November, 2018.The experiment was laidout in a randomized block design with twelve treatments and replicated thrice. The weed management practices consisted of sequential application of pre-emergence (PE) herbicides oxadiagryl, pendimethalin and pretilachlor 100, 1000 and 750 g/ha, each followed by post-emergence (PoE) application of penoxsulam + cyhalofop-p-butyl, florpyrauxifen-benzyl and halosulfuron-methyl each 130, 25, 67.5 g/ha; pre-emergence application of pendimethalin 1000 g/ha *fb* bispyribac-sodium 25 g/ha, two hand weeding at 20 and 40 DAS and unweeded check (**Table 1**). Uniform dose of 120 kg N, 60 kg P_2O_5 and 60 kg K_2O/ha was applied in the form of urea, single super phosphate and muriate of potash, respectively. Iron sulphate and zinc sulphate were applied at 50 and 25 kg/ha, respectively to overcome the deficiencies of iron and zinc in direct seeded rice as basal. Nitrogen was applied in three splits. One third dose of nitrogen along with entire dose of phosphorous and potassium was applied as basal. The remaining quantity of nitrogen was applied in two equal splits as top dressing at active tillering and at panicle initiation stage. The rest of the packages of practices were adopted as per recommendations of the Acharya N.G. Ranga Agricultural University. The required quantities of pre-and post-emergence herbicides were applied uniformly at one and 20 DAS, respectively, by using spray fluid at 500 L/ha with the help of battery operated knapsack sprayer fitted with flat fan nozzle. Weed density and dry weight were recorded randomly with the help of 0.25 m^2 quadrate. The data on weed density and dry weight were transformed to square root ($\sqrt{x+0.5}$) transformation to normalize their distribution. The yield attributing characters, *viz.* panicles/m^2, panicle length, total grains/panicle, filled grains/panicle, test weight, grain and straw yields were recorded at harvest.

The major weeds found in the experimental plots were *Cyperus rotundus* (55%), *Digitaria sanguinalis* (12%), *Commelina benghalensis* (7%), *Boerhavia erecta*. (5%), *Trichodesma indicum* (5%), *Dactyloctenium aegyptium* (3%), *Digera arvensis* (3%), *Cleome viscosa* (2%) and others (8%) in unweeded check plot. All the weed management practices significantly influenced the weed growth and yield of rainfed lowland rice (**Table 1**). The lowest density and dry weight of total weeds was recorded with pre-emergence application of pendimethalin 1000 g/ha *fb* florpyrauxifen-benzyl 25 g/ha, which was comparable with PRE application of pendimethalin 1000 g/ha *fb* halosulfuron-methyl 67.5 g/ha. The reduced density and dry weight of weeds in these weed management practices might be due to broad-spectrum and season long weed control because of sequential application of pre-and post-emergence herbicides.

Pre-emergence application of pendimethalin 1000 g/ha effectively controlled the weeds at early stages of crop growth and post-emergence application of florpyrauxifen-benzyl 25 g/ha effectively controlled the late coming weeds, including perennial sedge, *Cyperus rotundus* by disrupting the plant growth regulation process similar to synthetic auxin group of herbicides. The findings of the present study were in accordance with those of Epp *et al.* (2016) in rice and Gosh *et al.* (2017) in sugarcane. All the post-emergence herbicides did not showed any phytotoxicity to rice crop. Among the sequential application of herbicides tried, PE application of oxadiagryl 100 g/ha *fb* penoxsulam + cyhalofop-p-butyl 130 g/ha resulted in higher density and dry weight of total weeds, which was comparable with pre-emergence application of pretilachlor 750 g/ha *fb* penoxsulam + cyhalofop-p-butyl 130 g/ha. Post-emergence application of penoxsulam + cyhalofop-p-butyl 130 g/ha failed to control predominant weed *i.e. Cyperus rotundus* associated with direct-seeded rice compared to rest of the PoE herbicides. The highest density and dry weight of total weeds was observed with unweeded

Table 1. Effect of sequential application of pre- and post-emergence herbicides on weed growth, yield and economics of rainfed lowland rice

Treatment	Dose g/ha	Time of application (DAS)	Weed density (no/m^2)	Weed dry weight (g/m^2)	Panicles / m^2	Filled grains/ panicle	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Net returns (x10^3 `/ha)	B:C ratio
Oxadiargyl *fb* penoxsulam + cyhalofop-p-butyl	100+130	1 and 20	10.2(103)	18.0(324)	104	60.67	17.30	1.75	2.68	3.17	1.11
Pendimethalin *fb* penoxsulam + cyhalofop-p-butyl	1000+130	1 and 20	9.3(87)	16.4(269)	113	65.67	17.70	1.93	2.82	5.92	1.20
Pretilachlor *fb* penoxsulam + cyhalofop-p-butyl	750+130	1 and 20	9.9(97)	16.9(284)	113	65.67	17.70	1.84	2.72	4.93	1.17
Oxadiargyl *fb* florpyrauxifen-benzyl	100+25	1 and 20	5.4(29)	10.9(119)	166	73.33	19.43	2.36	3.36	15.88	1.57
Pendimethalin *fb* florpyrauxifen-benzyl	1000+25	1 and 20	4.7(21)	9.8(94)	201	82.33	21.20	3.52	4.64	36.47	2.30
Pretilachlor *fb* florpyrauxifen-benzyl	750+25	1 and 20	5.3(28)	10.8(116)	152	72.67	19.00	2.10	3.01	11.21	1.41
Oxadiargyl *fb* halosulfuron-methyl	100+67.5	1 and 20	5.2(26)	10.5(109)	181	75.00	19.70	2.67	3.69	17.35	1.55
Pendimethalin *fb* halosulfuron-methyl	1000+67.5	1 and 20	4.6(21)	10.0(99)	197	82.00	21.17	3.43	4.56	30.76	1.96
Pretilachlor *fb* halosulfuron-methyl	750+67.5	1 and 20	5.2(27)	10.6(112)	196	81.33	20.63	3.28	4.43	28.66	1.91
Pendimethalin *fb* bispyribac-sodium	1000+25	1 and 20	8.0(64)	12.9(167)	149	71.33	18.07	2.05	2.98	9.26	1.32
Two hand weedings	-	20 and 40	7.5(56)	162.7(13)	184	76.67	20.00	2.82	3.88	20.89	1.67
Unweeded control	-	-	12.3(150)	22.0(484)	78	53.00	16.80	0.92	1.58	-8.37	0.67
LSD (p=0.05)	-	-	0.49	1.04	12.3	5.21	1.29	0.29	0.34	4.96	0.15

Figures in parentheses are original values; *fb:* followed by check, which was significantly higher than rest of the weed management practices due to favorable conditions available for establishment of all the categories of weeds.

Different weed management practices imposed in rainfed lowland rice exerted significant influence on panicles/m^2, number of filled grains/panicle and 1000-grain weight. The highest stature of all the yield parameters were recorded with PE application of pendimethalin 1000 g/ha *fb* florpyrauxifen-benzyl 25 g/ha applied at 20 DAS, which were comparable with PE application of pendimethalin 1000 g/ha *fb* halosulfuron-methyl 67.5 g/ha. The increase in growth and yield attributes might be attributed due to reduction in competition offered by weeds on crop plants for growth resources. The highest grain (3.52 t/ha) and straw yield (4.64 t/ha) of rice was obtained with pre-emergence application of pendimethalin 1000 g/ha *fb* florpyrauxifen-benzyl 25 g/ha, which was comparable with pre-emergence application of pendimethalin 1000 g/ha *fb* halosulfuron-methyl 67.5 g/ha and both the weed management practices were significantly higher than rest of the weed management practices due to increased stature of yield components, *viz.* number of productive tillers/ m^2, number of filled grains/panicle and test weight as result of maintenance of weed free environment. The combined effect of all the yield components in these weed management practices resulted in enhanced grain and straw yield of rainfed lowland rice. The findings of the present study are in accordance with those of Pattar *et al*. (2005) in direct-seeded rice. Among the sequential application of pre-and post-emergence herbicides, the lowest values of the above said yield components and yield were recorded with pre-emergence application of oxadiagryl 100 g/ha *fb* penoxsulam + cyhalofop-p-butyl 130/ha. Decrease in grain and straw yield of rainfed lowland rice in unweeded check plots was 73.8 and 66.1% respectively, compared to best weed management practice of pre-emergence application of pendimethalin 1000 g/ha *fb* florpyrauxifen-benzyl 25 g/ha. Singh *et al*. (2005) also reported that uncontrolled weed growth in direct-seeded rice resulted in reduction in grain yield by 75.8%. The highest net returns (` 36468/ha) and benefit-cost ratio (2.30) were obtained with pre-emergence application of pendimethalin 1000 g/ha *fb* florpyrauxifen-benzyl 25 g/ha, due to increased yield and reduced cost of weed management practice.

REFERENCES

Epp JB, Alexander AL, Balko TW, Buysse AM, Brewster WK, Bryan K, Daeuble JF, Fields SC, Gast RE, Green RA and Irvine NM. 2016. The discovery of Arylex™ active and Rinskor™ active: Two novel auxin herbicides. *Bio-organic and Medicinal Chemistry* **24**: 362–371.

Gosh A, Mondal D, Bera S, Poddar R, Kumar A, Bandopadhyay P and Gosh RK. 2017. Halosulfuron-methyl: For effective control of *Cyperus* spp. in sugarcane (*Saccharum officinarum* L.) and it residual effect on succeeding greengram (*Vigna radiate* L.). *Journal of Crop and Weed* **13**(2): 167–174.

Pattar P, Reddy S and Masthana BG. 2005. Evaluation of halosulfuron-methyl for weed control in puddled direct-seeded rice (*Oryza sativa*). *Indian Journal of Agricultural Sciences* **75** (4): 230–231.

Singh S, Singh G, Singh VP and Singh AP. 2005. Effect of establishment methods and weed management practices on weeds and rice in rice-wheat cropping system. *Indian Journal of Weed Science* **37**(1&2): 51–57.

Indian Journal of Weed Science **51**(2): 206–208, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Integration of post-emergence herbicide application with hand weeding for managing weeds in transplanted rice

N.V. Kashid*

Agricultural Research Station, Vadgaon Maval, Pune 412 106, Maharashtra, India

**Email: kashidnv@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00043.1

Type of article: Research note

Received : 6 April 2019
Revised : 22 May 2019
Accepted : 24 May 2019

Key words

Bispyribac-sodium, Integrated weed management, Transplanted rice

ABSTRACT

A field experiment was conducted during *Kharif* seasons of 2015 to 2017 for three years at Agricultural Research Station, Vadgaon Maval, Pune, Maharashtra to find out the economical methods of weed control in transplanted rice. Post-emergence application of bispyribac-sodium 0.020 kg/ha (PoE) at 21 days after transplanting (DAT) followed by (*fb*) hand weeding at 45 DAT has effectively managed weeds in transplanted rice and produced the highest net returns (` 70107/ha) with higher B:C ratio (2.3) having lower weed index (2.83) and higher weed control efficiency (87.74 %).

Rice (*Oryza sativa* L.) is a staple food for more than half of the world population, providing energy for about 40% of the world population. Weed infestation during the early stages of crop growth is one of the major factors responsible for low productivity of transplanted rice.

Yield reduction in transplanted rice due to weeds was reported to be 28-45% (Raju and Reddy 1995, Nandal *et al*. 1999, Singh *et al.* 2003 Rao and Nagamani 2010). Weeds also increase the cost of cultivation, reduce input efficiency, interfere with agricultural operations and impair quality. Pre-emergence herbicides such as pretilachlor, butachlor, oxadiargyl and anilofos are being frequently used for effective management of weeds in transplanted rice (Sureshkumar *et al.* 2016) but the window of their application is very narrow (1-3 days after transplanting). The need of post-emergence herbicides is often realized by the growers to combat weeds emerging during later growth stages of crop. This situation warrants for initiating research efforts to evaluate and identify suitable post-emergence herbicides. Hence, present study was carried out to evaluate the efficacy and economics of different post emergence herbicides in managing weeds in transplanted rice.

A field experiment was carried out during *Kharif* 2015, 2016 and 2017 at Agricultural Research Station, Vadgaon Maval, Pune, Maharashtra. The experiment consisted of nine treatments comprising of unweeded check, weed free and weed control treatments, *viz*. 2,4-D EE 0.85 kg/ha, post-emergence application (PoE) at 21 days after transplanting (DAT), metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha, PoE at 21 DAT, bispyribac-sodium 0.020 kg/ha PoE at 21 DAT, 2,4-D EE 0.85 kg/ha PoE at 21 DAT *fb* hand weeding at 45 DAT, metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha, PoE at 21 DAT *fb* hand weeding at 45 DAT, bispyribac-sodium (0.020 kg/ha PoE at 21 DAT) *fb* hand weeding at 45 DAT and one hand weeding at 25 DAT. The experiment was laid out in randomized block design with three replications. The rice variety '*Phule Samruddhi*' was transplanted at 20 x 15 cm distance. All the herbicides were sprayed by using water 500 l/ha with the help of sprayer fitted with flat fan nozzle. The weed samples were taken in each of the treatment and were oven dried for about one week. The weed biomass was recorded by weighing the dried weed samples. All the other recommended package of practices, except weed control, were followed to raise the transplanted rice.

Effect on weeds

In the experimental plots dominant weed flora consisted of monocots as *Echinochloa colona* and *Echinochloa crus-galli* among grasses; *Cyperus iria* and *Cyperus difformis* among sedges while dicots like *Eclipta alba, Alternanthera philoxeroides, Bergia capensis* and *Sphenoclea zeylancia*.

Significantly lowest weed biomass and weed index with highest weed control efficiency were recorded in the weed free treatment (**Table 1** and **2**). The second best treatment was bispyribac-sodium 0.020 kg/ha, PoE at 21 DAT *fb* one hand weeding at 45 days having lowest weed biomass (19.80 g/m^2) with higher weed control efficiency (87.74%) and lower weed index (2.83). The highest weed biomass was recorded in unweeded check. Similar result were reported by Schmidt *et al.* (1999) and Das *et al.* (2015).

Effect on rice

The highest mean grain and straw yields of paddy (5.62 t/ha and 6.27 t/ha, respectively) were obtained in the weed free treatment. It was at par with

Table 1. Weed biomass, weed control efficiency and weed index in transplanted rice as affected by different weed management treatments

Treatment	Weed biomass (g/m^2)				Weed control efficiency (%)				Weed index			
	2015	2016	2017	Pooled	2015	2016	2017	Pooled	2015	2016	2017	Pooled
2,4-D EE 0.85 kg/ha PoE	62.0	71.1	59.6	64.2	63.0	55.2	62.3	60.2	38.3	39.3	37.5	38.4
Bispyribac-sodium 0.020 kg/ha PoE	57.6	66.8	52.7	59.1	65.6	58.0	66.6	63.4	30.4	31.5	28.8	30.2
Metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE	59.7	69.8	57.6	62.3	64.4	56.1	63.7	61.4	34.3	36.6	34.1	35.0
2,4-D EE 0.85 kg/ha PoE *fb* 1 HW (45 DAT)	37.0	39.1	35.4	37.2	77.9	75.3	77.5	76.9	21.4	22.6	21.1	21.7
Bispyribac-sodium 0.020 kg/ha PoE *fb* 1 HW (45 DAT)	19.5	21.1	18.8	19.8	88.4	86.7	88.1	87.7	2.3	2.1	4.1	2.8
Metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE *fb* 1 HW (45 DAT)	29.7	31.8	27.8	29.8	82.3	80.1	82.5	81.6	15.4	16.8	13.8	15.3
Hand weeding (25 DAT)	94.5	91.8	91.4	92.6	43.6	42.0	42.1	42.6	56.8	50.4	55.8	54.3
Weed free	0	0	0	0	100.0	100.0	100.0	100.0	0	0	0	0
Unweeded check	167.7	159.6	158.6	161.9	0	0	0	0	72.6	73.1	72.2	72.6
LSD (p=0.05)	5.4	9.6	8.5	7.4	2.66	4.17	3.65	3.26				

PoE –Post-emergence; DAT=Days after transplanting; *fb* = Followed by

Table 2. Grain and straw yields as affected by weed management treatments

Treatment	Grain yield (t/ha)				Straw yield (t/ha)			
	2015	2016	2017	Pooled	2015	2016	2017	Pooled
2,4-D EE 0.85 kg/ha PoE	3.49	3.24	3.66	3.46	3.91	3.63	4.10	3.88
Bispyribac-sodium 0.020 kg/ha PoE	3.94	3.65	4.18	3.93	4.42	4.09	4.68	4.40
Metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE	3.73	3.37	3.87	3.66	4.18	3.78	4.34	4.10
2,4-D EE 0.85 kg/ha PoE *fb* 1 HW (45 DAT)	4.44	4.13	4.62	4.40	4.97	4.63	5.17	4.93
Bispyribac-sodium 0.020 kg/ha PoE *fb* 1 HW (45 DAT)	5.52	5.24	5.63	5.46	6.19	5.76	6.30	6.08
Metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE *fb* 1 HW (45 DAT)	4.79	4.44	5.07	4.77	5.37	4.97	5.68	5.34
Hand weeding (25 DAT)	2.44	2.65	2.59	2.56	2.73	2.97	2.90	2.87
Weed free	5.66	5.33	5.87	5.62	6.35	5.87	6.58	6.27
Unweeded check	1.55	1.43	1.63	1.54	1.70	1.56	1.79	1.68
LSD (p=0.05)	0.62	0.64	0.66	0.64	0.70	0.71	0.74	0.71

PoE –Post-emergence; DAT=Days after transplanting; *fb* = Followed by

Table 3. Economics of transplanted rice cultivation as affected by weed management treatments

Treatment	Gross returns (x10^3 \`/ha)				Net returns (x10^3 \`/ha)				B:C ratio			
	2015	2016	2017	Pooled	2015	2016	2017	Pooled	2015	2016	2017	Pooled
2,4-D EE 0.85 kg/ha PoE	78.08	75.79	85.65	79.84	24.76	23.95	32.33	27.01	1.5	1.5	1.6	1.5
Bispyribac-sodium 0.020 kg/ha PoE	88.27	85.42	97.75	90.48	34.03	32.67	43.51	36.74	1.7	1.6	1.8	1.7
Metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE	83.44	78.90	90.59	84.31	30.38	27.33	37.53	31.75	1.6	1.5	1.7	1.6
2,4-D EE 0.85 kg/ha PoE *fb* 1 HW(45 DAT)	99.39	96.68	107.99	101.35	43.55	42.33	52.57	46.15	1.8	1.8	1.9	1.8
Bispyribac-sodium 0.020 kg/ha PoE *fb* 1 HW (45 DAT)	123.54	122.14	131.52	125.74	66.78	67.71	75.81	70.10	2.2	2.2	2.4	2.3
Metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha PoE *fb* 1 HW (45 DAT)	107.26	103.74	118.50	109.84	51.68	49.66	63.34	54.89	1.9	1.9	2.1	2.0
Hand weeding (25 DAT)	54.64	61.97	60.51	59.04	-6.25	7.56	5.03	3.99	1.0	1.1	1.1	1.1
Weed free	126.75	124.33	137.26	129.45	65.81	63.83	75.06	68.24	2.1	2.1	2.2	2.1
Unweeded check	34.74	33.30	38.12	35.39	-17.37	-17.32	-13.99	-16.23	0.7	0.7	0.7	0.7
LSD (p=0.05)	14.07	15.11	15.49	14.84	14.07	15.11	15.49	14.84				

PoE –Post-emergence; DAT=Days after transplanting; *fb* = Followed by the bispyribac-sodium (0.020 kg/ha, PoE at 21 DAT) *fb* one hand weeding 45 days with equivalent grain (5.42 t/ha) and straw (6.08 t/ha) yields. These result were in close conformity with those of Yadav *et al.* (2009).

Economics

Weed free treatment recorded significantly the highest gross returns (` 129454/ha) (**Table 3**) and was at par with bispyribac-sodium 0.020 kg/ha, PoE at 21 DAT *fb* one hand weeding at 45 DAT with gross returns of ` 1,25,740/ha. Significantly the highest net returns (` 70,107/ha) and B:C ratio (2.3) were obtained with bispyribac-sodium (0.020 kg/ha, PoE at 21 DAT) *fb* one hand weeding at 45 DAT, which was at par with the weed free treatment (**Table 3**).

It can be concluded that in transplanted rice, effective management of weeds with higher economical returns may be obtained with post-emergence application of bispyribac-sodium 0.020 kg/ha at 21 DAT *fb* one hand weeding 45 DAT.

REFERENCES

Das R, Bera S, Pathak A and Mandal MK. 2015. Weed management in transplanted rice through bispyribac sodium 10% SC and its effect on soil microflora and succeeding crop blackgram. *International Journal of Current Microbiology and Applied Sciences* **4**(6): 681–688.

Nandal DP, Om H and Dhiman SD. 1999. Efficacy of herbicides applied alone and in combinations against weeds in transplanted rice. *Indian Journal of Weed Science* **31**: 239–242.

Raju RA and Reddy MN. 1995. Performance of herbicide mixtures for weed control in transplanted rice. *Indian Journal of Weed Science* **27**: 106–107.

Rao AN and Nagamani A. 2010. Integrated Weed Management in India. *Indian Journal of Weed Science.* **42**(3&4): 123–135.

Schmidt LA, Scherder EF, Wheeler CC, Rutledge JS, Talbert RE and Baldwin FL. 1999. Performance of V10029 (bispyribac-sodium) in rice weed control programme. *Proceedings Southern Weed Science Society* **52**: 49–50.

Singh G, Singh VP, Singh M and Singh SP. 2003. Effect of anilofos and triclopyr on grassy and non-grassy weeds in transplanted rice. *Indian Journal of Weed Science* **35**: 30–32.

Sureshkumar R, Ashoka Reddy Y and Ravichandran S. 2016. Effects of weeds and their management in transplanted rice- A review. *International Journal of Research in Applied, Natural and Social Sciences* **4**(11): 165–180.

Yadav DB, Yadav A and Punia SS. 2009. Evaluation of bispyribac-sodium for weed control in transplanted rice. *Indian Journal of Weed Science* **41**(1&2): 23–27.

Indian Journal of Weed Science **51**(2): 209–213, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Weed floristic diversity in diversified cropping systems under mid-hill conditions of Himachal Pradesh

Gurpreet Singh*, Pawan Pathania, S.S. Rana and S.C. Negi

Department of Agronomy, Forages and Grassland Management, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh 176 062, India

**Email: gurpreetpitho@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00044.3

Type of article: Research note

Received : 12 April 2019
Revised : 19 June 2019
Accepted : 21 June 2019

Key words
Cropping systems
Shannon Weir Index
Weed density
Weed diversity

ABSTRACT

The present study was carried out in a continuing experiment at the Bhadiarkhar farm of the CSK HPKV. Eight cropping systems were evaluated during 2016-17 for their effects on weed menace under mid hill conditions of Himachal Pradesh. There were 24 weed species, which invaded different cropping systems. During *Kharif*, *Ageratum* sp. (28%) *Cynodon dactylon* (20%) and *Commelina benghalensis* (19%) were the predominant weeds. In *Rabi*, *Phalaris minor* (63%) was the most dominating weed followed by *Coronopus didymus* (10%) and *Spergula arvensis* (6%). In traditional 'rice-wheat' system 14 species in *Rabi* and 8 in *Kharif* season were found associated and species richness varied with diversification of systems. In *Rabi*, the highest diversity of weed species was in rice-wheat system and in *Kharif* weed flora was more diverse in okra, turmeric and colocasia based systems and was lower in rice-based systems. During *Kharif*, *Cynodon dactylon* had the highest important value index (IVI) irrespective of the cropping system followed by *C. benghalensis*. *Monochoria vaginalis* was the important weed in rice-based cropping systems while *Ageratum* sp. was important in upland systems. *Ageratum* sp., *Polygonum* sp. and *C. dactylon* invaded the experimental field both during *Kharif* and *Rabi*. In *Rabi*, *P. minor* had the highest IVI in all the cropping systems.

Rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), and maize (*Zea mays* L.) are the three main food crops in India, fundamental to national food security. Together these crops occupy 42.2% of the gross cropped area in India and contribute 85.7% to the total food grain production (Anonymous 2015). The crop productivity in India is low for rice (3.66 t/ha), maize (2.45 t/ha), and wheat (3.15 t/ha) as compared to their global averages of 4.53, 5.52 and 3.26 t/ha, respectively (Anonymous 2016).The mid-hill regions of Himachal Pradesh account for more than 41.01% of the cropped area of the state. The 'rice-wheat' cropping system is prevalent and occupies large area in these regions. Despite enormous growth of rice-wheat system, reports on stagnation in the productivity, with possible decline in production in future, have raised doubts on its sustainability (Ramanjaneyulu *et al.* 2006). Weeds are a major biological constraint that limits the production of rice by 10-100% and wheat by 10-60% (Yaduraju *et al.* 2015).Rotation composed of a diversity of crops with different life cycles is critical component of integrated weed management (Garrison *et al.* 2014). Cropping systems influence the crop productivity by altering the soil physical properties and changing the weed spectra in agricultural systems (Farooq and Nawaz 2014). Crop diversity can improve crop growth (Kirkegaard and Hunt 2010), thereby increasing crop competitiveness and tolerance to weeds (Anderson 2011). Therefore, an appraisal of weed floristic association in prominent crop sequences was done to have an effective strategic planning for weed management.

The present study was carried out in a continuing experiment at the Bhadiarkhar farm of the university. The experiment was started in *Kharif* 2014. The weed density was recorded in eight cropping sequences [C_1- 'rice – wheat', C_2- 'rice – pea – summer squash', C_3- 'okra – radish – onion', C_4- 'turmeric – pea – summer squash', C_5- 'rice – lettuce – potato', C_6- 'rice – palak – cucumber', C_7- 'rice – broccoli – radish', C_8- 'colocasia – pea + coriander'] during 2016-17 in RBD with four replications after 2 years. All the crops in different cropping systems were raised in accordance with recommended package of practices. The soil (0–15 cm) was acidic in reaction (pH 5.3), silty clay loam in texture, high in organic carbon (1.1%), medium in available N (362.4 kg/ha), very high in available P (73.6 kg/ha) and low in available K (115.2 kg/ha) at the initiation of the experiment (2014-15). The experimental field was under general 'rice–wheat' system prior to the commencement of the experiment.

Observations on species-wise weed count were taken at monthly interval at two representative locations within each plot using 25 x 25 cm quadrate. The mean weed count so obtained was converted into number per square metre by multiplying with factor 16. The data were subjected to statistical analysis using the techniques of analysis of variance as described by Gomez and Gomez (1984). Weed density data was square-root transformed ($\sqrt{x+0.5}$) prior to analysis. The treatment differences were compared at 5 per cent level of significance. Important value index was used to determine the overall importance of each species in a cropping sequence. In calculating this index, the percentage values of the relative frequency [Total no. of occurrence of the species/no. of occurrence of all the species x 100], relative density [Total no. of individuals of the species/Number of individuals of all the species x 100] and relative abundance [Total number of individuals of a species in all quadrats/ Total no. of individuals of all species in all quadrats x 100] were summed up together and the value was designated as IVI of the species.

Weed flora association

During *Kharif*, the total weed count was maximum in September in okra, turmeric and colocasia, but in rice it was fairly uniform throughout the season probably due to standing water (**Figure 1**). Weed count in rice-based cropping systems varied from 80 to 200/m^2 but in other cropping systems it was higher than 200/m^2 at all the observations.It varied from 200 to 650/m^2. *Ageratum* sp. was the most dominant weed in *Kharif,* contributing 28% to total weed flora. *Cynodon dactylon* and *Commelina benghalensis* were next in dominance constituting 20% and 19% of total weed flora, respectively. *Brassica* sp., *Monochoria vaginalis*, *Cyperus* sp. and other weeds constituted 11, 10, 6 and 6% of total *Kharif* weed flora. *Brassica* sp., *Fimbristylis* sp., *Artimisia argyi* and *Trifolium repens* were observed for some time in the season. *Polygonum alatum*, *Scirpus juncoides*, *Eleocharis* sp., *C.benghalensis* and *Phyllanthus niruri* had sporadic appearance.

In *Rabi*, total weed count was maximum in December under most of systems, which decreased progressively due to imposition of hand weeding by mid-January (**Figure1**). From January onwards, densities of total weeds ranged from 0 to 300/m^2 in different systems. In *Rabi*, *P.minor* was the most dominating weed contributing 63% to total weed flora. *C. didymus* (10%), *S.rvensis* (6%), *Ageratum* sp. (4%), *T. repens* (3%), *C.dactylon* (3%), *Polygonum* sp. (4%) and other weeds (7%) were also observed. *Lathyrus aphaca*, *Ageratum* sp., *C. dactylon*, *Polygonum hydropiper*, *C. didymus*, *P. minor*, *S. rvensis*, *V. sativa*, *P. alatum*, *T. repens* were prevalent throughout the *Rabi* season. *Bidens pilosa* and *A. ludoviciana* have shown their occurrence at termination of the season. *Artimisia argyi*, *Anagallis arvensis* and *Stellaria media* were noticed on some of the observations.

Weed diversity indices

Shannon weir index: There were 24 weed species found growing in different cropping systems. Such a higher diversity in maize based cropping systems was also reported by Suresha *et al.* (2015). In traditional 'rice-wheat' system 14 species in *Rabi* and 8 in *Kharif* season were found associated. 11 to 12 weed species were common in traditional 'rice-wheat' system and the alternative cropping systems in *Rabi*. Whereas, 7 to 8 weed species were common in the traditional and new cropping systems in *Kharif*. In *Rabi*, only one weed species was different in 'turmeric – pea – summer squash' and 'rice – broccoli – radish' compared to traditional 'rice –

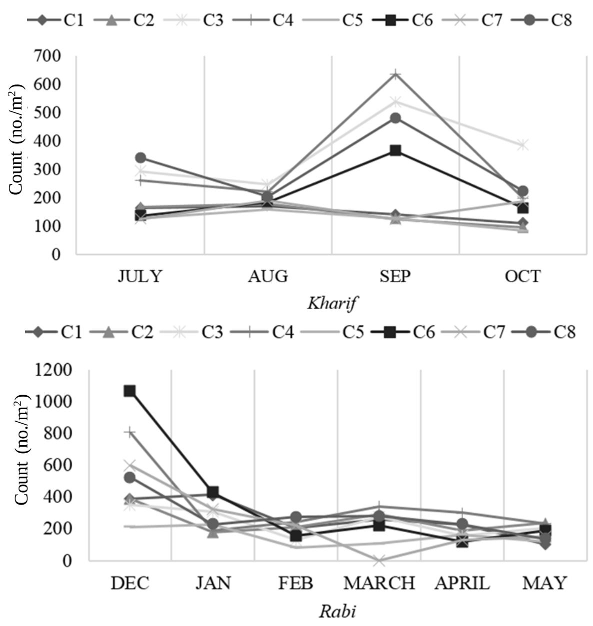


Figure1. Total weed count (no./m^2) in *Kharif* and *Rabi*

wheat' system. Whereas, in *Kharif* the variation was more and 1 to 3 weed species were different from 'rice – wheat' system in new cropping systems.

With diversification of rice-based cropping system, variation in infestation of weed flora occurred **(Table 1**). In *Rabi*, *A. arvensis* was new in 'turmeric – pea – summer squash' and *B. pilosa* in 'rice – broccoli – radish'. In *Kharif*, *Scirpus juncoides* in 'rice – pea – summer squash', *Polygonum alatum*, *T.repens* and *Fimbristylis* sp. in 'okra – radish - onion' and 'turmeric – pea – summer squash', *Eleocharissp.* in 'rice – palak – cucumber', *P. alatum* and *T. repens* in 'rice – broccoli – radish' and 'colocasia – pea + coriander' and *P. niruri* in 'colocasia – pea + coriander' were the species that were absent in traditional 'rice-wheat' system but were present in the mentioned (new) systems. From the same location in maize based cropping systems, Suresha *et al.* (2015) have also reported similar effect of cropping systems on weed floristic association.

Table 1. Cropping systems influence on shannon weir index of *Kharif* and *Rabi* weeds

Cropping system	No. of weed species common as C_1		No. of weed species present in new system but absent in C_1	
	Rabi	*Kharif*	*Rabi*	*Kharif*
C_1 Rice – wheat	14	8	-	-
C_2 Rice – pea – summer squash	11	8	0	1
C_3 Okra – radish - onion	11	7	0	3
C_4 Turmeric – pea – summer squash	12	7	1	3
C_5 Rice – lettuce – potato	12	7	0	0
C_6 Rice – palak – cucumber	12	8	0	1
C_7 Rice – broccoli – radish	12	7	1	2
C_8 Colocasia – pea + coriander	11	7	0	3

During *Kharif*, *C. dactylon* was most important weed having high important value index (IVI) irrespective of the cropping system followed by *C. benghalensis*. *M. vaginalis* was the important weed in rice-based cropping systems while *Ageratum* sp. was important in other cropping systems having higher IVI (**Table 2**). *Brassica* sp., *C. benghalensis, Cyprus* sp. and *P. hydropiper* were the other important weeds having higher important value index in *Kharif*. Guleria *et al.* (2018) also reported all these weeds as more aggressive in rice in the rice – wheat cropping system.

Some of the weeds like *Ageratum* sp., *Polygonum* sp. and *C. dactylon* those invaded the experimental field during *Kharif* were also present during *Rabi* **Table 2** and **3**. Suresha *et al.* (2015) also found *Ageratum houstonianum*, *A. conyzoides*, *Polygonum* sp. and *Galinsoga parviflora* invading maize based systems both during *Kharif* and *Rabi*. In *Rabi*, *P. minor* had the highest IVI in all the cropping systems. *C. didymus*, *Spergulla arvensis* and *T. repens* were other important weeds having higher IVI (**Table 3**).

Effect of cropping systems

Cropping sequences gave significant variation in the count of *M. vaginalis* (**Table 4**). *Monochoria* sp. was found growing in rice-based cropping systems only and all were comparable to each other in influencing the population of this weed. It was absent in okra (okra-radish-onion), turmeric (turmeric-pea-summer squash) and colocasia (colocasia-pea+coriander). *Ageratum* sp., a weed of upland situations was significantly higher under 'okra-radish-onion', 'colocasia-pea+coriander' and 'turmeric-pea-summer squash' cropping systems,

Table 2. IVI (important value index) of weed species in *Kharif*

Weed species	Rice – wheat	Rice – pea – summer squash	Okra – radish – onion	Turmeric – pea – summer squash	Rice – lettuce – potato	Rice – palak – cucumber	Rice – broccoli – radish	Colocasia – pea + coriander
Cyprus sp.	28.4	26.9	27.4	22.7	15.5	26.6	10.1	24.6
Polygonum alatum	0.0	0.0	7.2	7.3	0.0	0.0	4.7	6.1
Trifolium repens	0.0	0.0	6.7	6.8	0.0	0.0	4.7	7.2
Fimbristylis sp.	0.0	0.0	4.4	12.8	0.0	0.0	0.00	0.0
Monochoria vaginalis	62.1	76.3	0.0	0.0	70.5	43.8	57.6	0.0
Polygonum hydropiper	8.6	14.8	5.6	6.8	18.2	7.9	17.7	10.9
Ageratum sp.	30.3	8.6	102.2	88.1	18.2	12.4	55.1	105.1
Cynodon dactylon	57.9	51.0	49.9	57.1	95.9	50.9	65.3	49.0
Echinochloa sp.	5.2	7.0	5.6	10.7	0.0	7.5	0.00	13.1
Brassica sp.	55.1	61.9	32.0	25.4	28.9	48.0	47.5	27.0
Commelinabenghalensis	52.2	47.9	59.1	62.3	52.8	99.2	37.2	51.3
Scirpus juncoides	0.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0
Eleocharis sp.	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0
Phyllanthus niruri	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7

where upland crops *viz*. okra, colocasia and turmeric, respectively had occupied the land.

There was significant variation in the count of *Cyperus* sp. (*C. iria*, *C. difformis* and *C. esculentus*) due to cropping systems. 'Rice – broccoli – radish' remaining at par with 'rice – lettuce – potato' had significantly lower count of *Cyperus* sp. as compared to other cropping systems. Farooq and Nawaz (2014) had also reported significant influence of cropping systems in changing the weed spectra in agricultural systems.

Cropping systems also brought about significant variation in the count of *P. alatum,* but the weed had very low intensity. The weed was found only in upland cropping systems where okra, turmeric and colocasia were grown. It was absent in rice. *Fimbristylis* sp. count was also affected significantly due to cropping systems but the weed was present in low intensity. The population of the weed was significantly higher in 'rice – palak – cucumber' cropping system. But this cropping system was at par with 'rice – pea – summer squash' and 'turmeric – pea – summer squash' cropping systems. The population of *T. repens*, *P. hydropiper*, *C. dactylon*, *Echinochloa* sp., *Brassica* sp. and *C.benghalensis* was not significantly influenced due to cropping systems probably owing to their sporadic occurrence.

Phalaris minor was the most troublesome weed in *Rabi* and cropping systems brought about significant variation in its count. The count of *P. minor* was significantly higher in 'rice – palak – cucumber' and 'turmeric – pea – summer squash' and was lowest in okra – radish – onion (**Table 5**). *S. media* had low population but was significantly affected due to cropping systems. Its population was higher in upland rotations in contrast to the lowland where rice was cultivated during *Kharif* under

Table 3. IVI (important value index) of weed species in *Rabi*

Weed species	Rice – wheat	Rice – pea – summer squash	Okra – radish – onion	Turmeric – pea – summer squash	Rice – lettuce – potato	Rice – palak – cucumber	Rice – broccoli – radish	Colocasia – pea + coriander
Phalaris minor	110.7	107.7	60.5	151.1	109.3	168.5	153.0	102.7
Stellaria media	6.4	0.0	7.6	14.0	4.4	3.2	3.6	9.0
Spergulla arvensis	29.1	32.5	47.5	10.8	18.7	11.8	17.4	28.0
Polygonum alatum	12.4	17.6	20.0	8.2	21.5	7.4	10.0	14.1
Trifolium repens	14.9	17.0	22.7	17.9	11.8	20.4	10.0	27.1
Coronopus didymus	16.7	48.1	52.8	26.5	42.4	27.0	20.8	52.7
Vicia sativa	43.5	19.1	14.7	12.0	18.5	8.9	6.9	21.4
Polygonum hydropiper	15.6	14.7	10.7	10.5	17.1	6.1	10.0	14.7
Ageratum sp.	3.9	13.8	40.3	18.6	11.7	24.6	28.0	9.7
Cynodon dactylon	5.5	17.9	17.4	20.9	25.4	14.8	19.6	10.6
Lathyrus aphaca	9.7	4.5	5.8	3.2	12.0	4.2	3.6	9.9
Artemisia argyi	14.1	7.1	0.0	0.0	0.0	0.0	0.0	0.0
Anagallis arvensis	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0
Commelina benghalensis	3.1	0.0	0.0	3.2	0.0	3.2	0.0	0.0
Avena ludoviciana	14.5	0.0	0.0	0.0	7.3	0.0	10.8	0.0
Bidens pilosa	0.0	0.0	0.0	0.0	0.0	0.0	6.2	0.0

Table 4. Species-wise mean count (no./m^2) of weeds in *Kharif*.

Cropping system	*Cyprus sp.*	*Polygonum alatum*	*Trifolium repens*	*Fimbristylis* sp.	*Monochoria vaginalis*	*Polygonum hydropiper*	*Ageratum* sp.	*Cynodon dactylon*	*Echinochloa* sp.	*Brassica* sp.	*Commelina benghalensis*
Rice – wheat	2.8(7)	0.7(0)	0.7(0)	0.7(0)	4.8(24)	1.2(1)	2.3(8)	4.6(21)	0.9(0)	4.5(20)	4.0(17)
Rice – pea – summer squash	3.7(15)	0.7(0)	1.5(3)	1.8(3)	5.7(33)	2.0(4)	2.9(9)	4.7(23)	1.0(1)	4.8(23)	3.4(13)
Okra – radish - onion	3.9(17)	1.3(2)	1.3(1)	1.0(1)	0.7(0)	1.1(1)	10.7(115)	6.1(38)	1.1(1)	4.3(20)	6.4(49)
Turmeric – pea – summer squash	3.3(11)	1.4(2)	1.1(1)	1.4(3)	0.7(0)	1.1(1)	9.2(87)	6.7(45)	1.7(3)	3.5(14)	6.7(51)
Rice – lettuce – potato	1.6(2)	0.7(0)	0.7(0)	0.7(0)	4.7(22)	1.5(3)	1.6(3)	5.8(34)	0.7(0)	2.4(6)	3.5(13)
Rice – palak – cucumber	4.1(18)	0.7(0)	1.5(2)	2.2(5)	4.7(23)	1.2(1)	3.4(12)	5.4(29)	1.3(1)	5.1(26)	6.9(54)
Rice – broccoli – radish	1.3(1)	0.9(0)	0.9(0)	0.7(0)	4.8(23)	1.9(4)	3.7(21)	5.2(26)	0.7(0)	3.3(17)	2.9(12)
Colocasia – pea + coriander	3.4(12)	1.1(1)	1.3(1)	0.7(0)	0.7(0)	1.5(2)	10.0(102)	5.7(34)	2.0(4)	2.9(13)	5.9(37)
LSD (p=0.05)	1.5	0.5	NS	1.0	1.0	NS	2.8	NS	NS	NS	NS

*Figures in the parentheses are the means of original values. Data transformed to square root transformation ($\sqrt{x+0.5}$)

Table 5. Species-wise mean count (no./m^2) of weeds in *Rabi*

Cropping system	*Phalaris minor*	*Stellaria media*	*Spergula arvensis*	*Trifolium repens*	*Coronopus didymus*	*Vicia sativa*	*Ageratum* sp.	*Cynodon dactylon*	*Lathyrus aphaca*	*Artemisia argyi*	*Anagallis arvensis*	*Avena ludoviciana*
Rice – wheat	12.4(155)	1.1(1)	4.3(23)	2.8(7)	2.3(7)	6.2(40)	1.0(1)	1.2(1)	1.7(4)	2.4(7)	0.7(0)	2.5(7)
Rice – pea – summer squash	11.6(135)	0.7(0)	4.4(24)	2.8(8)	6.3(44)	3.0(9)	2.3(6)	2.7(8)	1.0(1)	1.0(1)	0.7(0)	0.7(0)
Okra – radish - onion	7.7(62)	1.5(2)	6.4(44)	3.6(13)	7.1(51)	2.6(7)	5.8(34)	3.0(9)	1.3(1)	0.7(0)	0.7(0)	0.7(0)
Turmeric – pea – summer squash	16.4(272)	2.6(7)	1.9(5)	3.0(9)	4.4(19)	2.3(5)	3.3(12)	3.5(14)	0.9(0)	0.7(0)	0.9(0)	0.7(0)
Rice – lettuce – potato	9.2(84)	0.9(0)	2.4(6)	1.8(3)	4.5(22)	2.4(6)	1.1(1)	3.3(11)	1.8(3)	0.7(0)	0.7(0)	1.1(1)
Rice – palak – cucumber	17.3(303)	0.9(0)	2.0(5)	3.4(11)	3.9(16)	1.7(3)	4.0(16)	2.5(7)	1.0(1)	0.7(0)	0.7(0)	0.7(0)
Rice – broccoli – radish	13.5(186)	0.9(0)	2.4(7)	1.7(3)	2.7(7)	1.3(1)	3.7(16)	2.7(9)	0.9(0)	0.7(0)	0.7(0)	1.7(3)
Colocasia – pea + coriander	12.0(145)	1.7(3)	4.3(22)	4.5(20)	6.7(54)	3.4(12)	1.8(3)	1.3(2)	2.0(4)	0.7(0)	0.7(0)	0.7(0)
LSD (p=0.05)	2.7	1.0	2.0	0.8	2.0	1.3	1.7	NS	NS	0.7	NS	0.9

Figures in the parentheses are the means of original values. Data transformed to square root transformation ($\sqrt{x+0.5}$)

submergence. The highest population of *S. arvensis* was recorded in 'okra – radish – onion'. Significantly lower population of Trifolium repens was recorded in 'rice – lettuce – potato' and 'rice – broccoli – radish'. All the new cropping systems resulted in significantly lower population of *V. sativa* as compared to conventional 'rice – wheat' cropping system. 'Rice – broccoli – radish' remaining at par with 'rice – palak – cucumber', 'turmeric – peas – summer squash' and 'rice – lettuce – potato' resulted in significantly lower count of *V. sativa*. There was significant variation in the count of *Ageratum* sp. due to cropping systems. But in the 'rice – wheat' system there was invasion of *Artimissia arzvi* and *A. ludoviciana* significantly higher than all the new cropping systems.

REFERENCES

Anderson RL. 2011. Synergism: a rotation effect of improved growth efficiency. *Advances in Agronomy* **112**: 205–226.

Anonymous. 2015. *The Pocket Book on Agricultural Statistics.* Directorate of Economics and Statistics Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi, India, p. 128.

Anonymous. 2016. FAO (Food and Agriculture Organization). *Save and Grow in Practice: Maize,Rice, and Wheat. A Guide to Sustainable Cereal Production.* Food and Agriculture Organization of the United Nations, Rome.

Farooq M and Nawaz A. 2014. Weed dynamics and productivity of wheat in conventional and conservation rice-based cropping systems. *Soil & Tillage Research***141**: 1–9.

Garrison AJ, Miller AD, Ryan MR, Roxburgh SH and Shea K. 2014. Stacked crop rotations exploit weed-weed competition for sustainable weed management. *Weed Science***62**: 166–176

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

Guleria G, Rana SS and Singh AK. 2018. Surveillance and distribution of different weeds in transplanted rice as influenced by integrated plant nutrition system (IPNS) in rice-wheat cropping system in Hilly area. *Journal of Pharmacognosy and Phytochemistry* **7**(4): 2788–2793.

Kirkegaard JA and Hunt JR. 2010. Increasing productivity by matching farming system management and genotype in water-limited environments. *Journal of Experimental Biology* **61**: 4129–4143.

Ramanjaneyulu AV, Sharma R and Giri G. 2006. Weed shift in rice-based cropping systems - a review. *Agricultural Reviews* **27**(1): 73–78.

Suresha, Kumar A, Rana SS, Negi SC and Kumar S. 2015. Assessment of yield and nutrient losses due to weeds in maize based cropping systems. *Himachal Journal of Agricultural Research* **41**(1): 42–48.

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.

Indian Journal of Weed Science **51**(2): 214–216, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Enhancing productivity and profitability through herbicidal weed control in sesame

M.P. Sahu, Namrata Jain*, Uma Bermaiya, Vinamarta Jain and Ashwan Kumar
Department of Agronomy, JNKVV, Jabalpur, Madhya Pradesh 482 004, India
**Email:* *j_namrata1@rediffmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00045.5

Type of article: Research note

Received : 17 February 2019
Revised : 29 April 2019
Accepted : 1 May 2019

Key words
Fenoxaprop
Pendimethalin
Quizalofop-ethyl
Weed control efficiency
Weeds

ABSTRACT

A field experiment was conducted at Research Farm of College of Agriculture, Tikamgarh, Madhya Pradesh during *Kharif*, 2016 to find out the suitable herbicides for weed control in sesame. The experiment was laid out in a randomized block design with twelve treatments, *viz*. pre-emergence application of pendimethalin at 750 g/ha, post-emergence herbicides; quizalofop-ethyl at 40 and 50 g/ha, fenoxaprop-ethyl at 75 and 100 g/ha, pendimethalin at 750 g/ha *fb* quizalofop at 40 and 50 g/ha, pendimethalin at 750 g/ha *fb* fenoxaprop at 75 and 100 g/ha, pendimethalin *fb* one hand weeding at 20 DAS, two hand weeding at 15 and 30 DAS and weedy check. Hand weeding twice at 15 and 30 DAS recorded the lowest intensity and dry weight of total weeds (2.74 g/m^2) followed by pendimethalin *fb* one hand weeding (3.35 g/m^2) and these treatments significantly reduced the intensity and dry weight of total weeds over rest of the herbicidal treatments and weedy check. Pre-emergence application of pendimethalin *fb* post-emergence, quizalofop and fenoxaprop significantly reduced the weed dry weight over alone application of pendimethalin. The net profit was the highest under two hand weeding (` 35,099/ha) followed by pendimethalin 750 g/ha *fb* one hand weeding (` 30,365/ha) and pendimethalin *fb* fenoxaprop-ethyl at 100 g/ha (` 27,811/ha), whereas the B:C ratio was higher under the application of pendimethalin 750 g/ha *fb* fenoxaprop-ethyl 100 g/ha (2.72).

Sesame is one of the most ancient oilseed crops grown and used by mankind. In Madhya Pradesh, sesame is grown during *Kharif* season in an area of 424 thousand ha area with total production of 1,24,383 tonnes and an average productivity of 293 kg/ha (IOPEPC 2017). One of the causes of lower productivity of sesame in the region is severe weed competition. The competitional stress of weeds on crop for nutrients, water, light and space are mainly responsible for poor yield of sesame. Prevalence of high temperature and frequent rainfall during the crop season coupled with slow plant growth particularly, during early growth stages favour luxuriant weed growth and causes about 50-75% reduction in seed yield of sesame (Dungarwal *et al.* 2003). The period from 15-30 DAS is the most critical period of crop-weed competition in sesame (Badkul *et al*. 2015). Therefore, it is essential to control weeds during the initial growth period. Besides the rising cost of labour, which contributes major share of cultivation charges of sesame, need to be replaced by an alternate effective and economical measure, which can help to boost the production per unit area of the crop (Punia *et al.* 2001). Weed control by using herbicides is one of the easier, time saving and economical alternative as compared to manual weeding. Chemical herbicides are applied as an alternative to hand weeding + hoeing and they are selective, cost effective, easy to apply and have persistence that can be managed. Therefore, the present experiment was carried out to find out the suitable herbicide for weed control in sesame.

Field studies were conducted during *Kharif* season of 2016 at the research farm of College of Agriculture, Tikamgarh situated at 24^0 45" N latitude, 78^0 53" E longitude and an altitude of 426.7 meter above the mean sea level. The soil of the experimental field was sandy loam in texture, neutral in reaction (pH 7.30) having medium in organic carbon (0.88 %) and available N (225 kg/ha), medium in phosphorus (17.70 kg/ha), and high in available K (415.6 kg/ha). The total rainfall received during growing season was 825 mm. The experiment consisted of twelve treatments comprised of pre-emergence application of pendimethalin at 750 g/ha, post-emergence herbicides; quizalofop-ethyl at 40 and 50 g/ha, fenoxaprop-ethyl at 75 and 100 g/ha, pendimethalin at 750 g/ha *fb* quizalofop at 40 and 50 g/ha, pendimethalin at 750 g/ha *fb* fenoxaprop at 75 and 100 g/ha, pendimethalin *fb* one hand weeding at 20 DAS, two hand weeding at 15 and 30 DAS and weedy check in a randomized block design with three replications. Sesame variety '*TKG-306*' was sown in row 30 cm apart, using 5 kg/ha seeds. Crop was fertilized 60 kg N, 40 kg P_2O_5 and 20 kg K_2O/ha as basal dose through urea, single super phosphate (SSP) and muriate of potash, respectively. Pendimethalin as pre-emergence, quizalofop-ethyl and fenoxaprop-ethyl was applied at 20 DAS with hand knapsack sprayer fitted with flat-fan nozzle at spray volume of 500 l/ha. Weed density and weed dry weight were recorded at 40 DAS with the help of 1 x 1 m quadrate by throwing randomly at three places in each plot. Weeds were removed and species wise weed dry weight was recorded after drying in hot air oven (60 ± 1^0C for 24 hours). Weed control efficiency was also calculated at harvest. The economics was calculated on the basis of prevailing market rates of agriculture produced and cost of cultivation.

Weed flora

Sesame was infested by wide range of monocot and dicot weeds. The major weed species in the experimental plots were *Cyperus rotundus*, *Cynodon dactylon*, *Eclipta alba*, *Leucus aspera* and *Mollugo pentaphylla*. There was predominance of monocot weeds in experimental field as they constituted the higher relative density of 65.48% as compared to dicot weeds (34.52%). In the monocot weeds, the density of *C. rotundus* was the highest (57.52%) followed by *C. dactylon* (7.96%) whereas among the dicots, *Eclipta alba* was more (14.76%) followed by *M. pentaphylla* (12.56 %) and *L. aspera* (7.20%).

Effect on weeds

Results revealed that hand weeding twice at 15 and 30 DAS recorded the lowest population of total weeds (4.58/m^2) followed by pendimethalin *fb* one hand weeding at 20 DAS (5.48/m^2). Pre-emergence application of pendimethalin 750 g/ha *fb* hand weeding at 20 DAS (5.48/m^2) found significantly superior than its alone application and followed application with post-emergence herbicides; quizalofop and fenoxaprop. Post-emergence application of quizalofop at 40 and 50 g/m^2 and fenoxaprop at 75 and 100 g/ha alone and its application after pre-emergence pendimethalin at 750 g/ha proved significantly superior over pendimethalin alone. Weedy check recorded significantly the highest weed population (8.36/m^2). Similarly, hand weeding twice at 15 and 30 DAS recorded the lowest dry weight of total weeds (2.74 g/m^2) followed by pendimethalin *fb* one hand weeding (3.35 g/m^2), and these treatments significantly reduced the dry weight of total weeds over rest of the herbicidal treatments and weedy check.

The maximum weed control efficiency (WCE) was recorded under hand weeding twice (89.45%) followed by pendimethalin 750 g/ha *fb* hand weeding at 20 DAS (84.86%), and these treatments were at par with pre-emergence application pendimethalin at 750 g/ha *fb* post-emergence fenoxaprop-ethyl at 100 g/ha at 20 DAS (Sukhadia *et al*. 2004). Among herbicidal treatments, pre-emergence application of pendimethalin *fb* fenoxaprop-ethyl at 75 and 100 g/ha and pendimethalin *fb* quizalofop-ethyl at 40 and 50 g/ha registered significantly higher WCE over pendimethalin and quizalofop alone, however, alone application of pendimethalin, quizalofop and fenoxaprop were at par with respect to WCE (**Table 1**).

Effect on crop

All the weed control treatments produced significantly higher number of capsules per plant, number of seeds per capsule, test weight and seed yield than weedy check. Two hand weeding at 15 and 30 DAS resulted in significantly the highest value in capsules/plant, test weight and seed yield over rest of the treatments. Similar findings were reported by Baskaran and Solaimalai (2002). Among the herbicides, alone application of pre-emergence pendimethalin at 750 g/ha, post-emergence quizalofop and fenoxaprop produced significantly lower number of capsules per plant, number of seed per capsule, test weight and seed yield over application of pre-emergence pendimethalin followed by post-emergence herbicides; quizalofop and fenoxaprop. Pendimethalin followed by hand weeding at 20 DAS produced significantly higher number of capsules/plant, number of seeds/capsule, test weight and seed yield over all the herbicidal treatments except pendimethalin followed by fenoxaprop at 75 and 100 g/ha. However, the lowest number of capsules per plant, number of seeds per capsule, test weight and seed yield was recorded under weedy check (**Table 1**).

The net monetary returns (NMR) under each treatment was determined by subtracting the cost of cultivation from gross monetary returns (GMR) of each treatment. The marginal profit of ` 8540/ha was obtained when crop was not weeded throughout the

Table 1. Effect of different herbicides on weed density, weed dry weight, weed control efficiency, yield attributes, seed yield, net monetary return and benefit cost ratio of sesame

Treatment	Weed density (no./m^2)	Weed dry weight (g/m^2)	Weed control efficiency (%)	No. of capsules/ plant	No. of seeds/ capsule	Test weight (g)	Seed yield (kg/ha)	Net monetary returns (x10^3 `/ha)	B:C Ratio
Pendimethalin 750 g/ha as pre-emergence	7.10(49.9)	8.75(76.1)	42.26	18.13	41.93	2.70	290	13.96	2.01
Quizalofop-ethyl 40 g/ha at 20 DAS	7.26(52.2)	8.08(64.7)	42.32	18.50	42.67	2.72	308	15.56	2.13
Quizalofop-ethyl 50 g/ha at 20 DAS	7.10(50.0)	7.78(59.9)	45.71	18.77	43.13	2.73	324	16.87	2.21
Fenoxaprop-ethyl 75 g/ha at 20 DAS	7.02(48.8)	7.60(57.3)	48.96	19.00	43.33	2.75	335	17.82	2.27
Fenoxaprop-ethyl 100 g/ha at 20 DAS	6.89(47.1)	7.33(53.2)	56.53	19.33	44.00	2.76	353	19.05	2.32
Pendimethalin 750 g/ha *fb* quizalofop-ethyl 40 g/ha at 20 DAS	6.22(38.3)	6.93(47.5)	62.49	21.20	47.33	2.78	435	25.49	2.64
Pendimethalin 750 g/ha *fb* quizalofop-ethyl 50 g/ha at 20 DAS	6.07(36.5)	6.70(44.4)	66.46	21.77	48.00	2.79	443	25.97	2.65
Pendimethalin 750 g/ha *fb* fenoxaprop-ethyl 75 g/ha at 20 DAS	6.00(35.6)	6.43(40.8)	68.10	22.03	48.67	2.81	454	26.93	2.70
Pendimethalin 750 g/ha *fb* fenoxaprop-ethyl 100 g/ha at 20 DAS	5.90 (34.3)	6.08(36.4)	76.56	22.27	49.33	2.82	468	27.81	2.72
Pendimethalin 750 g/ha *fb* hand weeding at 20 DAS	5.48(29.5)	3.35(10.7)	84.86	23.27	51.00	2.87	524	30.36	2.62
Hand weeding at 15 and 30 DAS	4.58(20.5)	2.74(7.0)	89.45	25.17	56.67	2.88	610	35.10	2.60
Weedy check	8.36 (69.8)	10.4(111.4)	0.00	16.27	38.67	2.68	212	8.58	1.72
LSD (p=0.05)	0.59	0.98	15.09	1.74	3.12	0.11	73.30	-	-

*values in parentheses are original values

crop season whereas it was the highest under two hand weeding (` 35,099/ha) followed by pendimethalin 750 g/ha *fb* one hand weeding (` 30,365/ha) and pendimethalin *fb* fenoxaprop-ethyl at 100 g/ha (` 27,811/ha). B:C ratio was higher under the application of pendimethalin 750 g/ha *fb* fenoxaprop-ethyl 100 g/ha (2.72) followed by pendimethalin 750 g/ha *fb* fenoxaprop-ethyl 75 g/ha (2.70) and pendimethalin 750 g/ha *fb* quizalofop ethyl 50 g/ha (2.65). Hand weeding twice and pendimethalin *fb* one hand weeding registered B:C ratio of 2.60 and 2.62, respectively, whereas it was the lowest (1.72) under weedy check. These results are in accord with Mathukia *et al*. (2015).

REFERENCES

Bedigian D and Vander Maesen LJG. 2003. Slimy leaves and oily seeds; Distribution and Use of Sesamum spp. And *Ceratotheca sesamoides* (Pedaliaceae) in Africa. pp. 271–274. In: *International Workshop, Nairobi, Prota Foundation Wageningen*. The Netherland.

Dungarwal HS, Chaplat PC and Nagda BL. 2003. Integrated weed management in sesame. *Indian Journal Weed Science* **35**(3&4): 236.

Jain Badkul Anamika, Jain Namrata and Chaurasia SK. 2015. Effect of weed management practices on yield of rainfed Sesame. pp. 84–85. In: *National Seminar on Weather and Climate Risks in Agriculture under Changing Climate Management and Mitigation* from March 12-13, 2015 held at JNKVV, College of Agriculture, Tikamgarh, Madhya Pradesh.

IOPEPC 2017. www.iopepc.org

Mathukia RK Sagarka BL and Jatav CN. 2015. Integrated weed management in summer sesame. *Indian Journal of Weed Science* **47**(2): 150–152.

Salunkhe DK, Chavan JK, Adsule RN and Kadam SS. 1992. *World Oilseeds: Chemistry, Technology and Utilization*. New York: Van Nostrand. Reinhold

Sukhadia NM, Ramani BB, Mathukia RK and Khanpara VD. 2004. Integrated weed management in *Kharif* sesame. *Indian Journal of Weed Science* **36**(3&4): 239–242.

Indian Journal of Weed Science **51**(2): 217–219, 2019

Print ISSN 0253-8040 Online ISSN 0974-8164

Response of mulching and weed management practices on weed control, yield and economics of garlic

M.T. Sanjay*, G.N. Dhanapal, P. Nagarjun and A. Sandeep

University of Agricultural Sciences (B), MRS, Hebbal, Bengaluru, Karnataka 560 024, India

**Email: mt.sanjay@gmail.com*

Article information

DOI: 10.5958/0974-8164.2019.00046.7

Type of article: Research note

Received : 15 February 2019
Revised : 21 April 2019
Accepted : 7 May 2019

Key words
Garlic
Integrated weed management
Mulching
Oxadiargyl

ABSTRACT

A field experiment was conducted during rainy season of *(Kharif)* 2014 and 2015 at Main Research Station, Hebbal, Bengaluru to know the bio-efficacy of different herbicides against weeds and their effect on growth, yield of garlic and to study the integrated impact of mulching and herbicides on weed growth and to know phytotoxicity effect, if any. The experiment was laid out in a split-plot design with ten treatments, comprising with and without paddy straw mulch 5.0 t/ha in main-plot and weed management methods like pendimethalin at 1.0 kg/ha, oxyflurofen at 0.22 kg/ha, oxadiargyl at 0.14 kg/ha, manual weeding twice at 20 and 40 DAS and weedy check in sub-plot. Results revealed that among weed management practices, significantly higher bulb yield was obtained in oxadiargyl 0.14 kg/ha (6.6 t/ha in 2014 and 6.2 t/ha in 2015), at par with manual weeding (6.5 t/ha in 2014 and 6.0 t/ha in 2015), due to lower weed density and dry weight resulting in higher net returns and benefit:cost ratio.

Garlic (*Allium sativum* L.) belonging to the family Amaryllidaceae, is the second most widely cultivated crop in this family other than onion. It consists of an underground bulb and above ground vegetative part, which also comprises of a flat as well as slender leaves. It has fibrous root system and is frost hardy. India is the second largest producer of garlic in the world next to China. It is cultivated commercially throughout tropical and subtropical belt of the world. It is one of the important cash crop of India. It is usually grown between the months of October-May, during which the weather is cool and dry that favours its growth and yield. Garlic crop is highly vulnerable to weed infestation due to its slow initial growth, non-branching habit, sparse foliage, shallow root system, frequent irrigation and high fertilizer application. Manual weeding is very difficult due to narrow row spacing of this crop besides non-availability of labour and increased cost involved in it. Yield loss in garlic due to weed competition was upto 94.8% (Anonymous 2009). Sometimes due to shortage of labour and unexpected rains, hand weeding and mechanical operations are more often either delayed or all left together. In such situations, the integrated weed management practice becomes much more important. Therefore, the studies were conducted with and without mulching along with pre-emergence herbicides to provide broad-spectrum weed control and to obtain higher garlic yield.

The field experiment was conducted during rainy season of *(Kharif)* 2014 and 2015 at Main Research Station, Hebbal, Bengaluru to know the bio-efficacy of different herbicides against weeds and their effect on growth and yield of garlic, and to study the integrated impact of mulching on weed growth and phytotoxicity effects. The experiment was laid out in a split-plot design with ten treatments, comprising without paddy straw mulch and paddy straw mulch at 5.0 t/ha in main-plot and weed management methods, *viz.* pre-emergence application of pendimethalin at 1.0 kg/ha, oxyflurofen at 0.22 kg/ha, oxadiargyl at 0.14 kg/ha, manual weeding twice at 20 and 40 DAS and weedy check in sub-plot.

Garlic was planted at a spacing of 15 × 10 cm. The gross plot size was 3 × 3 m. The data on species wise weed count in a quadrate of 50 × 50 cm were collected at 75 DAP (days after planting). From this, density of major weed species/m^2 (sedge, grasses and broad-leaf weeds) was worked out. The, dry weight of weeds' category- sedge, grasses and broad-leaf weeds (g/m^2) was also collected at 75 DAP. The data on weed density and dry weight were analyzed using transformation of square root of $(\sqrt{x+1})$ and log of $(\sqrt{x+2})$, depending on the variability. At harvest, the data on bulb yield, the economics of weed management practices were also worked out. The data collected on different traits was statistically analyzed using the standard procedure and the results were tested at five per cent level of significance as given by Gomez and Gomez (1984).

Weed flora

Major weed flora observed in the experimental plots were *Cyperus rotundus,* (among sedges), *Echinochloa crus-galli, Cynodon dactylon* (among grasses), whereas, among broad-leaf weeds, *Ageratum conyzoides, , Acanthospermum hispidum, Borreria articularis, Euphorbia hirta* and *Spilanthus acmella* were major weeds at 75 DAP. Among the weed species, the density of *E. crus-galli* and *S. acmella* were higher than other weed species, indicating their dominance from the beginning of the crop cycle in both the years.

Weed density (no./m^2) and dry weight (g/m^2)

At 75 DAP, the herbicides treatments were significantly superior as compared to weedy check with regards to weed density and dry weight. In weedy check the density of broad leaf weeds was higher followed by grasses and sedges at 75 DAP in 2014 and 2015 (**Table 1** and **2**). Hand weeding treatment recorded significantly lower weed density and weed dry weight compared to other treatments. Among the weed management treatments pre-emergence spraying of oxadiargyl at 0.14 kg/ha recorded the lower weed density and weed dry weight compared to other treatments in both the years, indicating the necessity of herbicides to manage complex weed flora in garlic. Interaction of the treatments was found non-significant. These findings are in conformity to Rahman *et al.* (2012) in garlic, Hussain *et al.* (2008) and Patel *et al.* (2011) in onion.

Phytotoxicity

None of the herbicides caused phyto-toxicity to garlic in terms of yellowing, curling, epinasty, hyponasty and wilting symptoms during both the years.

Bulb yield and weed control efficiency

Among herbicides, significantly higher bulb yield was obtained in oxadiargyl 0.14 kg/ha (6.6 t/ha in 2014 and 6.2 t/ha in 2015), which were on a par with manual weeding (6.5 t/ha in 2014 and 6.0 t/ha in 2015) as a result of more number of bulbils, bulb weight and reduced weed density and dry weight as reflected on the bulb yield **Table 3**. The bulb yield (1.1

Table 1. Effect of integrated weed management on weed density and weed dry weight in garlic at 75 DAP during 2014

Treatment	Weed density (no./m^2)				Weed dry weight (g/m^2)			
	Sedges+	Grasses+	BLW#	Total#	Sedge +	Grasses+	BLW#	Total#
Without paddy straw mulch	2.7(6.8)	3.6(12.7)	1.5(30.3)	1.7(49.8)	1.9(3.0)	2.6(5.0)	1.1(12.5)	1.3(20.5)
With paddy straw mulch 5.0 t/ha	2.7(6.8)	3.4(11.3)	1.4(29.0)	1.7(47.0)	1.9(3.0)	2.4(4.3)	1.0(11.0)	1.2(18.2)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	0.04	NS
Pendimethalin 1.0 kg/ha pre-emergence	2.9(7.7)	3.5(11.3)	1.5(31.6)	1.8(50.6)	2.1(3.4)	2.5(4.3)	1.1(11.5)	1.3(19.3)
Oxyflurofen 0.223 kg/ha pre-emergence	2.7(6.5)	3.8(13.5)	1.5(31.6)	1.8(51.6)	1.9(2.9)	2.6(4.8)	1.1(10.8)	1.3(18.5)
Oxadiargyl 0.14 kg/ha pre-emergence	2.3(4.9)	3.1(8.4)	1.4(21.8)	1.6(35.1)	1.6(1.6)	2.1(2.3)	1.0(8.0)	1.1(11.9)
Twice manual weeding at 20 and 40 DAS	1.9(3.0)	2.7(6.2)	1.2(14.3)	1.4(23.4)	1.3(0.5)	1.8(0.8)	0.7(2.2)	0.9(3.5)
Weedy check	3.6(12.0)	4.6(20.7)	1.7(48.8)	1.9(81.4)	2.7(6.3)	3.5(10.4)	1.4(25.2)	1.6(41.9)
LSD (p=0.05)	0.8	0.7	0.17	0.14	0.5	0.4	0.15	0.13

Data analysed using transformation, # = log ($\sqrt{x+2}$), + = square root ($\sqrt{x+1}$), values within the parentheses are original values
BLW = Broad-leaf weeds, DAS = Days after sowing

Table 2. Effect of integrated weed management on weed density and weed dry weight in garlic at 75-DAP during 2015

Treatment	Weed density (no./m^2)				Weed dry weight (g/m^2)			
	Sedges+	Grasses+	BLW#	Total#	Sedge +	Grasses+	BLW#	Total#
Without paddy straw mulch	3.0(8.5)	3.8(14.7)	1.5(40.1)	1.8(63.4)	2.2(4.5)	2.8(6.7)	1.2(19.0)	1.4(30.2)
With paddystraw mulch 5.0 t/ha	2.9(8.2)	3.8(14.2)	1.5(38.9)	1.7(61.3)	2.2(4.2)	2.8(6.3)	1.2(18.3)	1.4(28.8)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Pendimethalin1.0 kg/ha pre-emergence	3.2(9.5)	3.4(12.0)	1.6(44.6)	1.8(66.1)	2.4(5.0)	2.6(5.1)	1.3(19.6)	1.5(29.7)
Oxyflurofen 0.223 kg/ha pre-emergence	2.9(7.9)	4.3(18.0)	1.6(39.0)	1.8(64.8)	2.1(3.6)	3.0(7.1)	1.2(16.6)	1.4(27.3)
Oxadiargyl 0.14 kg/ha pre-emergence	2.5(5.5)	3.4(10.5)	1.4(30.3)	1.7(46.3)	1.8(2.4)	2.4(3.7)	1.1(11.1)	1.3(17.2)
Twice manual weeding at20 and 40 DAS	2.2(4.0)	3.1(8.6)	1.2(17.0)	1.5(29.6)	1.5(1.4)	2.1(2.6)	0.8(4.8)	1.0(8.8)
Weedy check	4.0(15.0)	4.9(23.4)	1.8(66.8)	2.0(105.2)	3.2(9.2)	4.0(14.0)	1.6(41.1)	1.8(64.3)
LSD (p=0.05)	0.7	0.9	0.3	0.2	0.5	0.5	0.3	0.2

Data analyzed using transformation, # = log ($\sqrt{x+2}$), + = square root ($\sqrt{x+1}$), values within the parentheses are original values
BLW = Broad-leaf weeds

Table 3. Effect of integrated weed management on bulb yield and weed control efficiency of garlic during 2014 and 2015

Treatments	10 bulb weight (g)		No. of bulbils/plant		Bulb yield (t/ha)		WCE (%)	
	2014	2015	2014	2015	2014	2015	2014	2015
Without paddy straw mulch	44.5	42.1	6.1	5.7	5.3	4.8	-	-
With paddy straw mulch 5.0 t/ha	45.8	43.1	6.5	6.0	5.4	4.8	-	-
LSD (p=0.05)	NS	NS	NS	0.2	NS	NS		
Pendimethalin 1.0 kg/ha pre-emergence	48.0	43.4	5.8	4.8	6.1	5.5	54.1	53.9
Oxyflurofen 0.223 kg/ha pre-emergence	48.7	46.7	6.3	5.8	6.3	5.7	55.8	57.5
Oxadiargyl 0.14 kg/ha pre-emergence	53.3	51.5	7.8	7.8	6.6	6.2	71.5	73.2
Twice manual weeding at 20 and 40 DAS	51.8	49.3	7.2	7.0	6.5	6.0	91.8	86.3
Weedy check	24.0	22.2	4.5	3.9	1.1	0.6	0.0	0.0
LSD (p=0.05)	7.2	1.5	1.4	0.2	0.3	0.6	NA	NA

Cost of herbicides: pendimethalin 30 EC – ` 450/700 ml; oxadiargyl 80 WP – ` 248/35 g; oxyflurofen – 570/100 ml; herbicide application cost - ` 500/ha. Garlic selling price – ` 35/kg of bulbils.

Table 4. Economics of integrated weed management in garlic

Treatment	Net returns (x10^3 `/ha)		B:C ratio	
	2014	2015	2014	2015
Without straw mulch + pendimethalin at 1.0 kg/ha pre-emergence	161.65	141.53	4.2	3.8
Without straw mulch + oxyflurofen at 0.223 kg/ha pre-emergence	162.21	149.83	4.2	3.9
Without straw mulch + oxadiargyl at 0.14 kg/ha pre-emergence	176.86	164.88	4.4	4.2
Without straw mulch + two manual weeding at 20 and 40 DAP	170.83	154.36	4.1	3.8
Without straw mulch + weedy check	-9.43	-26.51	0.8	0.4
With straw mulch + pendimethalin at 1.0 kg /ha pre-emergence	167.45	141.59	4.3	3.8
With straw mulch + oxyflurofen at 0.223 kg /hapre-emergence	173.26	147.72	4.4	3.9
With straw mulch + oxadiargyl at 0.14 kg /ha pre-emergence	181.18	169.12	4.5	4.3
With straw mulch + two manual weeding at 20 and 40 DAP	170.87	154.77	4.0	3.7
With straw mulch + weedy check	-11.15	-25.54	0.8	0.5

t/ha and 0.6 t/ha during 2014 and 2015 respectively,) was very low in weedy check. Use of straw mulch had no significant influence on the bulb yield. The interaction of straw mulch and weed management practices was also non-significant. Similar trend of results was obtained in weed control efficiency.These results are in accordance with Prakash *et al*. (2000) and Vermani *et al*. (2001).

Economics

Use of herbicides was cheaper than hand weeding. Higher B:C ratio was obtained in oxadiargyl 0.14 kg/ha with and without rice straw mulch (4.5 and 4.4 in 2015 and 4.3 and 4.2 in 2015). Whereas, lower B:C ratio was obtained in weedy check (0.8 in 2014 and 0.5 in 2015). This result was obtained due to effective weed management at critical stages by integration of effective pre-emergence herbicides along with mulching which resulted in higher bulb yield with reduced cost of cultivation **Table 4**. Similar findings have been also reported by Vermani *et al*. (2001).

It was concluded that oxadiargyl at 0.14 kg/ha effectively controlled the weeds and produced significantly higher bulb yield and fetched higher B:C ratio.

REFERENCES

Anonymous. 2009. Crop-weed competition studies in onion and garlic. pp. 21–22. In: *Annual Report 2008-09*. Directorate of Onion and Garlic, Indian Council of Agricultural Research, Rajgurunagar, Distt. Pune, Maharashtra.

Gomez KA and Gomez AA. 1984. *Statistical Procedure for Agricultural Research*, John Wiley and Sons Inc. New York, United States of America.

Hussain Z, Marwat KB, Alishah SI, Arifulla SA and Khan NM. 2008. Evaluation of different herbicides for weed control in onion (*Allium cepa* L.). *Sarhad Journal of Agriculture* **24**(3): 453–456.

Patel TU, Patel CL, Patel DD, Thanki DD, Patel PS and Jat RA. 2011. Effect of weed and fertilizer management on weed control and productivity of onion (*Allium cepa* L.) *Indian Journal of Agronomy* **56**(3): 267–272.

Prakash V, Pandey AK, Singh RD and Mani VP 2000. Integrated weed management in winter onion under mid hill conditions of North Western Himalayas. *Indian Journal of Agronomy* **45**(4): 816–825.

Rahman UH, Khattak AM, Sadiq M, Ullah K, Javeria S and Ullah I. 2012. Influence of different weed management practices on yield of garlic crop. *Sarhad Journal of Agriculture*. **28**(2): 213–218.

Vermani A, Nandal TR and Singh R 2001. Nutrient uptake and economics of weed management in garlic (*Allium sativum* L.) *Indian Journal of Weed Science* **33**(3&4): 225–226.