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Herbicide-resistant weeds: Management strategies and upcoming technologies

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ABSTRACT

Herbicides have contributed to substantial increase in crop yields over the past seven decades. Over reliance on herbicides for weed control has led to rapid evolution of herbicide-resistant (HR) weeds. Increased awareness of herbicide resistance and adoption of diversified weed control tactics by farmers is critical to manage HR weeds. HR weed management must include both chemical and non-chemical methods as well as the best management practices to prevent evolution and spread of HR weeds. The severity of the HR weed problem has also renewed efforts to discover new technologies. One technology will be a new generation of crops with resistance to glyphosate, glufosinate and other existing herbicides (*e.g.* ALS inhibitors, 2,4-D, dicamba, HPPD inhibitors, and ACCase inhibitors). These stacked-trait crops will provide new options with existing herbicides, but will not be the total weed management solution because several weeds have already evolved resistance to these herbicides. Another technology in the early stages of development that has potential to combat HR weeds is the use of RNA interference (RNAi) technology. The use of RNAi involves the topical application of double-stranded RNA (dsRNA) to interfere with the expression of herbicide resistance genes in weeds to reverse the resistance. RNAi is a revolutionary technology for resistant weed management, but is still years away from commercialization. While no new herbicides are on the horizon, in the near future, the HR management strategies must utilize an array of tools to disrupt HR weeds from evolving and spreading, with the ultimate goal of not allowing any weeds to survive and set seed.

Key words: Herbicide-resistant weeds, Management strategies, Upcoming technologies

Weeds have been with us since time immemorial and are not likely to disappear, despite the use of best weed management practices. Weeds interfere with profitable production of food, feed, fiber, and fuel crops. Development of safe, effective, and relatively inexpensive herbicides coupled with advances in application technology during the past seven decades have provided many successful weed control options in crop production. Efficient and judicious use of herbicides contributed to not only higher crop yields, but also, improved quality. Furthermore, herbicides, reduced labor and drudgery, use of animal drawn implements, machinery, and fuel used for mechanical weed control. Without a doubt, herbicides provided cost-effective, timely weed control and have helped producers become highly productive and remain economically viable.

The era of chemical weed control began with the introduction of 2,4-D in mid-1940s. Since then, we have witnessed development of a wide array of herbicides, ever more specific and more active. Currently, over 270 herbicides acting at 25 different primary target sites are on the market. Use of each herbicide although is limited to a specific situation, herbicides have greatly expanded pre-emergence and post-emergence weed control options in both crop and non-crop lands. It is now difficult to imagine modern crop production without the use of herbicides.

Herbicide use increased more than thirteen-fold (from16 to 217 million kg) between 1960 and 1981 as more U.S. farmers began to treat their fields with these chemicals. By 1980, more than 90-99% of the U.S. corn, cotton, and soybean area was treated with herbicides as compared to 5-10% of area planted in 1952 (Fernandez-Cornejo *et al.* 2014). Over reliance on herbicides for weed control has led to rapid evolution of herbicide-resistant (HR) weeds. The most common cause of evolution of resistant weeds is by exerting selection pressure on weeds with the use of same herbicide (or herbicides with the same target site of action) year after year. Herbicide resistance was first reported in 1970 in triazine chemical family (Heap 2016). Since that time, several weed species have evolved resistance to not only triazine herbicides, but also, to herbicides with different target sites of action. As of 2015, globally,

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248 weed species (104 monocots and 144 dicots) have evolved resistance to 157 herbicides representing 22 of the 25 known herbicide sites of action in 86 crops in 66 countries (Heap 2016).

Herbicide-resistant crops (HRCs), mainly glyphosate- and glufosinate-resistant soybean, corn, cotton, and canola were commercialized in the mid-1990s. The consistent weed control and economic benefits of HRCs encouraged the farmers to plant more area with HRCs each year in countries where adopted. In the US, 94% of soybean, 89% of cotton, and 89% of corn area was planted with glyphosate-resistant (GR) cultivars in 2015 (USDA 2016). Globally, 82% of soybean, 68% of cotton, and 30% of corn area was planted with GR cultivars in 2014. The remarkable success of GR crops has increased glyphosate use, consequently, increasing selection pressure that resulted in widespread evolution of GR weeds. As of 2015, globally, 32 weeds have developed resistance to glyphosate (Heap 2016). Once an effective weed control tool, glyphosate is now unreliable. Glyphosate has become a victim of its own success – used too often on same area with no diversity in weed management. Efficacy of glyphosate is declining as more weeds develop resistance. GR weeds can reduce crop yields and increase weed management costs (Culpepper *et al*. 2008, Webster and Sosnoskie 2010, Shaw *et al*. 2011).

Herbicide-resistant weed management with diverse approaches

After years of heavy dependence on a single solution to weed control, glyphosate-resistant crops and glyphosate herbicide system have become ineffective. Herbicide resistance is choice-driven. Users will either promote or prevent by the weed control choices they make. Herbicide dependence strategy has failed. Change is essential. Growers must change weed control practices.

Herbicides are still essential for weed management in modern cropping systems. Increased awareness of herbicide resistance and adoption of diversified weed control tactics by farmers is critical to manage HR weeds. HR weed management must include use of cultural (competitive cultivars, plant densities, row spacing, crop rotation, winter crops in rotation, cover crops), mechanical (tillage before planting, in-crop cultivation, hand hoeing, post-harvest tillage), chemical (residual herbicides, herbicide full-labelled rate, tank mixtures at the label rate, sequences, application timing, herbicide rotation with different modes of action), and biological tactics where and when available, for effective weed control (Nandula and Reddy 2012, Reddy and Nandula 2012). These practices were commonly used for weed control prior to herbicides. Growers were complacent, because herbicides simplified weed control and increased profitability.

Other management practices include use of weed-free crop seed, keeping fields weed-free, preventing within field and between fields movement of weed seed, and understanding the biology of the weeds and use of diversified weed management approaches to prevent weed seed production and depletion of weed seed in the soil seedbank. Norsworthy *et al.* (2012) have published a document on risks of herbicide resistance and suggested several best management practices and recommendations for herbicide-resistance management.

Herbicides are the primary and economical means of weed management in crop production. Any diversification of control tactics will no doubt increase cost of weed management in the short-term. Because of increased short-term costs associated with the use of diverse weed control tactics, growers are often hesitant to adopt proactive measures to manage HR weeds. Ignoring HR weeds now will only make herbicide resistance problem severe and expensive to manage later. Considering that the discovery of herbicides with new modes of action is rare, the indiscriminate use of current herbicides will lead to rapid evolution of more HR weeds resulting in loss of herbicides for future use. Integration of herbicides with non-chemical weed control tactics is critical to conserve herbicides resources for the future. Thus, the short-term costs associated with diverse weed control tactics are pale in comparison to long-term consequences.

Evolution and widespread infestation of GR Palmer amaranth (*Amaranthus palmeri*) in Georgia, USA, cotton weed management has moved from use of glyphosate only herbicide to diversified tactics (Sosnoskie and Culpepper 2014). In order to manage GR Palmer amaranth, growers are rotating herbicide chemistries and limiting their reliance on a single mechanism of action, and are applying residual herbicides throughout the cropping season, and integrating herbicide programs with hand weeding, tillage for incorporation of preplant herbicides, in-crop cultivation, post-harvest deep tillage once in three years to manage weeds. Consequently, these systems were more diverse, complex, and expensive than those used only a decade ago, but are effective in controlling GR Palmer amaranth in GR cotton.

Early detection

Aside from using an array of weed control tactics in HR weed management, early detection of resistant weeds is critical. Resistant weeds go undetected until growers observe about 30 percent weed control failure for a particular weed species. Early detection of resistant weeds is critical to avoid the spread of the resistant weed biotype. Unfortunately, resistant and susceptible plants look alike and resistance is not detected until the susceptible plants are killed and the herbicide-resistant plants survive following exposure to a dose of herbicide that would normally be lethal to the susceptible plants. If these resistant weeds are detected early, before their populations increase, growers can employ diverse weed management tactics that can prevent their spread.

New multiple herbicide-resistant crops

Agrochemical industries reduced research spending during the years glyphosate dominated the herbicide market. The discovery and development of a new compound is expensive, and the new product must exceed the high bar set by glyphosate. As a result, there are a fewer new herbicides under development.

The severity of the HR weed problem has also renewed efforts to discover new technologies. One technology will be a new generation of crops with resistance to glyphosate, glufosinate and other existing herbicides. Currently, Monsanto, Dow, Bayer, Syngenta and BASF are developing new stacked-trait crops in combination with glyphosate resistance. They are glyphosate, glufosinate (soybean, corn, cotton); glyphosate, ALS inhibitors (soybean, corn, canola); glyphosate, glufosinate, 2,4-D (soybean, cotton); glyphosate, glufosinate, dicamba (soybean, corn, cotton); glyphosate, glufosinate, HPPD inhibitors (soybean and cotton); glyphosate, glufosinate, 2,4-D, ACCase inhibitors (corn); and glufosinate, dicamba (wheat) (Green 2014). These stacked-trait crops will provide new options with existing herbicides, but will not be the total weed management solution because several weeds have already evolved resistance to these herbicides (Heap 2016).

RNA interference technology

Another technology in the early stages of development that has potential to combat HR weeds is the use of RNA interference (RNAi) technology. Monsanto is developing RNAi technology (BioDirect™); mechanism called RNA interference or gene silencing. It's a way to destroy specific RNA messages so that a particular protein is not made. It's an elegant way of targeting particular genes and turning those genes off. The use of RNAi involves the topical application of a mixture of glyphosate and double-stranded RNA (dsRNA) to interfere with the expression of herbicide resistance genes in weeds. Preliminary studies have demonstrated that BioDirect™, when combined with herbicide, can reverse the resistance. The technology has also been demonstrated with weeds resistant to ALS-, HPPD- and PPO-inhibiting herbicides (Green 2014, Shaner and Beckie 2014). Commercial success of genetic sprays depends on: spray getting into plant cells (uptake), shelf life of formulation, and integrity of formulation in extreme summer hot conditions. RNAi is a revolutionary technology for resistant weed management, but is still years away from commercialization.

Conclusion

While no new herbicides are on the horizon, in the near future, the HR management strategies must utilize an array of tools to disrupt HR weeds from evolving and spreading, with the ultimate goal of not allowing any weeds to survive and set seed. Simple and convenient, herbicide only strategy, has failed and growers must diversify both chemical and non-chemical tactics to manage HR weeds. Growers must and should bring diversity back. The future weed management tactics look lot more like the ones used in the past – the pre-GR crop era. HR weeds are here to stay and growers have to just manage them following two rules. Rule # 1: diversify weed management approaches using an array of control (cultural, mechanical, chemical, and biological) tactics to disrupt HR weeds from evolving and spreading. Since one size seldom fits all, diversified approaches must match local/region specific weed problems. Rule # 2: never forget the Rule #1.

REFERENCES

Culpepper AS, Whitaker JR, MacRae AW and York AC. 2008. Distribution of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) in Georgia and North Carolina during 2005 and 2006. *Journal of Cotton Science* **12**: 306-310.

Fernandez-Cornejo J, Nehring R, Osteen C, Wechsler S, Martin A and Vialou A. 2014. Pesticide use in U.S. agriculture: 21 selected crops, 1960-2008. United States Department of Agriculture, Economic Research Service, *Economic Information Bulletin Number 124*. 80 p.

Green JM. 2014. Current state of herbicides in herbicide-resistant crops. *Pest Management Science* **70**: 1351-1357.

Heap I. 2016. The international survey of herbicide-resistant weeds. Online. Internet. Accessed January 30, 2016. *Available www.weedscience.org.*

Nandula VK and Reddy KN. 2012. Weed resistance challenges and management under herbicide-resistant cropping systems. *Indian Journal of Agronomy* **57**: 302-309.

Norsworthy JK, Ward S, Shaw D, Llewellyn R, Nichols R, Webster T, Bradley K, Frisvold G, Powles S, Burgos N, Witt W and Barrett M. 2012. Reducing the risks of herbicide resistance: Best management practices and recommendations. *Weed Science* **60** (Special Issue):31-62.

Reddy KN and Nandula VK. 2012. Herbicide resistant crops: History, development and current technologies. *Indian Journal of Agronomy* **57**: 1-7.

Shaner DL and Beckie HJ. 2014. The future for weed control and technology. *Pest Management Science* **70**: 1329-1339.

Shaw DR, Owen MDK, Dixon PM, Weller SC, Young BG, Wilson RG and Jordan DL. 2011. Benchmark study on glyphosate-resistant cropping systems in the United States. Part 1: Introduction to 2006-2008, *Pest Management Science* **67**: 741-746.

Sosnoskie LM and Culpepper AS. 2014. Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) increases herbicide use, tillage, and hand-weeding in Georgia cotton. *Weed Science* **62**: 393-402.

USDA National Agricultural Statistics Service NASS. 2016. Economics, Statistics and Market Information System. Acreage. Accessed January 30, 2016. *Available http://usda.mannlib.cornell.edu/MannUsda/view Document Info.do?documentID=1000.*

Webster TM and Sosnoskie LM. 2010. The loss of glyphosate efficacy: A changing weed spectrum in Georgia cotton. *Weed Science* **58**: 73-79.

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Herbicide resistance in cereal production systems of the US Great Plains: A review

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ABSTRACT

The US Great Plains comprise the major cereal producing states in the country. In the US, wheat (winter and spring wheat) was grown in 45 million acres in 2014, with a total production of 55 M metric tons. Wheat after chemical fallow (W-F) dominates > 90% of the dryland cropping systems of the Northern Great Plains of the US, where soil moisture (< 300 mm of average annual precipitation) is often the limiting factor for continuous cropping. In the Central Great Plains of the US, wheat–corn/grain sorghum–fallow (W-C/G-F) is a common dryland rotation. An over-reliance on herbicides for weed control in these no-till cropping systems has resulted in weed shifts and escalated cases of resistance evolution in weed populations to single or multiple site-of-action herbicides. Early detection, increased awareness of socio-economic implications of herbicide-resistant weeds, and adoption of diversified weed control tactics would mitigate the further evolution of multiple herbicide-resistant weed biotypes in cereal production systems.

Key words: Cereals, Herbicide resistance, Weed control diversity

The US Great Plains include semi-arid regions bounded by the Mississippi river tall grass prairie on the East and the Rocky Mountains on the West, extending from the Canadian border on the north to Texas on the South. The Great Plains is characterized by hot summer days, an annual precipitation of 300 to 500 mm mostly during the summer, and cold and dry winter (Lenssen *et al*. 2007). The high level of temporal and spatial climate variability, with prolonged and severe drought periods are the major challenges to crop production in this region. This region is dominated by dryland crop production, with wheat being the major crop (Hansen *et al.* 2012). Growers have adopted no–tillage practices for soil moisture conservation in the dryland cropping systems of the region. In the Northern Great Plains, winter wheat after chemical fallow is the major no-till, dryland crop rotation. The purpose of the no-till, chemical fallow in the rotation is to prevent soil erosion, soil nutrient depletion, and more importantly, conserve soil moisture from winter precipitation for successful establishment of the winter wheat crop (Lenssen *et al*. 2007). However, growers in the Central and Southern Great Plains have adopted a relatively more diverse 3-year rotation of winter wheat–corn/grain sorghum–fallow (Hansen *et al.* 2012).

In these no-till systems, there is often a sole reliance on chemical weed control, with multiple post-emergence (PoE) applications of broad-spectrum herbicides, predominantly glyphosate, to obtain season-long weed control in the absence of crop and/or tillage (Fenster and Wicks 1982, Moyer *et al.* 1994). In the wheat–fallow rotation, glyphosate has been widely used to control weeds not only in fallow, but also, prior to crop planting (burndown) and post-harvest (Mickelson *et al.* 2004, Lloyd *et al.* 2011). Each field typically receives three to four applications of glyphosate each year (Kumar *et al.* 2014). Furthermore, this continuous no-till, wheat-based cropping system has resulted in build-up of specialized weed complex, such as wild oat (*Avena fatua* L.), downy brome (*Bromus tectorum* L.), foxtail species (*Setaria* spp.), kochia [*Kochia scoparia* (L.) Schrad], prickly lettuce (*Lactuca serriola* L.) and Russian thistle (*Salsola tragus* L.). Nevertheless, populations of these weed species have evolved resistance to one or more herbicide families (Heap 2016).

Globally, the maximum number of cases of herbicide-resistant weeds have been reported in wheat among all crops (Heap 2016). Glyphosate (burndown), acetyl-COA-carboxylase (ACCase)-inhibitors, acetolactate synthase (ALS)-inhibitors, and synthetic auxins (2,4-D, dicamba, fluroxypyr, MCPA) are the most common herbicide chemistries used in cereal production. This paper, presents specific cases of resistance evolution in the key grass

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and broad-leaved weed species to these site-of-action herbicides in the US Great Plains cereal production systems, and implications for long-term weed management.

Herbicide-resistant weeds in cereals in the US Great Plains

Wild oat: Wild oat biotypes resistant to difenzoquat (thiocarbamate) and triallate (cell elongation inhibitor) have been reported in cereal production fields in Montana, USA in 1990 (Heap 2016). Wild oat resistance to imazamethabenz-methyl (ALS inhibitor) was first reported in North Dakota and Montana in 1996 (Heap 2016). Resistance to mesosulfuron-methyl (ALS-inhibitor) was subsequently documented in South Dakota wheat fields in 2012 (Heap 2016). Wild oat resistance to ACCase inhibitors (graminicides) is widespread across the US Great Plains wheat belt, especially, against diclofop-methyl, clodinafop-propargyl, fenoxaprop-p-ethyl, and tralkoxydim herbicides used in cereals (Heap 2016). Furthermore, wild oat strains with evolved multiple resistance to difenzoquat, imazamethabenz-methyl, flucarbazone (ALS inhibitor), and tralkoxydim is a concern for wheat producers in Montana (Lehnhoff *et al.* 2013). Two of those multiple herbicide-resistant biotypes from Montana were also found to be 17.5- to 18.1-fold more resistant to triallate, 3.6- to 3.7-fold more resistant to pinoxaden, and 3.2-fold more resistant to paraquat compared with the susceptible biotypes (Keith *et al.* 2015). This seriously limits the herbicide options for wild oat control in wheat. Target-site mutations encompassing the ACC gene are known to confer resistance to ACCase-inhibitors. Also, a non-target-site based enhanced metabolism mediated by cytochrome P450 monooxygenases (P450s) conferred resistance to both ACCase- and ALS-inhibitor-resistant wild oat biotypes (Beckie *et al.* 2012, Keith *et al.* 2015).

Green foxtail: Green foxtail resistance to ACCase inhibitors used in cereals including diclofop-methyl, fenoxaprop-P-ethyl, fluazifop-P-butyl, pinoxaden, and also to sethoxydim has been reported in Montana (Heap 2016). There has been an increase in the occurrence of green foxtail populations with resistance to this site-of-action herbicides in wheat fields of this region. An isoleucine–leucine substitution in chloroplastic ACCase conferred resistance to sethoxydim in green foxtail (Délye *et al.* 2002).

Downy brome: Although not documented in wheat, downy brome populations with resistance to imazamox, primisulfuron-methyl, sulfosulfuron, and propoxycarbazone-sodium (ALS inhibitors) have been reported from Oregon, USA (Mallory-Smith *et al.* 1999, Park and Mallory-Smith 2004). Downy brome biotypes with resistance to clethodim, fluazifop-P-butyl, quazalofop-P-ethyl, and sethoxydim have also been documented (Ball *et al.* 2007). Resistance evolution in downy brome to ALS inhibitors used in winter wheat would be a serious concern for growers in this region. A single point mutation at the Pro197 (amino acid substitution from proline to serine) conferred cross-resistance to sulfonylurea and sulfonylaminocarbonyltriazolinone (SCT) herbicides in downy brome biotypes from Oregon (Park and Mallory-Smith 2004).

Prickly lettuce: Prickly lettuce biotypes resistant to chlorsulfuron, imazethapyr, metsulfuron-methyl, thifensulfuron-methyl, triasulfuron, and tribenuron-methyl have been reported in Idaho, Washington, and Oregon wheat fields; first case documented in 1987. Biotypes cross-resistant to synthetic auxins including 2,4-D, dicamba, and MCPA have also been reported in cereal production fields in Washington (Riar *et al.* 2011, Heap 2016). Reduced absorption and translocation of 2,4-D conferred resistance to the herbicide in a prickly lettuce biotype from Washington, USA (Riar *et al.* 2011).

Russian thistle: Russian thistle has developed resistance to ALS inhibitors used in wheat. Chlorsulfuron-resistant Russian thistle was first identified in Montana in 1987. Russian thistle is one of the predominant broad-leaved weeds in the no-till, wheat–fallow system. At maturity, the plant develops into a globose-elliptical shape, referred to as “tumbleweed” (Young *et al.* 2008). Glyphosate and 2,4-D were effective for Russian thistle control (Young *et al.* 2008), however, there is an enhanced selection pressure for resistance development in this weed species due to repeated use of these herbicides in wheat-based cropping systems of this region. The first global case of glyphosate-resistant Russian thistle has recently been reported in Montana from a wheat–chemical fallow field in Choteau County (Heap 2016, Jha and Kumar, unpublished data); the biotypes were also found resistant to ALS inhibitors. Glyphosate-resistant Russian thistle has also been found in Washington, USA in 2015 (Drew Lyon, personal communication). Two target-site mutations: Trp_{574}Leu and Pro_{197}Gln endowed resistance to ALS inhibitors in Russian thistle biotypes from the western Canada cereal production region (Warwick *et al.* 2010).

Kochia: Increased occurrence of kochia populations resistant to multiple herbicide chemistries is a serious challenge for cereal producers in the US Great Plains (Jha *et al*. 2015). Resistance of kochia to atrazine (PS II inhibitor) was first confirmed in 1976 in Kansas, USA, and it was subsequently reported in other Great Plains' states, including Montana (Heap 2016). Since 1989, there has been a widespread occurrence of kochia biotypes resistant to sulfonylurea herbicides, predominantly in the cereal-based cropping systems of this region (Heap 2016). Dicamba-resistant kochia was first found in 1994 in northern Montana wheat fields, and it now occurs in North Dakota, Idaho, Nebraska, and Colorado, USA (Jha *et al*. 2015, Heap 2016). The problem is further exacerbated because of the evolution of glyphosate-resistant kochia, first reported in western Kansas in 2007, and recently in ten other states; a potential threat to the no-till, cereal production in the US Great Plains (Kumar *et al*. 2014, Heap 2016). Kochia with evolved multiple resistance to four herbicide sites of action (glyphosate, dicamba, atrazine, and ALS inhibitors), reported in Kansas, seriously limits herbicide options to control this weed (Varanasi *et al*. 2015). A novel mechanism of glyphosate resistance *i.e.*, 5-enolypyruvyl-shikimate-3-phosphate synthase (EPSPS) gene amplification (2- to 14-folds increase in EPSPS: ALS gene copies in resistant relative to a single copy of the gene in the susceptible biotypes) confers resistance to glyphosate in kochia (Kumar *et al.* 2015a). Target-site mutations at Pro_{197}, Asp_{376}, and Trp_{574} loci of the *ALS* gene confers resistance to ALS inhibitors in kochia (Warwick *et al.* 2008, Kumar *et al.* 2015)

Herbicide resistance management in cereals

The best management practices (BMPs) for herbicide resistance (HR) management in weeds are established on the concept of 'diversity'. Norsworthy *et al.* (2012) stated – "Reducing herbicide selection pressure by adopting diversified weed control tactics, reducing the spread of resistance alleles by pollen or seed, and preventing weed seed bank additions are the key strategies to mitigate HR". Producers are often reluctant to adopt proactive HR management programs because they are more interested in short-term economic gains and lack awareness or education on the economic risks of HR until it evolves in their production fields (Beckie 2006). Although herbicides will continue to be the dominant weed control tool in the US cereal production, farmers should not anticipate many new site-of-action herbicides to be commercialized in the near future (Duke 2012).

Multiple, effective modes of action and pre-emergence (PRE) soil-residual herbicides will serve as a foundation for the HR weed management programs in cereals (Kumar and Jha 2015a). However, it should be noted that the persistence of soil-residual herbicides in high pH and low organic matter soils is the major constraint for diversifying crop rotations in the semi-arid US Great Plains. Although limited PRE herbicide options are available in wheat, growers should utilize products such as sulfentrazone or metribuzin, labelled in pulse crops such as pea, chickpea, or lentil, to obtain effective residual control of herbicide-resistant populations of kochia and Russian thistle in wheat–pulse rotation (Kumar and Jha 2015a). Glyphosate-resistant kochia seed bank in the fallow should be proactively managed in the rotational wheat crop with alternative, effective modes of action (applied as tank mixtures), such as bromoxynil + MCPA, pyrasulfotole + bromoxynil, dicamba + fluroxypyr, fluroxypyr + bromoxynil. The objective of the HR management programs should be to prevent seed set and replenishment of the weed seedbank. Paraquat + atrazine, linuron, or metribuzin, and saflufenacil + 2,4-D could be effective, alternative postharvest herbicides (multiple modes of action) in wheat for late-season control and seed prevention of glyphosate-resistant kochia (Kumar and Jha 2015b). It is to be further noted that using multiple, effective site-of-action herbicides is more effective than herbicide rotation in mitigating HR evolution in weed species through herbicide selection (Beckie and Rebound 2009).

An integrated weed management (IWM) approach for mitigating HR needs to be implemented in cereal production systems. For instance, integration of pulse crops into the wheat-fallow rotation would add weed control diversity in dryland cropping systems of the US Great Plains. The ACCase-resistant populations of grass weeds (wild oat and green foxtail) in wheat could be controlled by herbicides not selective in wheat, but labelled for use in the pulse crops grown in rotation. Nonselective herbicides, such as glyphosate or glufosinate, could potentially manage grass weed populations with metabolism-based resistance to ACCase and/or ALS-inhibitors (Beckie *et al.* 2012).

Tillage is an important component of IWM programs (Norsworthy *et al.* 2012). A shallow tillage using wide blades or sweeps can be used to control weeds during summer fallow, with minimum soil disturbance. Also, a shallow burial through minimum tillage can potentially reduce the seed-bank of small-seeded weed species, such as kochia, which cannot emerge from soil depths below 10 mm and exhibits low seed dormancy and persistence in the soil (seed persistence of 1 to 2 years) (Anderson and Nielsen 1996, Schwinghamer and Van Acker 2008). Additionally, legume green manures or cover crop mixtures have recently been investigated in the semi-arid dryland cereal production regions of the Western US as a fallow substitute (wheat–cover crop), for increased soil health and productivity (Miller *et al.* 2015). This can also reduce reliance on multiple applications of burndown herbicides such as glyphosate and 2,4-D in fallow, thereby, minimizing the selection pressure for HR development in weed species.

Successfully managing HR would require collaboration and information from multiple disciplines, including applied weed science, evolutionary biology, population genetics, molecular biology and biochemistry, physiology, and ecology. Additionally, economics, sociology and other social sciences would play an important role on growers' decision making and adoption of integrated HR weed management programs and changed farming practices at a community level (Ervin and Jussaume 2014). There needs to be an active, strong linkage between innovation, adoption, and diffusion of new weed control technologies and changed farming practices. Switching to new HR-stacked-trait crop technologies may not be the ultimate, long-term weed management solution, unless 'holistic approaches' for innovation, adoption, and diffusion of these new technologies are adopted. Precision weed control technologies using advanced optics such as light-activated sensor-controlled (LASC) sprayers (Weed Seeker) and hyperspectral imaging to differentiate plants, unmanned aerial vehicle (UAV)-automated sprayers and robotics, would play a crucial role in weed management in the near future.

In conclusion, less-frequent selective herbicide use, non-herbicidal tactics, and weed control diversity at a cropping systems level, can mitigate the evolution, spread, and economic impact of HR weeds in cereal production systems.

REFERENCES

Anderson RL and Nielsen DC. 1996. Emergence pattern of five weeds in the central Great Plains. *Weed Technology* **10**: 744-749.

Ball DA, Frost SM and Bennett LH. 2007. Accase-inhibitor herbicide resistance in downy brome (*Bromus Tectorum*) in Oregon. *Weed Science* **55**: 91-94.

Beckie HJ. 2006. Herbicide-resistant weeds: Management tactics and practices. *Weed Technology* **20**: 793-814.

Beckie HJ and Rebound X. 2009. Selecting for weed resistance: Herbicide rotation and mixture. *Weed Technology* **23**: 363-370.

Beckie HJ, Warwick SI and Sauder CA. 2012. Basis for herbicide resistance in Canadian populations of wild oat (*Avena fatua*). *Weed Science* **60**: 10-18.

Délye C, Wang T and Darmency H. 2002. An isoleucine-leucine substitution in chloroplastic acetyl-CoA carboxylase from green foxtail (*Setaria viridis* L. Beauv.) is responsible for resistance to the cyclohexanedione herbicide sethoxydim. *Planta* **214**: 421-427.

Duke SO (2012). Why have no new herbicide modes of action appeared in recent years? *Pest Management Science* **68**: 505-512.

Ervin D and Jussaume R. 2014. Integrating social science into managing herbicide-resistant weeds and associated environmental impacts. *Weed Science* **62**: 403-414.

Fenster CR and Wicks GA. 1982. Fallow systems for winter wheat in western Nebraska. *Agronomy Journal* **74**: 9-13.

Hansen N, Allen B, Baumhardt RL and Lyon D. 2012. Research achievements and adoption of no-till, dryland cropping in the semi-arid U.S. Great Plains. *Field Crops Research* **132**: 196-203.

Heap I. 2016. The international survey of herbicide resistant weeds. Internet. Accessed January 10, 2016. *Available at: www.weedscience.com.*

Jha P, Kumar V and Lim CA. 2015. Variable response of kochia [*Kochia scoparia* (L.) Schrad.] to auxinic herbicides dicamba and fluroxypyr in Montana. *Canadian Journal of Plant Science* **95**: 965-972.

Keith BK, Lehnhoff EA, Burns EE, Menalled FD and Dyer WE. 2015. Characterization of *Avena fatua* populations with resistance to multiple herbicides. *Weed Research* **55**: 621-630.

Kumar V, Jha P and Reichard N. 2014. Occurrence and characterization of kochia (*Kochia scoparia*) accessions with resistance to glyphosate in Montana. *Weed Technology* **28**: 122-130.

Kumar V, Jha P, Giacomini D, Westra EP and Westra P. 2015. Molecular basis of evolved resistance to glyphosate and acetolactate synthase-inhibitor herbicides in kochia (*Kochia scoparia*) accessions from Montana. *Weed Science* **63**: 758-769.

Kumar V and Jha P. 2015a. Effective pre-emergence and post-emergence herbicide programs for kochia control. *Weed Technology* **29**: 24-34.

Kumar V and Jha P. 2015b. Influence of herbicides applied postharvest in wheat stubble on control, fecundity, and progeny fitness of kochia scoparia in the US Great Plains. *Crop Protection* **71**: 144-149.

Lehnhoff EA, Keith BK, Dyer WE and Menalled FD. 2013. Impact of biotic and abiotic stresses on the competitive ability of multiple herbicide resistant wild oat (*Avena fatua*). *PloS one* **8**(5): e64478.

Lenssen AW, Waddell J, Johnson GD and Carlson GR. 2007. Diversified cropping systems in semiarid Montana: nitrogen use during drought. *Soil Tillage Research* **94**: 362-37.

Lloyd KL, Johnson JM, Gover AE and Sellmer JC. 2011. Pre-emergence and post-emergence suppression of kochia on rights-of-way. *Weed Technology* **25**: 292-29.

Mallory-Smith C, Hendrickson P and Mueller-Warrant G. 1999. Cross-resistance of primisulfuron-resistant *Bromus tectorum* L. (downy brome) to sulfosulfuron. *Weed Science* **47**: 256-257.

Miller PR, Bekkerman A, Jones CA, Burgess MH, Holmes JA and Engel RE. 2015. Pea in rotation with wheat reduced uncertainty of economic returns in southwest Montana. Agronomy Journal **107**: 541-550.

Mickelson JA, Bussan AJ, Davis ES, Hulting AG and Dyer WE. 2004. Post harvest kochia (*Kochia scoparia*) management with herbicides in small grains. *Weed Technology* **18**: 426-431.

Moyer JR, Roman ES, Lindwall CW and Blackshaw RE. 1994. Weed management in conservation tillage systems for wheat production in North and South America. *Crop Protection* **4**: 243-259.

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**(Special issue)(1): 31-62.

Park KW and Mallory Smith CA. 2004. Physiological and molecular basis for ALS inhibitor resistance in Bromus tectorum biotypes. *Weed Research* **44**: 71-77.

Schwinghamer TD and Van Acker RC. 2008. Emergence timing and persistence of kochia (*Kochia Scoparia*). *Weed Science* **56**: 37-41.

Riar DS, Burke IC, Yenish JP, Bell J and Gill K. 2011. Inheritance and physiological basis for 2,4-D resistance in prickly lettuce (*Lactuca serriola* L.). *Journal of Agricultural and Food Chemistry* ***59:*** 9417-9423

Varanasi VK, Godar AS, Currie RS, Dille AJ, Thompson CR, Stahlman PW and Jugulam M. 2015. Field evolved resistance to four modes of action of herbicides in a single kochia (*Kochia scoparia* L. Schrad.) population. *Pest Management Science* **71**: 1207-1212.

Warwick SI, Xu R, Sauder C and Beckie HJ. 2008. Acetolactate synthase target-site mutations and single nucleotide polymorphism genotyping in ALS-resistant kochia (*Kochia scoparia*). *Weed science* **56***:* 797-806.

Warwick SI, Sauder CA and Beckie HJ. 2010. Acetolactate synthase (ALS) target-site mutations in ALS inhibitor-resistant Russian thistle (*Salsola tragus*). *Weed Science* **58**: 244-251.

Young FL, Yenish JP, Launchbaugh GK, McGrew LL and Alldredge JR. 2008. Post-harvest control of Russian thistle (*Salsola tragus*) with a reduced herbicide applicator in the Pacific Northwest. *Weed Technology* **22**: 156-159.

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Herbicide resistance in kochia: From single to multiple resistance

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ABSTRACT

Herbicide resistance in weeds is evolving rapidly worldwide complicating weed management and threating agricultural sustainability and food security. Resistance has been reported to all known herbicide modes of action and no new mode of action has been marketed in the past 25 years. Though most reported cases of resistance involve a single herbicide site of action, multiple-site resistance is increasing. As an example of the progression from single to multiple site resistance, this paper reviews the evolution and implications of herbicide resistance in kochia [*Kochia scoparia* (L.) Schrad.), a common and economically important weed in the North American Great Plains.

Key words: ALS inhibitors, Glyphosate, Kochia, Herbicide resistance, Photosystem II inhibitors, Synthetic auxins

Early literature documents agriculturalists using various naturally occurring substances and by-products to control various plant pests, including weeds, and Romans applied salt to fields of enemies to prevent growing of crops (Timmons 1970, Smith and Secoy 1976). However, chemical weed control in agricultural crops and tree fruits is considered to be of recent origin, dating from the mid-nineteenth century when lime and salt were recommended for weed control in Europe. The modern era of chemical weed control began with the discovery and development of chlorophenoxy acetic acid herbicides in the early 1940s (Peterson 1967, Timmons 1970). This family of herbicides, 2,4-D and MCPA in particular, not only transformed agriculture by revolutionizing weed control, but gave rise to the discipline of weed science and an entire industry.

The chlorophenoxy chemical family and several additional classes of herbicides developed since 1940 have provided highly effectively weed control selectively in many crops, resulting in more efficient production and higher crop yields compared with hand weeding and/or cultivation. Currently, the vast majority of cropland hectares in developed countries, and increasingly those in under-developed countries, are treated with chemical herbicides annually. Because all natural weed populations may contain very low frequencies of individual plants (biotypes) that are naturally resistant to certain herbicides, an unintended consequence of extensive herbicide use few people initially anticipated was that frequent repeated use of any herbicide could lead to shifts in species composition of weed populations and select for tolerant or resistant biotypes.

Harper (1957) was among the first to warn of this evolutionary possibility. Numerous studies have since confirmed Harper's (1957) early prediction (Haas and Streibig 1992, Westra *et al.* 2004, Culpepper 2006, Wilson *et al.* 2007). Repeatedly using any single herbicide mechanism of action without alternative management tactics will eventually eliminate susceptible species or biotypes from an existing population and allow naturally tolerant or resistant biotypes to flourish and dominate the population (Gressel and Segel 1978, Maxwell and Mortimer 1994). Herbicide resistance is now widely recognized as the result of adaptive evolution of weed populations to intense selection pressure imposed by herbicides. Several recent reviews have documented the evolution of herbicide resistance (Powles and Yu 2010, Mithila *et al.* 2011, Burgos *et al.* 2013, Delye *et al.* 2013, Shaner 2014).

Genetic diversity is the heritable genetic variation within and among populations of species. Species with high genetic diversity, especially those that produce large quantities of seed that readily germinate, adapt and evolve faster in response to changing environmental conditions and selection pressures than species with low genetic diversity. Thus, species with high genetic diversity are prone to evolved resistance to herbicides. There is more than one mechanism of resistance for most herbicide modes of action and several known amino acid substitutions within target site proteins that prevent herbicide binding and disruption of critical biochemical pathways. Non-target site resistance mechanisms (*e.g.* reduced herbicide uptake or translocation, herbicide sequestration, or enhanced

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metabolism) allow plants to survive by preventing herbicide from reaching the target site or by producing more of the targeted enzyme than the herbicide can inhibit (*e.g.* over expression or gene amplification).

Currently, herbicide resistance has been confirmed in 247 weed species in 66 countries with evolved resistance to 22 of the 25 known herbicide sites of action (Heap 2015). Developed countries in which in most arable hectares are treated with herbicides have the greatest number of weed species resistant to known herbicide sites of action. Most reported cases involve resistance to a single herbicide site of action; however, several major weeds have evolved resistance to two or more sites of action. One example is Kochia, a broad-leaved weed of great economic importance throughout the North American Great Plains. This paper reviews the evolution and implications of herbicide resistance in kochia to raise awareness of the increasing threat of multiple herbicide resistance in weeds.

Herbicide resistance in kochia

kochia is a drought-tolerant annual forb with C_4 photosynthetic pathway believed to have been introduced into the United States from Eurasia as an ornamental in the late 1800s (reviewed in Friesen *et al.* 2009). This alien species is highly adaptive and drought-tolerant. Herbarium collections reveal kochia's rapid westward expansion in the North Western United States. Forcella (1985) speculated that kochia's exponential spread into Montana and Wyoming from 1940 to 1960 may have been facilitated by the chemical displacement of 2,4-D-sensitive species from their weed niches and replaced with 2,4-D tolerant taxa, such as kochia. Today, kochia is a major weed in agronomic crops and disturbed non-cropland areas throughout semi-arid and arid regions of the western United States and South-western Canada (Friesen *et al.* 2009).

High genetic diversity and short seed longevity in soil increase the probability of rare herbicide resistant biotypes within a population. Genetic diversity in kochia was found to be very high with greater proportion of diversity within populations than between populations (Mengistu and Messersmith 2002). High genetic diversity in kochia is maintained through substantial gene flow within and between populations by way of protogynous flowering, facultative open pollination, and tumbleweed mode of seed dispersal over long distances (Eberlein and Fore 1984, Stallings *et al.* 1995). Kochia is prone to evolved herbicide resistance, currently having evolved resistance to four modes of action and several cases of multiple site of action resistance.

Photosystem II inhibitors (groups C1 and C2)

Several active ingredients in the triazine family of herbicides (Group C1) were developed in the mid- and late-1950s and have been used in numerous agronomic crops, pastures, tree fruits and forestry, and on industrial sites. Some of those herbicides, such as atrazine and simazine, are still widely used today. As early as the mid-1970s, kochia growing along rail road embankments in Idaho and other Central and Western states was no longer controlled by triazine herbicides after many years of use for complete vegetation control (Bandeen *et al.* 1982). Those populations were found to be resistant to all commercial symmetrical-triazine herbicides and they rapidly spread to adjacent cropland, especially maize fields which usually were treated with atrazine or simazine. Within the following decade triazine-resistant kochia was present in several Midwest U.S. states along with several other major broad-leaved species in numerous states and other countries (Heap 2015). Additionally, kochia along rail road rights-of-way in North Dakota and Minnesota with resistance to diuron and tebuthiuron (Group C2) and metribuzin (Group 1) was discovered in 2004 (Mengistu *et al.* 2005). Resistance to triazine and triazinone herbicides most often is due to a target-site mutation (*e.g.* $serine_{264}$ to glycine substitution) which interferes with herbicide binding on the D1 protein in photosystem II, thereby inhibiting photosynthesis. However, resistance to diuron, tebuthiuron and metribuzin in kochia was due to a valine to isoleucine substitution at residue 219 of the psbA target-site in some plants and the more common $serine_{264}$ to glycine substitution in other plants (Mengistu *et al.* 2005).

ALS inhibitors (group B)

Sulfonylureas are a family of herbicides first commercialized for use in wheat and barley crops in 1982, and later in many crops. Also, in this group is the imidazolinone family consisting of six herbicides used in cereal and legume crops, forestry, non-cropland and on imidazolinone-resistant maize, rice, canola, sunflower, and wheat. Herbicides in this group kill weeds by inhibiting the enzyme acetolactate synthase (ALS) necessary for biosynthesis of amino acids essential for plant growth. Cereal grain and many other crops are able to metabolize sulfonylureas, whereas susceptible weeds and non-imidazolinone-resistant crops cannot. In 1987, selection of kochia and prickly lettuce (*Lactuca* *serriola* L.) biotypes resistant to sulfonylurea herbicides in Kansas (Primiani *et al.* 1990) and Idaho (Mallory-Smith *et al.* 1990) wheat fields, respectively, was confirmed after as few as five consecutive years of sulfonylurea herbicide use. Evolved resistance to ALS-inhibiting herbicides in multiple species increased at an alarming rate, including ALS-resistant kochia in 13 U.S. states and Canadian provinces within seven years and nearly 150 species worldwide within 25 years after commercialization (Heap 2015). Target-site-based resistance resulting from several known amino acid substitutions in the conserved region of the ALS enzyme is the most common resistance mechanism in ALS inhibitor-resistant weeds.

Synthetic auxins (group O)

As a result of the reduced efficacy of ALS-inhibiting herbicides, producers began using dicamba extensively to control ALS-resistant kochia. It was not surprising then when in 1994 numerous kochia plants were not controlled with field use rates of dicamba in a maize field in Nebraska and in wheat fields in Northern Montana following several years of extensive dicamba use in cereal grain crops (Cranston *et al.* 2001). Testing of progeny of uncontrolled kochia plants in Montana revealed the frequency of plants producing resistant progeny was very low, but resistant biotypes were four- to five-fold more resistant than susceptible biotypes and the resistance could not be attributed to differential herbicide absorption, translocation, or metabolism. These findings led the authors' to speculate that dicamba resistance is a qualitative trait. More than 15-years later, Crespo *et al.* (2014) reported injury among 67 Nebraska kochia accessions treated with a 560 g/ha dose of dicamba ranged from 23 to 78% at 21 days after treatment. Furthermore, there was an 18-fold difference in dicamba dose required to achieve 90% injury between the least and most susceptible of four accessions selected from the larger group. In a similar study of 34 kochia accessions mostly from Kansas collected in 2012, there was an eight-fold difference in plant dry weight reduction five weeks after plants were treated with 420 g/ha of dicamba (Brachtenbach 2015). Results from the Nebraska and Kansas studies substantiate producer reports of reduced dicamba effectiveness for kochia control. The physiological, biochemical, and molecular basis for dicamba resistance in kochia has been studied extensively, but the precise mechanism(s) have not yet been determined (Mithila *et al.* 2011).

EPSPS synthase inhibitor

Glyphosate has been used extensively for many years for preplant burndown and to control volunteer crop plants and most grass and broad-leaved weeds in Great Plains cropping systems. The area treated with glyphosate and the total amount applied annually increased dramatically following the rapid adoption of glyphosate-resistant (GR, Roundup Ready®) crops. Glyphosate's broad spectrum effectiveness and relatively inexpensive cost attracted producers to often use glyphosate exclusively, especially in GR crops. These use patterns contributed to intense selection pressure on weed species, including Kochia, to evolve resistance to glyphosate.

Multiple failures to control kochia with glyphosate were first reported in Kansas in 2007 and subsequently were confirmed to be the first cases of glyphosate resistance in kochia (Waite *et al.* 2013, Heap 2015). More than 10 widely dispersed kochia populations in Kansas were confirmed resistant to glyphosate in 2010, with several other populations likely resistant but unconfirmed (Godar *et al.* 2015b). Resistance levels ranged from 3- to 11-fold based on greater EPSPS gene copy number compared to a susceptible population. Resistance to glyphosate due to gene amplification was first reported by Gaines *et al.* (2010).

By the end of 2012, GR kochia was widespread throughout the central Great Plains and also was confirmed that year in northern portions of the Great Plains extending into Canada. Currently, presence of GR kochia populations has been confirmed in 10 Great Plains states (Colorado, Kansas, Idaho, Montana, Nebraska, North Dakota, Oklahoma, Oregon, South Dakota, and Texas) and three Canadian provinces (Alberta, Saskatchewan and Manitoba) (Heap 2015). The distribution of GR kochia continues to expand into additional states and provinces.

Multiple site-of-action resistance

Because each of the herbicide groups mentioned above are commonly used in Great Plains cropping systems, it was only a matter of time until multiple site resistance evolved in kochia. The first reported cases of multiple resistance were along railroads in Illinois and in crop fields in Indiana where kochia was resistant to ALS- and photosystem II-inhibitors (Heap 2015). However, kochia is not a major agronomic weed in Midwest states, so the economic impact likely was not great. Conversely, the discovery of

ALS inhibitor- and glyphosate-resistant kochia in western Canada in 2012 (Beckie *et al.* 2013, Hall *et al.* 2013) arguably has had much greater economic impact and poses a threat to sustainable farming systems in the Northern Great Plains where kochia is a major agronomic weed and where ALS resistance is widespread (Beckie *et al.* 2013). The following year (2013), weed scientists in Kansas confirmed the first known case of resistance to four groups of herbicides (atrazine, group C1; chlorsulfuron, group B, glyphosate, group G; and dicamba, group O) in a single kochia population (Varanasi *et al.* 2015). The ratio of R:S plants to individual herbicides varied from 25% of plants resistant to atrazine to more than 85% of plants resistant to field use rates of chlorosulfuron, dicamba, and glyphosate. Resistance to atrazine and chlorsulfuron was due to target-site mutations in psbA and ALS genes, respectively, and resistance to glyphosate was due to EPSPS gene amplification. The mechanism of resistance to dicamba has not been determined.

Implications of evolved herbicide resistance

Economic considerations are a major criterion for most producers in making weed management decisions. Many producers are reluctant to proactively change effective weed management practices to more complex and/or expensive practices as long as current practices are still effective. Often the first reactive response to ineffective weed control is to increase herbicide use rate. In response to declining glyphosate effectiveness on kochia, Kansas producers increased glyphosate use rates from an average of 0.8 to 1.2 kg/ha and increased application frequencies from 2.0 to 2.9 during the years before discovery of GR-kochia in 2007 to 2012 (Godar *et al.* 2015a). During that same time period, Kansas producers reduced the exclusive use of glyphosate on GR crops from 49 to 15% of fields and began diversifying weed management practices. Clearly, the spread of GR kochia forced changes in practices and increased costs of weed management.

Canadian researchers have concluded the presence of GR weeds will increase environmental impact of weed management by requiring additional herbicides or by growers resorting to tillage to control GR weeds, the latter resulting in reduced soil quality and increased fossil fuel consumption (Beckie *et al.* 2014). The predicted environmental impact of increased tillage is supported by results of a visual survey of 1500 winter wheat stubble fields in Western Kansas in late August 2011 (Stahlman *et al.* 2011). Survey found 64% of wheat stubble fields had been sprayed with herbicide(s) to control weeds post-harvest and 31% of the fields had been tilled. Some of the tilled fields had been tilled after earlier herbicide treatment failed to control kochia. Poor herbicidal control of kochia in many fields and higher-than-expected percentage of tilled fields indicate a shift to more tillage to control herbicide-resistant kochia following wheat harvest. Evolution of weed resistance to herbicides not only complicates weed management but also threatens sustainable agricultural production and soil and water conservation gains achieved during past decades (CAST 2012).

REFERENCES

Bandeen JD, Stephenon GR and Cowett ER. 1982. Discovery and distribution of herbicide-resistant weeds in North America, pp. 9-30. In: *Herbicide Resistant Plants.* (Eds. Le Baron HM and Gressel J). John Wiley & Sons, New York.

Beckie HJ, Blackshaw RE, LR, Hall LM, Saunder CA, Martin S, Brandt RN and Shirrff SW. 2013. Glyphosate- and acetolactate synthase inhibitor-resistant kochia (*Kochia scoparia*) in Western Canada. *Weed Technology* **61**: 310-318.

Beckie HJ, Sikkema PH, Soltani N, Blackshaw RE and Johnson EN. 2014. Environmental impact of glyphosate-resistant weeds in Canada. *Weed Technology* **62**: 385-392.

Brachtenbach DA. 2015. kochia *scoparia response to dicamba and effective management practices for soybeans*. M.S. Thesis. Kansas State University, Manhattan. 53 p.

Burgos NR, Tranel PJ, Strieberg JC, Davis VM, Shaner D, Norsworthy JK and Ritz-Burgos C. 2013. Review: Confirmation of resistance to herbicides and evolution of resistance levels. *Weed Science* **61**: 4-20.

CAST (Council for Agricultural Science and Technology). 2012. *Herbicide-resistant Weeds Threaten Soil Conservation Gains: Finding a Balance for Soil and Farm Sustainability.* Issue Paper 49. CAST, Ames, Iowa.

Cranston HJ, Kern AJ, Hackett JL, Miller EK, Maxwell BD and Dyer WE. 2001. Dicamba resistance in *Kochia*. *Weed Science* **49**: 164-170.

Crespo RJ, Berhards ML, Sbatella GM, Kruger GR, Lee DJ and Wilson RG. 2014. Response of Nebraska kochia (*Kochia scoparia*) accessions to dicamba. *Weed Technology* **28**: 151-162.

Culpepper AS. 2006. Glyphosate-induced weed shifts. *Weed Technology* **20**: 277-281.

Delye C, Jasieniuk M and Le Corre V. 2013. Deciphering the evolution of herbicide resistance in weeds. *Trends in Genetics* **29**: 649-658.

Eberlein C and Fore Z. 1984. Kochia biology. *Weeds Today* **15**: 5-6.

Forcella F. 1985. Spread of kochia in the North Western United States. *Weeds Today* **16**: 4-6.

Friesen LF, Beckie HJ, Warwick SI and Van Acker RC. 2009. The biology of Canadian weeds. 138. Kochia *scoparia* (L.) Schrad. *Canadian Journal of Plant Science* **89**: 141-167.

Gaines TA, Zhang W, Wang D, Bukun B, Chisholm ST, Shaner DL, Nissen SJ, Patzoldt WL, Tranel PJ, Culpepper AS, Grey TL, Webster TM, Vencill WK, Sammons RD, Jiang J, Preston C, Leach JE and Westra P. 2010. Gene amplification confers glyphosate resistance in *Amaranthus palmeri*. *Proceedings National Academy of Science USA* **107**: 1029–1034.

Godar AS and Stahlman PW. 2015a. Consultant's perspective on the evolution and management of glyphosate-resistant kochia (*Kochia scoparia*) in Western Kansas. *Weed Technology* **29**: 318-328.

Godar AS, Stahlman PW, Jugulam M and Dille JA. 2015b. Glyphosate-resistant kochia in Kansas: EPSPS gene copy number in relation to resistance levels. *Weed Science* **63**: 587-59.

Gressel J and Segel LA. 1978. The paucity of plants evolving genetic resistance to herbicides: Possible reasons and implications. *Journal of Theoretical Biology* **75**: 349-371.

Haas H and Streibig JC. 1982. Changing patterns of weed distribution as a result of herbicide use and other agronomic factors. p 57-79. In: *Herbicide Resistant Plants*. (Eds. LeBaron HM and Gressel J). John Wiley & Sons, New York.

Hall, LM, Beckie HJ, Low R, Shiriff SW, Blackshaw RE, Kimmel N and Neeser C. 2013. Survey of glyphosate-resistant kochia (*Kochia scoparia* L. Schrad.) in Alberta. *Canadian Journal of Plant Science* **94**: 127-130.

Harper, JL. 1957. Ecological aspects of weed control. *Outlook on Agriculture* **1**: 197-205.

Heap I. The International Survey of Herbicide Resistant Weeds. Online. Internet. Wednesday, Accessed on November 28, 2015. *Available at www.weedscience.org.*

Mallory-Smith CA, Thill DC, and Dial MJ. 1990. Identification of sulfonylurea herbicide-resistant prickly lettuce (*Lactuca serriola*). *Weed Technology* **4**: 163-168.

Maxwell BD and Mortimer AM. 1994. Selectino for herbicide resistance, pp. 1-25. In: *Herbicide Resistance in Plants: Biology and Biochemistry.* (Eds. Powles SB and Holtum JAM). Lewis, Boca Taron, FL.

Mengistu LW, Christoffers MJ and Lym RG. 2005. A psbA mutation in kochia *scoparia* (L.) Schrad. from railroad right-of way with resistance to diuron, tebuthiuron and metribuzin. *Pest Management Science* **61**: 1035-1042.

Mengistu LW and Messersmith CG. 2002. Genetic diversity in *Kochia*. *Weed Science* **50**:498-503.

Mithila J, Hall JC, Johnson WG, Kelley KB and Riechers DE. 2011. Evolution of resistance to auxinic herbicides: historical perspectives, mechanisms of resistance, and implicatinos for broadleaf weed management in agronomic crops. *Weed Science* **59**: 445-457.

Peterson GE. 1967. The discovery and development of 2,4-D. *Agricultural History* **41**: 243-254.

Powles SB and Yu Q. 2010. Evolution in Action: Plants Resistant to Herbicides. *Annual Review of Plant Biology* **61**: 317-347.

Primiani MM, Cotterman JC and Saari LL. 1990. Resistance of kochia (*Kochia scoparia*) to sulfonylurea and imidazolinone herbicides. *Weed Technology* **4**: 169-172.

Shaner DL. 2014. Lessons learned from the history of herbicide resistance. *Weed Science* **62**: 427-431.

Smith AE and Secoy DM. 1976. Early chemical control of weeds in Europe. *Weed Science* **24**: 594-597.

Stahlman PW, Godar AS, Westera P and Brachtenbach DA. 2013. Distribution and management of glyphosate-resistant kochia (*Kochia scoparia* L. Schrad.) in the Central Great Plains of the United States, p. 31. In: *Proceedings Global Herbicide Resistance Challenge Conference,* Fremantle, Western Australia. p 31.

Stallings GP, Thill DC, Mallory-Smith CA and Shaffii B. 1995. Pollen-mediated gene flow of sulfonylurea-resistant kochia (*Kochia scoparia*). *Weed Science* **43**: 95-102.

Timmons FL. 1970. A history of weed control in the United States and Canada. *Weed Science* **18**: 294-306.

Varanasi VK, Godar AS, Currie RS, Dille JA, Thompson CR, Stahlman PW and Jugulam M. 2015. Field evolved resistance to four modes of action of herbicides in a single kochia (*Kochia scoparia* L. Schrad.) population. *Pest Management Science* **71**: 1207-1212.

Waite, J, Thompson CR, Peterson, DE, Currie RS, Olson BLS, Stahlman PW and Al-Khatib, K. 2013. Differential kochia (*Kochia scoparia*) population response to glyphosate. *Weed Science* **61**: 193-200.

Westra P, Wilson RG, Miller SD, Stahlman PW, Wicks GA, Chapman PL, Withrow J, Legg D, Alford C and Gaines TA. 2008. Weed population dynamics after six years under glyphosate- and conventional herbicide-based weed control strategies. *Crop Science* **48**: 1170-1177.

Wilson RG, Miller SD, Westra P, Kniss AR, Stahlman PW, Wicks GW and Kachman SD. 2007. Glyphosate-induced weed shifts in glyphosate-resistant corn or a rotation of glyphosate-resistant corn, sugarbeet, and spring wheat. *Weed Technology* **21**: 900-909.

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Modeling the evolution of herbicide resistance in weeds: Current knowledge and future directions

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ABSTRACT

Simulation models have been instrumental in understanding the evolutionary dynamics of herbicide resistance in weeds and making informed management decisions for preventing/delaying resistance. Continued improvements in model development and analysis will be critical to address the complex interactions involved in herbicide resistance evolution Here we review current knowledge on the development of herbicide resistance simulation models using published examples and also discuss future directions.

Key words: Herbicide resistance, Simulation modeling, Population dynamics, Selection pressure, resistance best management practices

Simulation models have long been employed to understand weed population dynamics and changes to vital rates in response to crop and weed management practices (Holst *et al.* 2007). Their utility has been further extended to gain a deeper understanding of herbicide resistance evolution in weed communities and devise effective resistance management strategies (*e.g.,* Maxwell *et al.* 1990, Maxwell and Mortimer 1994, Diggle *et al.* 2003, Neve *et al.* 2011). Simulation models save tremendous amount of time and resources, which would otherwise be spent on conducting long-term field experiments, which are often impracticable. A prime benefit of using simulation models is that they allow for the comparison of various management options and evaluate the relative benefits of different management combinations in reducing the risk of resistance (Jasieniuk *et al.* 1996, Cavan *et al.* 2000). For instance, Bagavathiannan *et al.* (2013) used a model to compare the relative benefits of altered planting dates, cultivation, crop/trait rotations, and herbicide rotations in proactive herbicide resistance management in barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.). Thus, models can serve as excellent decision-support tools for growers and weed managers for making informed management decisions.

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Model components

The evolution of herbicide resistance is influenced by three key factors: (1) factors related to the ecology and biology of the weed species, (2) genetic factors governing the rate of resistance evolution, and (3) management factors. Therefore, models that simulate herbicide resistance evolution are comprised of three integral components - ecology and biology, population genetics, and management (Diggle *et al.* 2003, Roux and Reboud 2007). A general framework of a herbicide resistance simulation model for an annual weed species is presented in (Figure 1). The processes on ecology and biology is usually represented by a demographic sub-model, which accounts for initial seedbank size, annual germination proportion, seedling recruitment pattern, density-dependent survival and fecundity, post-dispersal seed loss, and seed immigration/emigration. The genetic processes include initial frequency of resistance alleles, mode of inheritance of resistance, mating system, dominance, and fitness. Management is a critical factor determining resistance evolution, particularly the combinations of management options used and efficacies of different options.

Roux and Reboud (2007) suggested that genetic factors are important for a highly outcrossing species, whereas management is important for a predominantly selfing species in influencing resistance dynamics. Further, the intrinsic population dynamics, particularly seedbank persistence

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(Mortimer *et al.* 1992) and fitness (Vila-Aiub *et al.* 2009) can greatly influence resistance. The significance of ecological fitness and gene flow in governing the evolution and dynamics of herbicide resistance was demonstrated by Maxwell *et al.* (1990). Model sensitivity analysis is used to identify the prime parameters that influence model dynamics. Some notable ones for which the models were found to be highly sensitive include initial seedbank density, initial frequency of resistance alleles, proportion of seedling recruitment, post-dispersal seed loss, and annual seedbank loss (Neve *et al.* 2011, Bagavathiannan *et al.* 2013). Model analysis revealed that the likelihood for resistance evolution is low under low initial seedbank size, low initial frequency of resistance alleles, low levels of seedling recruitment, high post-dispersal seed loss, and high annual seedbank loss (Fig. 2). Stochasticity is often included in the models to account for likely spatial and temporal variations in parameter values across different production fields and years. Diggle and Neve (2001) outlined the specifics of herbicide resistance simulation modeling and the applications and limitations of various methodologies used in model development.

Examples of model applications

Herbicide resistance simulation models are broadly grouped into simplified major-gene based models, models simulating polygenic resistance evolution, models accounting for spatial heterogeneity in resistance evolution and spread (*i.e.* spatially explicit models), and models used as education and extension tools.

Simplified major-gene-based models: In a pioneering research, Gressel and Segel (1978) used a simple population model in an attempt to identify important factors that influence the evolution of herbicide resistance. They used the model to illustrate the evolution of resistance under conditions of monoculture and/or single herbicide usage. In subsequent research, Gressel and Segel (1990) modeled the effectiveness of herbicide rotations and mixtures for managing resistance. Maxwell *et al.* (1990) used a population model to predict the evolution, spread, and dynamics of resistant and susceptible weed genotypes and found that resistance could evolve rapidly under repeated herbicide applications in the absence of a nearby susceptible source population. Gorddard *et al.* 1995) adopted the resistance simulation model developed by Maxwell *et al.* (1990) and developed an optimal control model for weed management under herbicide resistance, with a goal of finding an economic balance between ongoing control of susceptible weeds and future likelihood for resistance evolution.

Mortimer *et al.* (1992) assessed the fitness of susceptible and resistant biotypes of blackgrass (*Alopecurus myosuroides* Huds.) under different herbicide selection regimes and tested their impacts on resistance. They emphasized that the interaction between density-dependent and density-independent regulations was a critical factor in controlling the frequency of resistance alleles. Using a simple model, Jasieniuk *et al.* (1996) compared the rates of resistance evolution under various mutation rates, management efficacies, and levels of outcrossing. Cavan *et al.* (2000) investigated the effect of cultivation regimes, herbicide factors (rotations and kill rate), initial frequency of resistance alleles, and initial seedbank density on the number of years taken for the evolution of target-site resistance for aryloxyphenoxypropionate (AOPP) and cyclohexanedione (CHD) herbicides in blackgrass. The authors developed a subsequent model (Cavan *et al.* 2001) for predicting and managing the risks of resistance evolution for AOPP and CHD herbicides in wild oat (*Avena fatua* L.). Hanson *et al.* (2002) developed a quantitative model to simulate the evolution of imazamox resistance in jointed goatgrass (*Aegilops cylindrical* Host) in imazamox-resistant wheat (*Triticum aestivum* L.) production in the Pacific Northwest, specifically assessing the impacts of different agronomic practices on the evolution and persistence of resistance in this species.

Gustafson (2008) developed a herbicide resistance modeling system (HERMES) to explore the sustainability of glyphosate in glyphosate-resistant cropping systems. Results suggested that prudent use of additional herbicides are necessary to sustain the utility of glyphosate in North American cropping systems. Werth *et al.* (2008) used a simulation model for guiding the development of a robust crop management plan for minimizing the risk of glyphosate-resistance evolution in some of the major weeds present in Australian glyphosate-resistant cotton production systems. Thornby and Walker (2009) developed a model for predicting the evolution of glyphosate resistance in awnless barnyardgrass/ junglerice (*Echinochloa colona* (L.) Link) in Northern Australian sub-tropical grains farming region and examined the rate of resistance evolution under a range of key model parameters and under conditions expected to result in high selection pressure.

Jacquemin *et al.* (2009) modeled the effect of herbicide mixtures on the evolutionary dynamics of a weed population in which resistance has already occurred for one of the modes of action (MOAs) used in the mixture. Their findings illustrated that use of herbicide mixtures as a resistance management strategy is inadequate if resistance has already been detected in that population. Neve *et al.* (2011) investigated various herbicide use strategies (herbicide mixtures and rotations) applied at various timings to identify effective management options for mitigating the risk of glyphosate resistance evolution in Palmer amaranth (*Amaranthus palmeri* S. Wats) in the midsouthern US cotton production system. Richter *et al.* (2012) developed an evolutionary genetic model, using the joint evolutionary dynamics model of Huillet and Martinez (2011), for understanding the evolution and dynamics of metabolic (monogenic) resistance under field conditions.

Models have also evaluated the risk of multiple herbicide resistance evolution conferred by more than one unlinked major gene. Diggle *et al.* (2003) modeled the risk of multiple resistance evolution conferred by two discrete, unlinked nuclear genes in a finite weed population. They compared the effectiveness of herbicide mixtures and annual herbicide rotations and concluded that herbicide mixtures (or combinations) rather than annual rotations can greatly delay resistance evolution. Bagavathiannan *et al.* (2014a) predicted the risk of simultaneous and independent evolution of resistance to more than one resistance trait (resistance to the acetolactate synthase (ALS) and acetyl-CoA carboxylase (ACCase) inhibitors) in barnyardgrass in mid Southern US rice production. Results illustrated the value of combining multiple effective MOAs (three or more) in minimizing the risk of resistance in this species.

Single-gene based models were also used for risk assessment of transgenic herbicide-resistant crop lines. For instance, Madsen *et al.* (2002) employed a simulation model to understand the risk of glufosinate resistance evolution in weedy rice (*Oryza sativa* L.) in glufosinate-resistant rice production in Latin America.

Models concerned with polygenic resistance: The majority of the existing models are concerned with single major genes, but polygenic resistance is also likely to occur depending on the nature of management regime followed. Gardner *et al.* (1998) modeled strategies for preventing both single-gene based and polygenic resistance and recommended that a revolving dose strategy (*i.e.*, dosage rotation) can be effective in delaying resistance evolution to both modes compared to successive applications of constant doses. Renton (2009) developed the PERTH model (Polygenic Evolution of Resistance To Herbicides), an individual-based simulation model for demonstrating the polygenic basis of resistance evolution in annual ryegrass (*Lolium rigidum* Gaud.) under low herbicide doses. Manalil *et al.* (2012) utilized the PERTH model along with data collected from field study for identification of the resistance mechanism in a ryegrass population selected under low-dose applications and found that resistance was polygenic.

Spatially explicit models: Most models developed so far predict resistance under homogeneous environments. However, production fields are typically heterogeneous and resistance evolution and spread largely occurs at spatially heterogeneous patterns. A small number of models have been developed by accounting for the movement of propagules (*i.e.*, gene flow) in a heterogenous spatial scale. Using a spatio-temporal model, Richter *et al.* (2002) modeled the spread of herbicide resistance in a hypothetical grass weed and suggested that spatial spread of resistance could be minimized by maintaining untreated strips between adjacent production fields. Roux and Reboud (2007) used a model to understand herbicide resistance dynamics in a spatially heterogeneous environment by accounting for the presence of favorable and unfavorable areas across a cultivated landscape. The model outputs indicated that resistance dynamics is governed by interactions among various factors, some of which are not controlled by human and are spatially variable. Liu *et al.* (2010) modeled the spatial spread of glyphosate-resistant common waterhemp (*Amaranthus rudis* Sauer.) in the US Midwest. With maximum wind speeds of 10 m/s, the model predicts resistance movement for less than 20 km in four years. When comparing model outputs with field observations, the authors concluded that factors other than wind (such as movement of farm equipment) may play an important role in the long-distance spread of resistance. Rummland *et al.* (2012) predicted the spatial distribution of resistant loose silkybent (*Apera spica-venti* (L.) P. Beauv.) plants spreading across a production field, by simulating random seed distribution and gene flow using a cellular automation process.

Models as educational tools: Besides their use as research tools, models can also serve as excellent educational tools in transferring research knowledge to growers. These models do not necessarily simulate or predict resistance, but test various combinations of strategies on long-term weed seedbanks and economics, with direct relevance to herbicide resistance management. They tremendously help the extension personnel demonstrate to the clients the benefits of adopting or the penalties of not adopting a given resistance management practice. In fact, growers and crop consultants can themselves use such models to evaluate and compare various weed management strategies on the long-term sustainability and profitability of farming operations. Rainbolt *et al.* (2004) modified a general life cycle model into an extension teaching tool to demonstrate the effects of weed biology factors and crop rotation on resistance evolution in a number of major weed species in the Pacific Northwest dryland wheat-based cropping systems. Stanton *et al.* (2008) developed a risk calculator to enable farmers and crop advisors assess the risk of glyphosate resistance evolution in annual ryegrass in Australia. Another notable example is the ryegrass integrated management (RIM) model, widely adopted in the Australian Southern grainbelt (Pannell *et al.* 2004, Lacoste and Powles 2014). The original RIM model was adapted to other weed species, notably RIMPhil for barnyardgrass (Beltran *et al.* 2011), RIM for wild radish (*Raphanus raphanistrum* L.) (Monjardino *et al.* 2003), PIM for poppy (*Papaver rhoeas* L.) (Torra *et al.* 2010), and PAM for Palmer amaranth (Bagavathiannan *et al.* 2014b). The RIM model has also served as the basis for 'weed seed wizard', a more advanced user-oriented software model for guiding Best Management Practices for herbicide resistance management in Australia (Renton *et al.* 2007).

Challenges and limitations

Simulation models as both research and educational tools have been greatly assisting the development and transfer of valuable knowledge, but there are some limitations and challenges to the development and application of models for resistance management. A prime limitation is the lack of specific data for parameter estimation. Rapid progress has been made over this past decade in collecting necessary biological and management data for supporting model developments, but there is still a long way to go in amassing a comprehensive knowledge base. Specifically, details on mutation rates, initial frequency of resistance alleles, genetic basis of resistance, fitness costs associated with resistance alleles, seedbank dynamics, patterns of gene flow, and metapopulation dynamics within agricultural landscapes is yet to be accumulated. The current models rely heavily on simplifying assumptions and expert opinions in generating predictions. Furthermore, most of the existing resistance simulation models are deterministic (do not account for environmental and demographic stochasticity) and spatially implicit (assume that the production fields are homogeneous). As a result, there are uncertainties on the accuracy of model predictions. Yet, models remain valuable as the best available tool in understanding system behavior, given the limited inherent knowledge of the system. The models will gradually become more robust as more relevant data are continued to be collected.

A model requires validation in order to secure trust among users. Validation can be replicative, predictive or structural (Zeigler 1985, Troitzsch 2004). Replicative and predictive validation deals with match between model predictions and data already acquired or to be acquired from the real system, respectively. Structural validation, however, deals with reproducing real system behavior in a way that the system functions to produce the behavior. Model validation typically presents practical challenges due to the hidden weed population and farming system variables (Rykiel 1996, Thornby and Walker 2009). Moreover, timely validation is critical to make useful decisions for preventing resistance before it is too late. Direct empirical validation from field evidence has been used as a convenient way for model validation in some situations (Neve *et al.* 2011, Bagavathiannan *et al.* 2014a). Even then required information from such field evidences are extremely difficult to obtain because details are recorded only after resistance is noticed, but the field management history over the life of the system is rarely documented (Thornby and Walker 2009). Thus, empirical field validations may be useful, but not adequate.

A number of alternative approaches have been proposed to validate the models. Barlas (1996) suggested that model validations should be based on verification of model structure and output patterns rather than its predictive accuracy. Balci (1995) outlined 15 principles for model validation, emphasizing that it is unreasonable to expect perfect representation of the system since models are only an abstraction of the system in question. Balci (1995) further argued that validation is not a binary variable (correct or incorrect), but is a test of the degree of model credibility and judgment on the model sufficiency for specific applications. Expert knowledge test of model structure was also suggested as a way of validating the model throughout the course of its development (Thornby *et al.* 2009). Although some of the validation approaches noted above may not be ideal, the shortfall should be weighed against the value of the model as a decision-support tool in making timely management decisions.

REFERENCES

Bagavathiannan MV, Norsworthy JK, Lacoste M and Powles S. 2014b. PAM: A decision support tool for guiding integrated management of Palmer amaranth. p. 220. In: *Proceedings of the Weed Science Society of America Annual Meeting*. Vancouver, Canada: Weed Science Society of America.

Bagavathiannan MV, Norsworthy JK, Smith KL and Neve P. 2013. Modeling the evolution of glyphosate resistance in barnyardgrass (*Echinochloa crusgalli*) in cotton-based production systems of the midsouthern United States. *Weed Technology* **27**: 475-487.

Bagavathiannan MV, Norsworthy JK, Smith KL and Neve P. 2014a. Modeling the simultaneous evolution of resistance to ALS- and ACCase-inhibiting herbicides in barnyardgrass (*Echnichloa crus-galli*) in Clearfield® rice. *Weed Technology* **28**: 89-103.

Balci O. 1995. Principles and techniques of simulation validation, verification and testing. pp. 147-154. In: *Proceedings of the Winter Simulation Conference*. Eds. Alexopoulos C, Kang K, Lilegdon WR, Goldsman D.

Barlas Y. 1996. Formal aspects of model validity and validation in system dynamics. *System Dynamics Review* **12**: 183-210.

Beltran JC, Pannell DJ, Doole GJ and White B. 2011. RIMPhil: a bioeconomic model for integrated weed management of annual barnyardgrass (*Echinochloa crusgalli*) in Philippine rice farming systems. *Working Paper 1112*, School of Agricultural and Resource Economics, The University of Western Australia, Crawley, Australia.

Cavan G, Cussans J and Moss SR. 2000. Modelling different cultivation and herbicide strategies for their effect on herbicide resistance in *Alopecurus myosuroides*. *Weed Research* **40**: 561-568.

Cavan G, Cussans J, and Moss S. 2001. Managing the risks of herbicide resistance in wild oat. *Weed Science* **49**: 236-240

Diggle A and Neve P. 2001. The population dynamics and genetics of herbicide resistance - a modeling approach, pp. 61-100. In: *Herbicide Resistance in World Grains* (Eds. Powles SB and Shaner DL), CRC Press, Boca Raton, FL, USA.

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.

Gardner S, Gressel J and Mangel M. 1998. A revolving dose strategy to delay the evolution of both quantitative vs. major monogene resistances to pesticides and drugs. *International Journal of Pest Management* **44**: 161-180.

Gorddard RJ, Pannell DJ and Hertzler G. 1995. An optimal control model for integrated weed management under herbicide resistance. *Australian Journal of Agricultural Economics* **39**: 71-87.

Gressel J and Segel LA. 1978. The paucity of plants evolving genetic resistance to herbicides: possible reasons and implications. *Journal of Theoretical Biology* **75**: 349-371.

Gressel J and Segel LA. 1990. Modelling the effectiveness of herbicide rotations and mixtures as strategies to delay or preclude resistance. *Weed Technology* **4**: 186-198.

Gustafson DI. 2008. Sustainable use of glyphosate in North American cropping systems. *Pest Management Science* **64**: 409-416.

Hanson DE, Ball DA and Mallory-Smith CA. 2002. Herbicide resistance in jointed goatgrass (*Aegilops cylindrica*): simulated responses to agronomic practices. *Weed Technology* **16**: 156-163.

Holst N, Rasmussen IA and Bastiaans L. 2007. Field weed population dynamics: a review of model approaches and applications. *Weed Research* **47**: 1-14.

Huillet T and Martinez S. 2011. Discrete evolutionary genetics: multiplicative fitness and mutation-fitness balance. *Applied Mathematics* **2**: 11-22.

Jacquemin B, Gasquez J and Reboud X. 2009. Modelling binary mixtures of herbicides in populations resistant to one of the components: evaluation for resistance management. *Pest Management Science* **65**: 113-121.

Jasieniuk M, Brûlé-Babel AL and Morrison IN. 1996. The evolution and genetics of herbicide resistance in weeds. *Weed Science* **44**: 176-193.

Lacoste M and Powles S. 2014. Upgrading the RIM model for improved support of Integrated Weed Management Extension efforts in cropping systems. *Weed Technology* **28**: 703-720.

Liu J, Tranel PJ and Davis AS. 2010. Modeling the spread of glyphosate-resistant waterhemp. *Proceedings of the North Central Weed Science Society* **65**: 59.

Madsen KH, Valverde BE and Jensen JE. 2002. Risk assessment of herbicide-resistant crops: a Latin-American perspective using rice (*Oryza sativa*) as a model. *Weed Technology* **16**: 215-223.

Manalil S, Renton M, Diggle A, Busi R and Powles SB. 2012. Simulation modelling identifies polygenic basis of herbicide resistance in a weed population and predicts rapid evolution of herbicide resistance at low herbicide rates. *Crop Protection* **40**: 114-120.

Maxwell BD and Mortimer AM. 1994. Selection for herbicide resistance. pp. 1-25. In: *Herbicide Resistance in Plants: Biology and Biochemistry*. (Eds. Powles SB, Holtum JAM), Lewis Publishers, London, UK.

Maxwell BD, Roush ML and Radosevich SR. 1990. Predicting the evolution and dynamics of herbicide resistance in weed populations. *Weed Technology* **4**: 2-13.

Monjardino M, Pannell DJ and Powles SB. 2003. Multispecies resistance and integrated management: a bioeconomic model for integrated management of rigid ryegrass (*Lolium rigidum*) and wild radish (*Raphanus raphanistrum*). *Weed Science* **51**: 798-809.

Mortimer AM, Ulf-Hansen PF and Putwain PD. 1992. Modelling herbicide resistance-a study of ecological fitness. pp. 283-306. In: *Achievements and Developments in Combating Pesticide Resistance*. (Eds. Denholm I, Devonshire AL and Hollomons DW). Elsevier Science Publishers, Essex.

Neve P, Norsworthy JK, Smith KL and Zelaya IA. 2011. Modelling evolution and management of glyphosate resistance in *Amaranthus palmeri*. *Weed Research* **51**: 99-112.

Pannell DJ, Stewart V, Bennett A, Monjardino M, Schmidt C and Powles SB. 2004. RIM: a bioeconomic model for integrated weed management of *Lolium rigidum* in Western Australia. *Agricultural Systems* **79**: 305-325.

Rainbolt CR, Thill DC, Yenish JP and Ball DA. 2004. Herbicide-resistant grass weed development in imidazolinone-resistant wheat: weed biology and herbicide rotation. *Weed Technology* **18**: 860-868.

Renton M, Peltzer S and Diggle A. 2007. Using the seedbank wizard to understand and manage weed seedbanks. Weeds CRC/UWA/DAFWA. *http://www.hear.org/emapi/2007/pdfs/emapi2007renton.pdf.*

Renton M. 2009. The weeds fight back: individual-based simulation of evolution of polygenic resistance to herbicides, pp. 574-580. In: *International Congress on Modelling and Simulation*. MSSANZ and IMACS (2009), 18th World IMACS Congress and MODSIM09. (Eds. Anderssen RS, Braddock RD, Newham LTH) *http://www.mssanz.org.au/modsim09/*

Richter O, Langemann D and Rumland J. 2012. A discrete evolutionary genetic model for the emergence of metabolic resistance. *Julius-Kühn-Archiv*. **434:** 119-125.

Richter O, Zwerger P and Bottcher U. 2002. Modelling spatio-temporal dynamics of herbicide resistance. *Weed Research* **42**: 52-64.

Roux F and Reboud X. 2007. Herbicide resistance dynamics in a spatially heterogeneous environment. *Crop Protection* **26**: 335-341.

Rummland J, Kerlen D, Nordmeyer H and Richter O. 2012. Modelling the development of herbicide resistance. In: *Proceedings of the 25th German Conference on Weed Biology and Weed Control,* Braunschweig, Germany.

Rykiel EJ Jr. 1996. Testing ecological models: the meaning of validation. *Ecological Modeling* **90**: 229-244.

Stanton RA, Pratley JE, Hudson D and Dill GM. 2008. A risk calculator for glyphosate resistance in *Lolium rigidum* (Gaud.). *Pest Management Science* **64**: 402-408.

Thornby D, Diggle AJ and Walker SR. 2009. Real-world recommendations: do limits to validation constrain model usefulness?, pp. 609-615. In: *International Congress on Modelling and Simulation*. MSSANZ and IMACS (2009), (Eds. Anderssen RS, Braddock RD and Newham LTH). 18th World IMACS Congress and MODSIM Congress. http://www.mssanz.org.au/modsim09/.

Thornby DF and Walker SR. 2009. Simulating the evolution of glyphosate resistance in grains farming in northern Australia. *Annals of Botany* **104**: 747-756.

Torra J, Cirujeda A, Recasens J, Taberner A and Powles SB. 2010. PIM (Poppy Integrated Management): a bio-economic decision support model for the management of *Papaver rhoeas* in rain-fed cropping systems. *Weed Research* **50**: 127-139.

Troitzch KG. 2004. Validating simulation models. *Proceedings of the 18th European Simulation Multiconference*. SCS Europe.

Vila- Aiub MM, Neve P and Powles SB. 2009. Fitness costs associated with evolved herbicide resistance alleles in plants. *New Phytology* **184**: 751-767.

Werth JA, Preston C, Taylor IN, Charles GW, Roberts GN and Baker J. 2008. Managing the risk of glyphosate resistance in Australian glyphosate-resistant cotton production systems. *Pest Management Science* **64**: 417-421.

Zeigler BP. 1985. *Theory of Modelling and Simulation*. Krieger, Malabar.

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Herbicide resistance in weeds: Survey, characterization and mechanisms

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ABSTRACT

This paper presents a systematic diagnostic approach towards the characterization of herbicide resistance in a given weed population with regards to profile (single, multiple, cross resistance), magnitude (fold level), mechanism, and related bio-physiological aspects. Diagnosing herbicide-resistant weeds can be achieved by crafting robust procedures for seed sampling, survey protocol and seed collection, seed processing and storage, germination, emergence and growth (sufficient number of representative plants), treatment conditions (*i.e.,* discriminating dose, adjuvants, spray volume and parameters, water quality, and nutrient status), experimental design, appropriate controls including wild type/susceptible accessions, and biological parameters being measured. Understanding the processes and means by which weeds withstand labeled herbicide treatments is an important step, as well, towards devising effective herbicide resistance management strategies. Several physiological, biochemical, and molecular approaches for studying resistance mechanisms are available to researchers. The various omics approaches including genomics (DNA), transcriptomics (RNA), proteomics (proteins), and metabolomics (metabolites) will revolutionize herbicide resistance research.

Key words: Herbicide resistance, Mechanisms, Omics, Survey

Weeds have been in existence since before humans took up cultivation of plants for food, feed, fuel, and fiber. Before the advent of synthetic organic-based herbicides in the 1940s, weeds were controlled for thousands of years by mechanical, cultural, and biological means. 2,4-Dichlorophenoxy-acetic acid was the first herbicide to be used selectively to control weeds. Since then, several herbicides belonging to different chemical classes and possessing diverse modes of action have been synthesized and commercialized around the world. Herbicides have vastly contributed to increasing world food production in an efficient, economic, and environmentally sustainable manner. However, repeated application(s) of the same herbicide or a different herbicide with a similar mode of action on the same field, growing season after growing season, has contributed to the widespread occurrence of resistance to herbicides in several weed species. The goal of this paper is to present a systematic diagnostic approach towards the characterization of herbicide resistance in a given weed population with regards to profile (single, multiple, cross resistance), magnitude (fold level), mechanism, and related bio-physiological aspects.

Herbicide tolerance versus resistance

The Weed Science Society of America (WSSA) defines herbicide tolerance as "the inherent ability of a species to survive and reproduce after herbicide treatment." This implies that there was no selection or genetic manipulation to make the plant tolerant; it is naturally tolerant. Herbicide resistance is defined as "the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type. In a plant, resistance may be naturally occurring or induced by such techniques as genetic engineering or selection of variants produced by tissue culture or mutagenesis" (WSSA 1998). Herbicide resistance has also been defined as "the evolved capacity of a previously herbicide-susceptible weed population to withstand a herbicide and complete its life cycle when the herbicide is used at its normal rate in an agricultural situation" (Heap and Lebaron 2001).

Definitions used in herbicide resistance literature

Discovery of herbicide resistance in weeds and subsequent research over the past decades has generated a wealth of information, which has contributed to a much better understanding of how plants function and respond to the environment in which they thrive. For example, triazine resistant weeds have served as an ideal model system to understand the mode of action of the photosystem II-inhibiting herbicides. The knowledge accumulated from this research has brought forth several concepts and expressions that are frequently used in herbicide resistance discourse. A non-exhaustive compendium

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of these terms is listed below [selected definitions adapted from Raven *et al.* (1992)].

Accession. A collection of individual plants of a weed species whose characteristics (genetic, physiological, biochemical, or biological) are yet to be determined.

Allele. An alternative form or copy of a gene.

Biotype. A plant selection that has a unique genotypic pedigree.

Cross-Resistance. The expression of a mechanism that endows the ability to withstand herbicides from the same or different chemical classes with similar mode of action (Hall *et al.* 1994). It can be target-site based or nontarget-site based (reduced uptake, translocation, activation; increased metabolism-deactivation; compartmentation/sequestration).

Dominance. State of an allele whose phenotypic expression is similar both in the homozygous and heterozygous stages.

Ecotype. A biotype that has adapted to a specific growing environment.

Evolution. Progressive change in the gene pool of a given weed (species) population in response to most recent growing conditions (herbicides in this context).

Fitness. Ability of a biotype to survive and reproduce in an environment that may or may not include herbicide treatment.

Genotype. The complement of a plant's complete hereditary information.

Hormesis. Stimulation of growth processes in plants treated with low doses of herbicide(s).

Inheritance. Process of transfer of a genetic trait from one generation to the next.

Mating System. System by which pollen moves from the anthers to the stigma of the same flower or different flowers on the same plant (self-pollination), or to stigma of flowers on a different plant (cross-pollination) of a weed species.

Multiple Resistance. The expression of more than one resistance mechanism endowing the ability to withstand herbicides from different chemical classes (Hall *et al.* 1994). Multiple-resistant plants may possess two or more distinct resistance mechanisms (Gunsolus 1993).

(Gene) Mutation. An inheritable change to genetic material or the process resulting in such a change.

Negative Cross-Resistance. An expression of mechanism that occurs when a resistant biotype is more susceptible to other classes of herbicides than the susceptible biotype (Gressel 1991).

Population. A group of plants of a single weed species with potential to interbreed and inhabit a specific geographic area.

Recessive. Condition of an allele whose expression is veiled by a dominant allele in the heterozygous stage.

Selection Pressure. The effectiveness of natural selection in altering the genetic composition of a population over a series of generations (King and Stansfield 2002).

Target Site. A gene or gene product (protein) on which a herbicide is potently inhibitory.

Trait. A genetic characteristic of interest.

Diagnosis of herbicide resistance

Diagnosing herbicide-resistant weeds is a first step in resistance management, and monitoring their nature, distribution, and abundance demands efficient and effective screening tests (Beckie *et al.* 2000). This can be achieved by crafting robust procedures for seed sampling, survey protocol and seed collection, seed processing and storage, germination, emergence and growth (sufficient number of representative plants), treatment conditions (*i.e.*, discriminating dose, adjuvants, spray volume and parameters, water quality, and nutrient status), experimental design, appropriate controls including wild type/susceptible accessions, and biological parameters being measured.

Field survey and seed sampling

An appropriate and unbiased sampling procedure is required to accurately detect or predict the occurrence of herbicide resistance in a weed population. Grower surveys, cropping and herbicide application history, on-site visual examination of fields, and data from grain elevators, seed cleaning facilities, or cotton gins are common sources of information to decide survey objectives, techniques, and extent of survey.

Selection of a field site for collecting suspect weeds depends upon the objective (Beckie *et al.* 2000). For example, investigation of poor herbicide performance in a particular field, the occurrence of resistance in one or more weed species to a particular herbicide or to herbicides with the same or different sites of action, grower suspicion of resistant weeds in a field, broad nonperformance of a particular herbicide or herbicide chemistry, or a roadside survey will determine the extent of the survey and techniques to be used.

A large field could be divided in to workable sub-units and each sub-unit may be sampled separately. A larger geographic area could be divided in to sectors and each sector may be further categorized in to smaller sub-divisions for convenience and accuracy of sampling. Roadside surveys are convenient, rapid, and cover a large sampling area. Seed collected from individual plants must be kept separate if the sampling area is small or if suspect weed infestation is patchy. Samples from large fields or sampling areas may be bulked, but a few representative samples must be kept separate as a reference. Prior knowledge of biology of the weed species is advantageous to avoid unnecessary sampling of 'seed heads' from male plants in case of dioecious genera such as Palmer amaranth (*Amaranthus palmeri* S. Wats.) and waterhemp (*Amaranthus tuberculatus* Moq. Sauer) or nonsampling of seed-bearing nodes in monoecious ragweeds that are distal to the male flower-bearing terminal nodes.

As far as possible, detailed information on cropping and herbicide history must be acquired. Accurate records of site at time of sampling should be noted such as condition of field (dry or wet), weather conditions, date and time of the day during collection, global positioning system (GPS) location of site, crop and crop growth stage (if crop present), growth stage of weed, level of infestation, general weed control in the field (if crop present), and any other discernable information such as neighboring fields, etc. Seed samples collected from suspect fields must be dried in properly ventilated and dry areas to prevent microbial contamination and physiological deterioration.

Dose response

Typically, dose response experiments are performed on whole plants. Herbicide treatments are applied within a window of growth stages of the weed species based on the herbicide label. Further, additives/adjuvants and spray delivery volume are determined centered on label recommendations. Potentially resistant plants are compared with characterized susceptible/wild type plants of the same weed species. Herbicide dose range for the resistant biotype/population/accession should encompass the recommended label rate as well as rates above and below. Herbicide doses for the susceptible biotype/accession must include the recommended rate as well as doses low enough to capture the lowest measurable phytotoxic symptomology.

The following criteria for dose response studies are adapted from Beckie *et al.* (2000). Six to eight herbicide doses are recommended for evaluation of potentially herbicide resistant weed populations. Herbicide injury is measured as a visual estimate or mortality or growth reduction. Resistance is determined by comparing the dose response of the resistant plants to the susceptible plants. A nonlinear regression model is fitted to the data to explain the response of measured biological data to the herbicide dose range. The herbicide dose required to cause a 50% inhibition of growth (% control – ED_{50}; shoot dry weight – GR_{50}; mortality – LD_{50}) is extrapolated from the regression equation based on parameters of the fitted model. Resistance index or the relative proportion of resistance if calculated by dividing the value for resistant plants by the value for susceptible plants.

Dose response experiments involving application of herbicides on whole plants require greenhouse/growth chamber space, access to a spray chamber or backpack sprayer, pots, trays, soil, fertilizer, and support personnel. All of these facilities require availability of adequate financial resources. Also, screening a large collection of putative resistant accessions is often time consuming and labor intensive. An alternative could be the utilization of other methods such as plant cuttings (Boutsalis 2001), germinating and growing seedlings in Petri plates or 24-cell culture cluster plate (Shaner 2010), or floating excised whole leaves or leaf discs (Koger *et al.* 2005). However, the level of variability in a weed population makes it difficult to obtain consistent measurements to accurately assess resistance in a population (Shaner 2010).

Bioassays

A biological assay, or bioassay in short, is a study or research project that investigates effect(s) of a treatment on a particular process in a living organism. Bioassays can play a major role in determining inherent differences between putative resistant and known susceptible biotypes of a weed species. Several biochemical and physiological processes in plants, based on response to herbicidal treatments, have been characterized via bioassays to test for herbicide resistance. These include photosynthesis, transpiration, chlorophyll biosynthesis, shikimate accumulation, *etc.* (briefly reviewed by Shaner 2010).

Herbicide resistance mechanisms

Understanding the processes and means by which weeds withstand labeled herbicide treatments is an important step, as well, towards devising effective herbicide resistance management strategies. In general, five modes of herbicide resistance have been identified in weeds: (1) altered target site due to a mutation at the site of herbicide action resulting in complete or partial lack of inhibition; (2) metabolic deactivation, whereby the herbicide active ingredient is transformed to nonphytotoxic metabolites; (3) reduced absorption and/or translocation that results in restricted movement of lethal levels of herbicide to point/site of action; (4) sequestration/compartmentation by which a herbicide is immobilized away from the site of action in cell organelles such as vacuoles or cell walls; and (5) gene amplification/ over-expression of the target site with consequent dilution of the herbicide in relation to the target site.

Physiological, biochemical, and molecular approaches for studying resistance mechanisms

Current methodologies employed in herbicide resistance mechanisms research include: biochemical (enzyme kinetics and assays), physiological [photosynthesis, transpiration, respiration, chlorophyll biosynthesis, absorption and translocation using radioisotopes (Nandula and Vencill 2015)], and molecular [DNA/RNA-based: polymerase chain reaction (PCR) and single nucleotide polymorphisms (SNP), DNA sequencing, or quantitative PCR (qPCR)] techniques (Fig. 1). Newer mechanisms of herbicide resistance will most likely be discovered in the near future through the applications of 'omics' tools (Fig. 1).

Omics aims at the collective characterization and quantification of pools of biological molecules that translate into the structure, function, and dynamics of an organism or organisms. The various omics approaches include genomics (DNA), transcriptomics (RNA), proteomics (proteins), and metabolomics (metabolites) (Délye 2013). Also, recent advances in molecular analysis such as next generation sequencing (NGS: RNA-Seq, and restriction site associated DNA sequencing (RAD-Seq)) are rapidly becoming routine.

Conclusion

Accurate and timely diagnosis of the nature and level of herbicide resistance in a weed population and knowledge about the inherent resistance mechanism(s) involved will greatly strengthen efforts towards devising sound herbicide resistant weed management strategies. New technologies, especially, molecular tools such as NGS and 'omics' approaches, are revolutionizing herbicide resistance research.

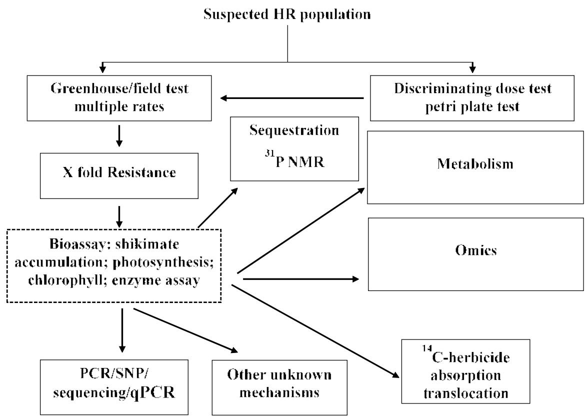

Fig. 1. Sequence of methods for testing herbicide resistance in weeds (modified from Shaner 2010).

REFERENCES

Beckie HJ, Heap IM, Smeda RJ and Hall LM. 2000. Screening for herbicide resistance in weeds. *Weed Technology* **14**: 428-445.

Boutsalis P. 2001. Syngenta quick test: a rapid whole-plant test for herbicide resistance. *Weed Technology* **15**: 257-263.

Délye C. 2013. Unravelling the genetic bases of non-target-site-based resistance (NTSR) to herbicides: a major challenge for weed science in the forthcoming decade. *Pest Management Science* **69**: 176-187.

Gressel J. 1991. Why get resistance? It can be prevented or delayed, pp. 1-25. In: *Herbicide Resistance in Weeds and Crops* (Eds. Caseley JC, Cussans GW and Atkin RK). Butterworth-Heinemann, Oxford, UK.

Gunsolus JL. 1993. *Herbicide Resistant Weeds*. North Central Regional Extension Publication 468. Minnesota Extension Service, University of Minnesota, St. Paul, MN, USA.

Hall LM, Holtum JAM and Powles SB. 1994. Mechanisms responsible for cross resistance and multiple resistance, pp. 243-261. In: *Herbicide Resistance in Plants: Biology and Biochemistry* (Eds. Holtum JAM and Powles SB). Lewis Publishers, Boca Raton, FL, USA.

Heap I and Lebaron H. 2001. Introduction and review of resistance, pp. 1-22.In: *Herbicide Resistance and World Grains* (Eds. Shaner DL and Powles SB). CRC Press, Boca Raton, FL, USA.

King RC and Stansfield WD. 2002. *A Dictionary of Genetics*. Oxford University Press, Oxford, UK.

Koger CH, Shaner DL, Henry WB, Nadler-Hassar T, Thomas WE and Wilcut JW. 2005. Assessment of two nondestructive assays for detecting glyphosate resistance in horseweed (*Conyza canadensis*). *Weed Science* **53**: 559-566.

Nandula VK and Vencill WK. 2015. Herbicide absorption and translocation in plants using radioisotopes. *Weed Science* (Special Issue) **63**: 140-151.

Raven PH, Evert RF and Eichhorn SE. 1992. Pp. 737-762. *Biology of Plants*, 5th ed. Worth Publishers, New York, USA.

Shaner DL. 2010. Testing methods for glyphosate resistance, pp. 93-118. In: *Glyphosate Resistance in Crops and Weeds: History, Development, and Management* (Ed. Nandula VK). John Wiley & Sons, Inc., Hoboken, NJ, USA.

Weed Science Society of America (WSSA). 1998. Herbicide resistance and herbicide tolerance defined. *Weed Technology* **12**: 789.

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Genomic distribution of EPSPS copies conferring glyphosate resistance in Palmer amaranth and kochia

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ABSTRACT

Palmer amaranth and kochia are major problem weeds in many cropping systems in the United States. Wide acceptance of glyphosate tolerant crop technology has resulted in extensive use of glyphosate, consequently, a number of weeds including Palmer amaranth and kochia evolved resistance to glyphosate throughout the US. Within a span of 5-7 years the glyphosate resistance in these weeds has spread extensively, devastating several major crops. Understanding the mechanisms of herbicide resistance is valuable to determine the level of resistance as well as how the resistance spreads in the populations. Glyphosate resistance mechanisms in Palmer amaranth and kochia have been investigated extensively. Although resistance to glyphosate has evolved as a result of amplification of 5-enolpyruvylshikimtate-3-phosphate synthase (EPSPS), the target site of glyphosate, but the distribution and configuration of amplified copies of EPSPS gene in the genomes of these two species is different. The EPSPS gene amplification may have possibly mediated by transposons in Palmer amaranth and whereas, likely to have resulted because of unequal recombination in kochia. These findings suggest that the EPSPS amplification can occur via different mechanisms in different weeds. Evolution of glyphosate resistance as a result of EPSPS gene amplification is a threat to long-term sustainability of glyphosate-resistant crop technology.

Key words: EPSPS, Gene amplification, Glyphosate resistance, Glyphosate, Kochia, Palmer amaranth

Glyphosate is widely used for wide spectrum weed control in both cropland and non-crop land, more importantly, in Roundup Ready cropping systems. Originally, when glyphosate was introduced for weed control, it was extensively used as a non-selective herbicide, for vegetation management in non-crop areas. Upon introduction of glyphosate-resistant (GR) crops in the late 1990, combined with wide acceptance of this technology, led to accelerated use of this herbicide totaling ~128 million ha worldwide in 2012 (James 2012). Adoption to GR crop technology has made a significant contribution to global agriculture and the environment as it not only increased farm income by $32.2 billion (Brookes and Barfoot 2013) but also moderated the negative environmental impacts of mechanical weed management practices (Bonny 2011; Gardner and Nelson 2008). This was possible because, glyphosate offers a simple, effective and economic weed management option in GR crops. In addition, it provides immense value in no-till crop production systems by enabling soil and moisture conservation. However, consequence of extensive use of glyphosate resulted in intensive selection pressure. As a result, several weed populations globally have evolved resistance to glyphosate. Herbicide resistance, in particular the recent proliferation of glyphosate resistance in weed species worldwide is a major crop protection threat; nearly two dozen GR weed species have been reported in the last 15 years (Heap 2015).

Glyphosate inhibits 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) enzyme, impairing conversion of shikimate to chorismate in the shikimate pathway (Amrhein *et al.* 1980, Duke and Powles 2008). This metabolic pathway facilitates the synthesis of aromatic amino acids: phenylalanine, tyrosine, and tryptophan. Glyphosate, acts as a competitive inhibitor of EPSPS, leading to accumulation of shikimate and plant death occurs as a result of lack of aromatic amino acid synthesis (Duke and Powles 2008).

It was hypothesized that the likelihood of weeds evolving resistance to glyphosate is negligible (Bradshaw *et al.* 1997), primarily because of its complex biochemical interactions in the shikimate pathway, and also due to the absence of known

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glyphosate metabolism in plants. Nonetheless, several cases of glyphosate resistance were confirmed throughout the world (Heap 2015). The first case of glyphosate resistance was reported in rigid ryegrass (*Lolium rigidum*) in Australia in 1996, the same year GR-crop technology was first released in the market (Baerson *et al*. 2002). Currently, there are 32 glyphosate resistant weeds in 22 different countries around the world (Heap 2015). The main factor driving this increase in resistance to glyphosate is over reliance on this single chemical option for weed control in GR minimum till production in many cropping systems (Duke and Powles 2008).

Several different mechanisms of glyphosate resistance have been reported in weeds. These mechanisms can be grouped into two broad categories: Non-target-site and target-site based. Non-target-site resistance to glyphosate involves physiological and biochemical processes that prevent the herbicide from reaching its intended site of action, while target-site based resistance involves changes to the site-of-action of glyphosate, *i.e*. EPSPS. Non-target based mechanism of glyphosate resistance, as a result of reduced translocation was documented in rigid ryegrass, common waterhemp and horseweed (Preston and Wakelin 2008), whereas sequestration or compartmentalization of glyphosate into vacuole was also reported in horseweed (Sammons and Gaines 2014). The known target-site based glyphosate resistance mechanisms include mutations (Baerson *et al.* 2002) or duplication/amplification (Gaines *et al*. 2010) of EPSPS gene. Importantly, duplication/amplification of the EPSPS appears to be the basis for glyphosate resistance in several weeds (Sammons and Gaines 2014). The mechanisms of glyphosate resistance in weeds has been comprehensively reviewed by Sammons and Gaines (2014). The purpose of this review is to discuss the mechanisms of evolution of glyphosate resistance via EPSPS gene amplification using two important weeds, Palmer amaranth and kochia as examples.

EPSPS gene amplification mechanisms

Generally, amplification of EPSPS gene causes increased expression, elevated enzyme activity, and higher protein content of the gene (Sammons and Gaines 2014). This increase in the EPSPS gene copies results in excessive amount of the enzyme production, which in turn acts like a sponge, binding and deactivating glyphosate in solution, while the remaining unbound portion of EPSPS functions normally, ensuring plant growth and development. This has become a very widespread mechanism of glyphosate resistance, and screening for elevated EPSPS copy number has become a normal procedure in determining glyphosate resistance in weeds (Sammons and Gaines 2014). Glyphosate resistance, mediated by EPSPS gene duplication has been reported in many species such as Italian ryegrass (Salas *et al.* 2011), kochia (*Kochia scoparia*) (Jugulam *et al.* 2014, Wiersma *et al.* 2014), Palmer amaranth (Gaines *et al*. 2010, *et al.* 2012, Mohseni-Moghadam *et al.* 2013), and waterhemp (Chatham 2015). This mechanism has been extensively studied, and increase in EPSPS copies correlated positively with increased level of resistance to glyphosate when compared to susceptible plants with lower EPSPS copy number (Gaines *et al*. 2010 and Jugulam *et al*. 2014). It has been found that different species require different EPSPS copy numbers to confer resistance to glyphosate. For example, Palmer amaranth from Georgia and elsewhere in the United States required 30 to 50 copies of glyphosate to survive a field dose of glyphosate (868 g ae/ha) (Gaines *et al.* 2010, 2011). Other species, such as kochia needed 3-10 copies for withstanding the same field use rate of glyphosate (Jugulam *et al*. 2014; Wiersma *et al.* 2014).

EPSPS gene amplification in GR Palmer amaranth

The first case of EPSPS gene amplification-based glyphosate resistance was reported in a Palmer amaranth population from Georgia, USA (Gaines *et al*. 2010). In this population, there is a massive increase (>100-fold relative to glyphosate-susceptible plants) in EPSPS copies (Gaines *et al*. 2010). The copy number threshold necessary for glyphosate resistance and inheritance are most likely explained by the genetic mechanisms involved in EPSPS amplification in this species. Florescence in situ hybridization (FISH) of glyphosate-resistant Palmer amaranth (Gaines *et al*. 2010) suggests that EPSPS copies spread throughout the genome and they hypothesize that this pattern of distribution of EPSPS copies may have been facilitated via transposable elements. This hypothesis was tested in another study by Gaines *et al*. (2013). The results of this study suggest that miniature-repeat transposable elements (MITEs) are found closer to EPSPS gene. Furthermore, Activator (Ac) transposases and repetitive sequences associated with transposons were also found. Although this study does not conclusively suggest the involvement of transposable elements in EPSPS copy distribution, it provides some evidence for a possible role of these elements in gene duplication in GR Palmer amaranth. On the other hand, EPSPS gene amplification was found to be caused as a result of amplification of only one of two

EPSPS alleles (Gaines *et al.* 2013, Wiersma *et al.* 2014) in kochia. The other allele is present only in susceptible plants. No evidence of alternative splicing of the EPSPS gene has been seen in kochia, and no other genes seem to have their expression reduced as a result of elevated EPSPS copy number. Furthermore, glyphosate-resistant Palmer amaranth also show no fitness penalty in the absence of herbicide with increases in gene copy number and expression. Palmer amaranth plants with increased EPSPS copy number and expression were found to grow and reproduce similar to susceptible plants, so this trait will most likely persist in the absence of selection by glyphosate (Giacomini *et al.* 2104).

EPSPS gene amplification in GR kochia

Field-evolved GR kochia populations were first reported in western KS, USA in 2007 (Heap 2015). However, it quickly widespread throughout the US Great Plains and Canadian Provinces by 2013 (Heap 2015). The evolution of GR in kochia populations is also attributed to amplification of the EPSPS gene (Wiersma *et al.* 2014). Unlike in GR Palmer amaranth, EPSPS: acetolactate synthase (ALS) copies ranging from 3 to 9 were found in GR kochia (Jugulam *et al.* 2014, Wiersma *et al.* 2014). GR kochia populations were 3- to 11-times resistant (population level) to glyphosate compared to a glyphosate susceptible population. Similar to GR Palmer amaranth, EPSPS expression was also positively correlated with EPSPS copies (Wiersma *et al.* 2014). FISH results of GR kochia indicate that unlike in Palmer amaranth, all the amplified EPSPS copies are located on two homologous chromosomes, and these copies are aligned in tandem on these chromosomes as illustrated by fiber FISH analyses (Jugulam *et al.* 2014). Continuous variation in EPSPS copies, and a positive correlation between EPSPS expression and copies (Wiersma *et al.* 2014), suggests that the EPSPS copy number in kochia increases through an adaptive process. Furthermore, hybridization of EPSPS probes at distal ends of homologous chromosomes of kochia also suggests that duplication of EPSPS gene in GR kochia may have occurred as a result of unequal crossover, because, the gene duplication via unequal crossover most likely occurs at telomere region of chromosomes (Royle *et al.* 1988, Amarger *et al.* 1998, Ames *et al.* 2008).

The natural occurrence of EPSPS gene amplification in GR weeds is becoming prevalent in more weeds and this will be a threat to sustainable use of glyphosate in crop production. As discussed above, massive amplification of the EPSPS gene and distribution of these copies throughout the genome (Gaines *et al.* 2010), likely mediated by transposable elements (Gaines *et al.* 2013), has been found in GR Palmer amaranth. On the other hand, EPSPS copies arranged in tandem on a single chromosomes was reported from our laboratory (Jugulam *et al.* 2014). More importantly, these results trigger an intriguing question about the mechanisms of glyphosate, specifically whether EPSPS copy number increased in response to a positive selection or whether rare plants with multiple copies existed prior to selection. Therefore, uncovering molecular basis of EPSPS gene amplification mechanisms will help us understand how plants will respond to glyphosate selection resulting in evolution and spread of resistance to this important herbicide.

REFERENCES

Amarger V, Gauguier D, Yerle M, Apiou F, Pinton P, Giraudeau F, Monfouilloux S, Lathrop M, Dutrillaux B and Buard J. 1998. Analysis of distribution in the human, pig, and rat genomes points toward a general subtelomeric origin of minisatellite structures. *Genomics* **52**: 62-71.

Ames D, Murphy N, Helentjaris T, Sun N and Chandler V. 2008. Comparative analyses of human single- and multilocus tandem repeats. *Genetics* **179**: 1693-1704.

Amrhein N, Deus B, Gehrke P and Steinrücken HC. 1980. The site of the inhibition of shikimate pathway by glyphosate. *Plant Physiology* **66**: 830-834.

Baerson SR, Rodriguez DJ, Tran M, Feng Y, Biest NA and Dill GM. 2002. Glyphosate-resistant goosegrass: Identification of a mutation in the target enzyme 5-enolpyruvylshikimate-3-phosphate synthase. *Plant Physiology* **129**: 1265-1275.

Bonny S. 2011. Herbicide-tolerant transgenic soybean over 15 years of cultivation: Pesticide use, weed resistance, and some economic issues. The case of the USA. *Sustainability* **3**: 1302-1322.

Bradshaw LD, Padgette SR, Kimball SL and Wells BH. 1997. Perspectives on glyphosate resistance. *Weed Technology* **11**: 189-198.

Brookes G and Barfoot P. 2013. The global income and production effects of genetically modified (GM) crops 1996-2011. *GM Crops Food* **4**: 74-83.

Chatham LA, Bradley KW, Kruger GR, Martin JR, Micheal JR, Owen DK, Peterson DE, Mithila J and Tranel PJ. 2015. A multi-state study of the association between glyphosate resistance and EPSPS gene amplification in waterhemp (*Amaranthus tuberculatus*). *Weed Science* **63**: 569-577.

Duke SO and Powles SB. 2008. Glyphosate: A once-in-a-century herbicide. *Pest Management Science* **64**: 319-325.

Gaines TA, Ward SM, Bukun B, Preston C, Leach JE and Westra P. 2012. Interspecific hybridization transfers a previously unknown glyphosate resistance mechanism in *Amaranthus* species **5**: 29-38 DOI: 10.1111/j.1752-4571.2011.00204.x

Gaines TA, Wright AA, Molin WT, Lorentz L, Riggins CW, Tranel PJ, Beffa R, Westra P and Powles SB. 2013. Identification of genetic elements associated with EPSPS gene amplification. *PLOS One* **8**: e65819.

Gaines TA, Zhang W, Wang D, Bukun B, Chisholm ST, Shaner DL, Nissen SJ, Patzoldt WL, Tranel PJ and Culpepper AS.2010. Gene amplification confers glyphosate resistance in *Amaranthus palmeri*. *Proceedings of National Academy of Science* **107**: 1029-1034.

Gardner JG and Nelson GC. 2008. Herbicides, glyphosate-resistance and acute mammalian toxicity: simulating an environmental effect of glyphosate-resistant weeds in the USA. *Pest Management Science* **64**: 470-478.

Giacomini D, Westra P and Ward SM. 2014. Impact of genetic background in fitness cost studies: An example from glyphosate-resistant Palmer amaranth. *Weed Science* **62**: 29-37.

Heap I. 2015. The international survey of herbicide resistant weeds. Accessed September 13, 2015. Online. Internet. *Available at: www.weedscience.com.*

Hoen DR, Park KC, Elrouby N, Yu Z, Mohabir N, Cowan RK and Bureau TE. 2006. Transposon-mediated expansion and diversification of family ULP-like genes. *Molecular Biology and Evolution* **23**: 1254-1268.

James C. 2012. 2012 ISAAA report on global status of Biotech/GM Crops. In: *International Service for the Acquisition of Agri-Biotech Applications Brief 44-2012*, Ithaca.

Jugulam M, Niehues K, Godar A, Koo DH, Danilova T, Friebe B, Sehgal S, Varanasi V, Wiersma A, Westra P, Stahlman PW and Gill BS. 2014. Tandem amplification of a chromosomal segment harboring 5-enolpyruvylshikimate-3-phosphate synthase locus confers glyphosate resistance in kochia *scoparia*. *Plant Physiology* **166**: 1200-1207.

Mohseni-Moghadam M, Schroeder J and Ashigh J. 2013. Mechanism of resistance and inheritance in glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) populations from New Mexcico, USA. *Weed Science* **61**: 517-525.

Preston C and Wakelin AM. 2008. Resistance to glyphosate from altered herbicide translocation patterns. *Pest Management Science* **64**: 372-376.

Ribeiro DN, Pan Z, Duke SO, Nandula VK, Baldwin BS, Shaw DR and Dayan FE. 2014. Involvement of facultative apomixes in inheritance of EPSPS gene amplification in glyphosate-resistant *Amaranthus palmeri*. *Planta* **239**: 199-212.

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Weed management in cotton: The potential of GM crops

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ABSTRACT

In recent times, biotechnology has been widely used for crop improvement. Today, about 2 billion hectares of global area is planted with genetically modified (GM) crops. In India, the first GM crop to be introduced was Bt cotton. The current acreage planted with Bt cotton is 93% of the total cotton acreage. However, the average yield is lower than that of other countries suggesting an opportunity to increase yield further. One of the major factors affecting yield is weed competition which reduces yield by 50 to 85%. Effective weed control is achieved by Integrated Weed Management (IWM) which includes adoption of transgenic herbicide tolerant crops (HTCs). The major transgenic HTCs grown in the world are soybean, cotton, corn and canola and the yield increase due to effective weed management is significant. In cotton, glyphosate and glufosinate tolerant systems have been used successfully across the globe and are being tested at the moment in India. Over reliance on single MOA (mode of action) rather than a diversified IWM system with multiple, complementary herbicide MOAs can lead to emergence of herbicide tolerant weeds. Therefore, there is a need to use diversified management practices for sustainable weed control in cotton.

Keywords: Cotton, Genetically modified, Glufosinate, Glyphosate, Herbicide, Integrated weed management, Yield

Global population is on the rise and has reached 7 billion. In India alone, the population is 1.2 billion. However, the area under cultivation is on the decrease and the current food production will not meet the growing demand. There is an immediate need to increase crop productivity to meet this demand. This necessitates the use of better seeds, better hybrids, germplasm, improved agronomic practices and novel technologies for enhancing crop productivity and yield. Biotechnology has opened the doors to improving productivity with the introduction of genetically modified crops. Ever since the first release of biotech crops, there has been an increase in the rate of adoption of these crops globally. In 2015, 28 countries planted biotech crops and it is estimated that more than half the world's population lives in these 28 countries (James, 2015). Soybean and cotton are the major biotech crops to be widely cultivated (Fig. 1).

In India, cotton is an important commercial crop supporting the livelihood of about 7.7 million farmers. Cotton occupies an area of 12.25 million ha of which 11.6 million ha (94%) is genetically modified cotton (Bt cotton) (Choudhary and Gaur, 2015). India is the second largest exporter of cotton (FICCI report, 2012). In the last seven decades that cotton has been grown, production and productivity have steadily increased. However, in the last few years it appears to have reached a plateau. Current production is about 39 million bales (Choudhary and Gaur, 2015). The low production/productivity is attributed to lack of appropriate micronutrient and fertilizer management, prevalence of sucking pests, weeds, small farm area and more of the cotton acreage being grown in drought prone regions (GAIN report 2013). The current average yield of 500 kg/ha is significantly lower than other countries like Brazil (1393 kg/ha)

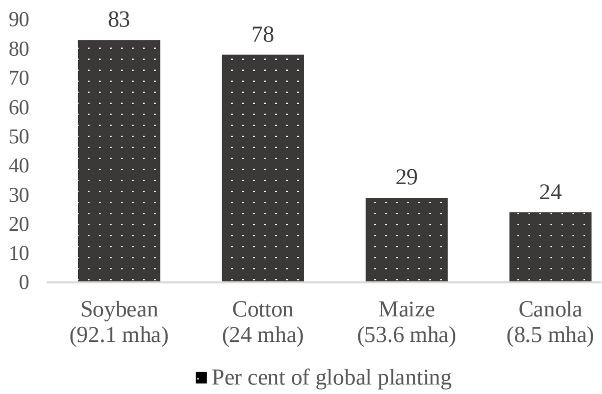

Fig. 1. Biotech crop area as per cent of global area planted for principal crops (million hectares) (James 2015)

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(The Crop Site 2013), China (1311 kg/ha) and USA (900 kg/ha) (FICCI report 2012). There is an increasing demand for cotton fiber, both for local consumption (27.5 million 170 kg bales) as well as export to other countries. Further, consumption of cotton seed oil for domestic use is increasing as it is economical and the keeping quality is also better (Economic Times 2013). This huge gap in the production and demand opens up tremendous opportunities to increase yield (GAIN Report 2013, Economic Times 2014).

Yield in cotton is dependent on the climatic conditions, rainfall pattern, weed competition and incidence of pests and diseases. Weeds are a potential problem in cotton cultivation and reduce yield by 50 to 85% depending upon the nature and intensity (Jain *et al.* 1981). Weeds also enhance production costs posing an income risk to the farmers (Frisvold *et al.* 2009).Weed management therefore assumes prime importance. This review focuses on the different methods for weed management and gives a brief insight into the current technology available.

Impact of weeds on cotton

Cotton is a long duration crop and typically takes about 140-160 days to complete its life cycle. Throughout the growth cycle it is exposed to weeds and the competition therein. Every crop has a critical period of weed control (CPWC) which refers to the minimum time period during which the crop must be weed free. In cotton, the CPWC is the first 15 to 60 days (Ayyadurai and Poonguzhalan 2011). Maximum yield can be derived when there is at least 95% weed control (Sharma 2008).

Weeds compete for available resources like sunlight, water, nutrients and space. In fields infested by weeds, the top soil is drier compared to weed free plots and this is attributed to a higher extent of water removal from the top 15cm of soil. Smooth pig weed (*Amaranthus hybridus*) reduced soil moisture content from depths of 122 to 183 cm to a greater extent than cotton. Weed competition after the first and second irrigation cycles reduces yield to an extent of 20 per cent. In terms of competition for nutrients, weeds deplete the soil by removing 5-6 times Nitrogen, 5-12 times Phosphorous and 2-5 times Potassium than cotton crop thus reducing yields by 54-85 per cent (Information from ikisan http://www.ikisan.com/ Cropper cent20Specific/Eng/links/knt_cotton Weedpercent20Management.shtml). Grassy weeds, which grow in the cotton rows or which get blown into cotton are difficult to remove and stain the lint reducing fiber quality (Charles and Roberts 2013). Weeds also serve as hosts for insect pests (Table 1) and diseases resulting in increased production costs ultimately reducing yield. It has been shown that weeds could also release allelopathic chemicals suppressing growth of cotton (Riffle et al, 1987). However, the impact of weeds on growth and yield is dependent on the type of weeds, the extent of spread and their duration during the crop growth period (Chiunnuswamy and Chinnagounder 2013).

Table 1. Weeds in cotton serving as alternate hosts to different pests of cotton

Weed species serving as alternate hosts	Insect pests
Datura ferox, *Lantana camera*, *Nicandra physaloides*	American boll worm (*Helicoverpa armigera)*
Abutilon spp., *Sida* spp., *Hibiscus panduraeformis*, *Urena lobata*, *Chorchorus* sp.	Spotted bollworm (*Erias* spp.)
Hibiscus esculentus, Hibiscus panduraeformis, Abutilon indicum.	Pink bollworm (*Pectinophora gossypiella*)
Malva parviflora, Hibiscus spp., *Urena lobata*	Shoot weevil (*Alcidodes affaber*)

Based on the soil and climatic conditions weed flora are diverse with the major categories being grasses and broad-leaved weeds. The most prevalent weeds across cotton fields in India are *Cyanodon dactylon*, *Cyperus rotundus*, *Panicum ripens*, *Euphorbia* sp. and *Trianthema potulacstrum*. Weeds specific to different cotton growing regions in India (Table 2) has been documented by Nagrare *et al.*(2011).

Table 2. List of weeds specific to different cotton growing areas in India

Region/State	Weeds
Tamil Nadu	*Dactyloctenium aegyptium*
Karnataka	*Abutilon indicum, Panicum isachne, Bracharia romosa, Bracharia cruciformis, Euphorbia geniculata, Tridax procumbens, Flavaria australasica and Setaria* sp. *Digitaria marginata,* and *Amarathus* sp.
Andhra Pradesh	*Corchorus olitorius, Abutilon indicum* and *Sida acuta*
Punjab	*Silene conoidea* and *Sphenoclea zeylanica*
Haryana	*Trianthema portulacastrum, Helianthus,Cyamopsis tetragonoloba*
Maharashtra	*Trianthema portulacastrum, Digera muricata, Taraxacum officinale, Euphorbia* sp., *Abutilon indicum*
Gujarat	*Trianthema portulacastrum, Digera muricata, Taraxacum officinale, Euphorbia* sp., *Abutilon indicum*

In a field study conducted at Regional Agricultural Research Station, Lam, Guntur appli-cation of post- emergence herbicides increased yield by 66-75% compared to unsprayed plots. Weed density and weed dry matter was significantly reduced in the sprayed plots (Bharathi *et al.* 2011). A combination of pre- and post-emergent herbicides resulted in 96.8% weed control. Seed cotton yield increased from 22.98 to 38.25% compared to untreated controls (Shaik *et al.* 2006).

Weed management techniques

Weed management is an integral component of sustainable farming systems and comes with a cost. In a typical cotton growing season of 140-160 days, weeding is done at least three times, 15-20 days after sowing (the early-leaf stage), after 35-40 days (before square formation) and 55-60 days (before flowering). The practices adopted should prevent weed interference with the main crop, reduce the extent of weed seeds in the soil, be non injurious to the main crop, not reduce the lint quality and should be economical and sustainable. The timing of weed control and the execution of weed management practices also play an important role (Prabhu *et al* 2012).

In India, most often manual weeding practices are followed and the average cost incurred by a farmer is about 32% of his total production cost (Gandhi and Namboodiri 2009). The first manual weeding requires at least 10 laborers an acre and the number goes up to 15 to 20 for the next two weeding. For weeding alone, a farmer incurs a cost of ₹ 10,000 (Rajeswari and Charyulu1996, Seed News 2011). Given this challenge and expense, other weed management strategies need to be employed. A brief insight on the five general weed management strategies practiced in cotton (Ashigh *et al.* 2012) is given below.

Prevention: This involves preventing weeds from entering the fields by control before they set seed and planting certified seed. Tillage and harvesting equipment should be clean of weeds when moving between fields.

Cultural practices: This focuses on agronomic practices that include crop rotation, appropriate fertilization, spacing, use of cover crops and date of planting which favors cotton growth. Rotating crops suppresses weeds due to variation in the specific host. Cotton grown in narrow spacing (25 inch rows) requires a shorter weed free maintenance period compared to that grown with broad spacing (40 inch rows). Cover crops suppress weeds by preventing their germination.

Mechanical: This is a non selective option and implies the use of mechanical tools like rotary weeders, disks, hoes or mechanical choppers. This is an efficient technique for annual weeds. Three to four intercultivations (hoeing) should be taken at 15 day intervals 30 days after sowing. It helps in keeping the plot weed free and maintains soil moisture.

Chemical control: This is the most popular method used and a number of herbicides are available. This requires skilled labor as the appropriate herbicides have to be applied in the right quantities and at the right time. Herbicides are classified as pre-emergence and post-emergence applications (Table 3).

Table 3. Herbicides commonly used in weed control in cotton

Time of application		Herbicide
Pre-plant	Pre-plant incorporated	Pendimethalin, Trifluralin
	Pre-plant burn down	Thifensulfuron-methyl, tribenuron-methyl
Post-plant	Pre-emergent	Diuron, Fluometuron, pyrithiobac-sodium
	Post-emergent	Clethodim, fluazifop-p-butyl, metolachlor, oxyfluorfen, pyrithiobac-sodium, sethoxydim

A single technique does not provide the complete solution to weed management. Integrated Weed Management (IWM) which is a combination of strategies offers solution to this daunting problem. IWM involves good seedbed preparation, manual weeding, crop rotation, optimum plant population, intercultivation and herbicide use. IWM practices should be selected based on the soil profile, climatic conditions, crop rotation practices and most importantly the weed species prevalent in the farm. IWM is advantageous as it uses multiple practices (cultural, chemical, mechanical) to manage weeds in an economical and sustainable manner (Farrell and Johnson 2005).

A combination of weed management techniques were employed by Chinnuswamy and Chinnagounder (2013). Their results suggest that manual weeding at 25 and 45 DAS (days after sowing) or application of pendimethalin as a pre-emergent spray 3 DAS improved yield of seed cotton. Alternatively, power weeding 25 DAS and manual weeding at 45 DAS was also found to be promising. Pre-emergent application of pendimethalin controlled grassy and broad leaved weeds and sedges. In addition, a second application at 45 DAS along with two manual weeding gave good weed control and resulted in higher seed cotton yield (Manikandan 2011). In another experiment conducted in *Kharif* season in Raichur, pre-emergent application of pendimethalin with post-emergent application of quizalofop-ethyl, inter-cultivation and manual weeding at 60 DAS resulted in significantly higher seed cotton yields and higher returns (Prabhu *et al* 2012).

A combination of weed management techniques has proven effective in controlling weeds. An additional option available to the farmers which should be considered is the adoption of genetically modified herbicide-tolerant crops which are now a component of Integrated Weed Management systems in many regions across the globe (Duke 1999).

Herbicide tolerant cotton

Genetic modification has enabled development of herbicide tolerant crops which are now cultivated widely in different countries across the globe. The first herbicide tolerant crop released was soybean followed by cotton and corn (Green, 2012). From then on, the acreage under herbicide tolerant crops has grown tremendously with soybean, cotton and corn occupying maximum area. This technology has now expanded to a number of other crops of commercial importance. In the United States, acreage under herbicide tolerant cotton expanded from 10% in 1997 to about 91% in 2014 while soybean area increased from 17% to 94%. Adoption of herbicide tolerant corn was slow in the initial years but the current figures stand at 89% (Fig. 2) (USDA, ERS, 2015). In India, insect tolerant cotton (Bt cotton) is the only bioengineered crop to be cultivated.

In cotton, glyphosate or glufosinate are the most commonly used herbicide systems. Glyphosate is a nonselective, broad-spectrum foliar herbicide known to control more than 300 weed species. It controls a spectrum of weeds ranging from annuals, perennials, sedges and broad-leaved plants (Green and Owen 2011). Glyphosate functions by inhibiting EPSPS (5-enolpyruvylshikimate 3-phosphate synthase) a key enzyme in the shikimate pathway. The strategy used to introduce glyphosate resistance in crops is overexpression of an insensitive form of EPSPS (such as the EPSPS enzyme derived from *Agrobacterium tumifaciens* strain CP4 or the engineered Zm-2mEPSPS enzyme). Plants expressing such glyphosate insensitive EPSPS proteins are tolerant to commercial applications of glyphosate herbicide. The commercial product Roundup Ready® (RR) has this technology (Table 4) (Dill *et al.* 2008).

Table 4. Commercially available transgenic herbicide tolerant cotton

Herbicide Resistance trait	Gene source	Trait
Glyphosate	Cp4 epsps	MON1445
	Two cp4 epsps	MON88913
	Zm-2mepsps	GHB614
Glufosinate	bar	LLCotton25

Glufosinate is also a nonselective, broad-spectrum foliar herbicide impacting growth of more than 120 broad- leaved and grassy weed species. However, as it is a contact herbicide it cannot be used to effectively control perennials (Heap 2010).

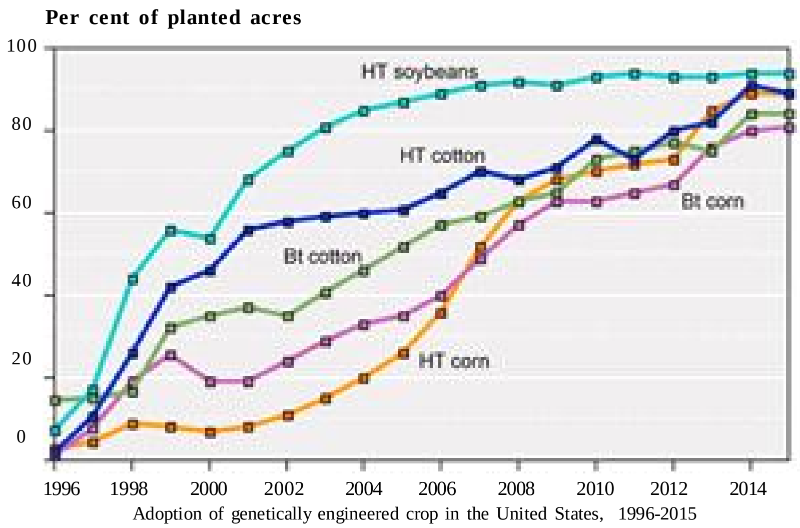

Fig. 2. Adoption of genetically engineered crops in the United States (1996-2015). Data for each crop category includes varieties with both HT and *Bacillus thuringiensis* (Bt) (stacked) traits (USDA, ERS 2015)

Data for crop category include varieties with both HT and Bt (stacked) traits. Source: USDA, Economic Research Service using data from fernandez-Cornejo and Mebride (2002) for the years 1996-99 and USDA, National Agricultural Statistics, June Agricultural Survey for the years 2000-2015

Glufosinate functions by inhibiting glutamine synthetase a key enzyme catalyzing the conversion of glutamate to glutamine in the nitrogen metabolism pathway (Senseman 2007). Glufosinate tolerance is the result of introducing either the pat or bar genes which were isolated from *Streptomyces viridochromogenes* and *Streptomyces hygroscopicus*, respectively. Both genes code for enzymes that inactivate glufosinate by acetylation (Mullner *et al.* 1993). Liberty Link® cotton employs the bar gene from *S. hygroscopicus* (Table 4).

Potential of genetically-modified herbicide tolerant crops (HTC)

Effective weed control involves an Integrated Weed Management (IWM) system including herbicide tolerant crops. The area under herbicide tolerant crops is increasing over the years. In Australia, farmers growing glyphosate tolerant crops reported better control of nutgrasses and vines which could not be controlled by traditional methods. In addition, hoeing was reduced resulting in lesser production costs (Sadler 2012). Similar reports have been obtained from farmers in the United States.

Charles *et al.* (2004) reported that by growing glyphosate tolerant cotton, 7.8 million kilos of herbicide was saved while growing glufosinate tolerant cotton saved 215,000 kilos of herbicide. A survey conducted by Werth *et al.* (2006), suggests that glyphosate usage was higher in fields planted with glyphosate tolerant cotton (2.3 to 3.2 kg active ingredient per ha) but use of other pre-emergent herbicides was reduced (3.38 kg to 2.55 kg active ingredient per ha). Other reports suggest that the frequency of application and the volume of herbicide applied were impacted. While there were two additional glyphosate applications every season there was a reduction in the use of other herbicides (Preston and Roush 1998).

As reported in two studies conducted by Sankula *et al.* (2005) and Sankula (2006), it was estimated that in the United States planting Roundup Ready® cotton reduced herbicide usage by 6.3 million kg active ingredient in 2004 and 7.8 million kg active ingredient in 2005. Use of Liberty Link® cotton reduced herbicide usage by 74,000 kg active ingredient in 2004 and 215,000 kg active ingredient in 2005. In the San Joaquin valley, it is estimated that the cost savings due to RR technology varied from $25 to $200 an acre (Wright *et al* 2013). Adoption of herbicide tolerant crops increased the usage of glyphosate but significantly reduced use of other herbicides.

Benefits and risks of HTC technology adoption

Adoption of herbicide tolerant crops holds a lot of promise. One of the most important advantages is the environmental safety of glyphosate due to its favorable physicochemical characteristics. Glyphosate is not toxic to mammals and the tight adsorption to soil leaves no residual toxicity to the subsequent crops (Gianessi 2005). Toxicology studies of glyphosate have been conducted by Sharma and co-workers (2012). Their results suggest high soil adsorption of glyphosate, thus inhibiting its penetration to water sources. The ground ubiquity score (is the leaching potential of a herbicide vis-a-vis associated environmental pollution risk) being lesser than 1.8 classifies glyphosate as a non-leaching herbicide. Therefore, glyphosate is not a hazard to ground water contamination. Further, studies conducted by Sailaja and Satyaprasad (2006) report that glyphosate uses the glycine pathway of degradation in soil with complete degradation by the 20th day after application. Grunewald *et al.* (2001) have reported the behavior of glyphosate and AMPA (á-Amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid) in soil and water with the half life of glyphosate ranging from 11-17 days. These studies indicate the rapid degradability of glyphosate in soil thereby reducing toxicity in the soil.

Glyphosate and glufosinate being broad spectrum herbicides, the number of sprays and use of other toxic herbicides is minimized in turn reducing labor requirement (Duke 1999). Use of HTC promotes no-till or reduced till practices thereby aiding in soil conservation and reducing water pollution from nutrient and sediment run off (Knezevic 2002, Fawcett and Towery 2002, Cerdeira and Duke 2006). Lack of weeds in HTC grown areas also mitigates infestation by pests and diseases (Joel *et al.* 1995, Liu *et al.* 1998, Brookes and Barfoot 2009, Green 2012). This ensures lower cost of production and higher cost benefit ratio for the farmers.

Herbicides impose selection pressure on the weed population. When the same herbicide is used repeatedly or if herbicides with the same mechanism of action are used, weeds may develop resistance over generations (ANR publication, 2013). A number of researchers have indicated that continuous and sequential use of glyphosate in the absence of other weed management practices imposes high selection pressure on weed flora resulting in glyphosate resistant weeds (Swanton *et al.* 2000, Shaner 2000, Benbrook 2001, Owen 2008). In cotton cropping systems, RR cotton is often rotated with RR corn resulting in RR corn becoming a volunteer weed. Non optimal crop rotation practices also result in herbicide tolerant crops turning out to be volunteer weeds which reduces yield (Owen and Zelaya 2004).

There is growing concern on development of herbicide resistant weeds. Repeated use of a single weed control technique in the absence of other weed management practices continuously over the years could have resulted in herbicide resistant weeds. As on date, 60 countries have reported herbicide tolerant weeds from about 350 unique species. The herbicides to which weeds have developed resistance are photosystem II inhibitors and ALS (Acetolactate synthase) inhibitors as they are used widely on cereals and grains (ANR publication 2013). Employing appropriate diverse management practices will reduce selection pressure from a single practice and mitigate the development of herbicide resistant weeds (Hurley *et al.* 2009). This includes pre-plant herbicide applications (Sosnoskie and Hanson 2013, Wright *et al.* 2013), deep tillage, use of mould boards or other tillage implements for tillage, crop rotation, use of residual herbicides along with glyphosate, mixing different herbicides together and herbicides with multiple modes of action (Duary 2008).

Concluding thoughts

The key to effective weed management is integration of diverse technologies like herbicides, agronomic practices and biotechnological approaches. This forms the basis for an integrated weed management program. Rather than a single tool/ technique being adopted, a suite of tools/techniques need to be utilized. A farmer now has multiple options to choose from and he needs to do so judiciously. This would be cost effective and give higher economic returns.

Perspectives for the future

The quest is on for durable and sustainable weed management practices. Herbicides with different modes of action but similar weed spectrum provide an option to combine herbicides for more durable weed management. Seeds with multiple traits like quality, disease resistance, insect protection and weed control could be developed by breeding or transformation technology. Stacking strategies also hold a lot of promise. Stacked products are available and are being used commercially. Across the globe, 13 countries planted stacked traits on an area of 51 million hectares, an increase of 4.3 million hectares compared to 2013 (James 2014). In double cropping systems comprising of soybean and wheat, stack of glyphosate and sulfonyl urea have been used effectively (Dupont Biotechnology 2007). Glyphosate and glufosinate dual stacks are also in commercial use in cotton, corn and soybean (Green 2012). In the United States, adoption of stacked traits is increasing with stacked cotton reaching 79 per cent of cotton plantings in 2015. Genetically engineered cotton including stacked traits reached 94 per cent of the total cotton acreage in 2015 (Fig. 3) (USDA, ERS, 2015).

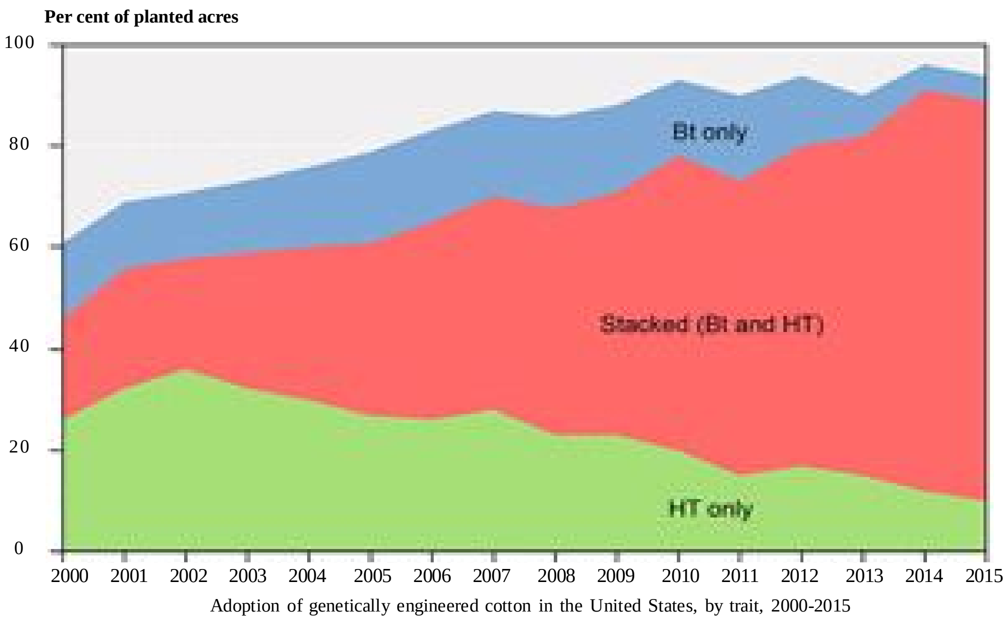

Fig. 3. Adoption of genetically engineered cotton in the United States by trait, 2000-15 (USDA, ERS, 2015)

Source: Economic Research Service using data from USDA, National Agricultural Statistics, June Agricultural Survey

Precision Agriculture with capability of imaging techniques helps identify the extent of weed infestation allowing determination of the appropriate timing and application rate of herbicides for maximized benefits (Duke 1999). Adoption of Bt cotton has been successful for Indian farmers. The cost of production of Bt cotton is higher compared to non Bt cotton under irrigated conditions. However, the output value is higher and the net profit from Bt cotton is about 56% compared to non-Bt cotton (Gandhi and Namboodiri 2009). The economic data for 16 years (1996-2012) suggests that farmers in India gained US$14.6 billion. In addition, insecticide application reduced by 50% contributing to a sustainable environment and improved quality of life (James 2013). Given the success of Bt cotton in India, adoption of herbicide tolerant cotton would be promising and sustainable. This would also help reduce the yield gap and put farmers in India on par with other cotton growing regions of the world in terms of production and productivity. Farmers need to use this technology judiciously and include this in their IWM program.

REFERENCES

ANR publication. 2013. Selection pressure, shifting populations and herbicide resistance and tolerance. *No. 8493*, July 2013.

Ashigh J, Mohseni-Moghadam M, Idowu J and Hamilton C. 2012.*Weed Management in Cotton*. Guide A-239. Cooperative Extension Service. College of Agricultural, Consumer and Environmental Sciences. NM State University.

Ayyadurai P and Poonguzhalan R. 2011. Critical period of crop-weed competition in zero-till cotton. *Indian Journal of Weed Science* **43**: 228-230.

Benbrook CM. 2001. Trouble times amid commercial success for Roundup ready soybeans. *AgBioTech InfoNet Technical Paper. Number* **4**. 6.

Bharathi S, Pavani M and Narayana E. 2011. Response of Bt. cotton to post-emergence herbicides in vertisols of Krishna zone. *International Journal of Applied Biology and Pharmaceutical Technology* **2**: 504-510.

Brookes G and Barfoot P. 2009. Global impact of biotech crops: income and production effects 1996–2007. *AgBioForum* **12**: 184-201.

Charles GW, Taylor I and Roberts G. 2004. The impact of the cotton farming system on weed succession: implications for herbicide resistance and adoption of an integrated weed management approach. *Proceedings of the 14th Australian Weeds Conference*, BM Sindel and SB Johnson, Charles Sturt University, Wagga Wagga, NSW.

Cerdeira AL and Duke SO. 2006. The current status and environmental impacts of glyphosate-tolerant crops: A review. *Journal of Environmental Quality* **35**: 1633-1658.

Charles G and Roberts G. 2013. Managing weeds in cotton. In: *WEEDpak -A Guide to Integrated Weed Management in Cotton*, Cotton Research and Development Corporation, Australia.

Chinnuswamy N and Chinnagounder C. 2013. Evaluation of weed control efficacy and seed cotton yield in transgenic cotton. *Journal of Applied Research* **3:** 10-12.

Choudhary B and Gaur K. 2015. *Biotech Cotton in India, 2002 to 2014*. ISAAA Series of Biotech Crop Profiles. ISAAA: Ithaca, NY.

Dill GM, CaJacob CA and Padgette SR. 2008. Glyphosate-tolerant crops: adoption, use and future considerations. *Pest Management Science* **64**: 326-331

Duary B. 2008. Recent advances in herbicide resistance in weeds and its management. *Indian Journal of Weed Science* **40**: 124-135.

Duke S. 1999. *Weed Management: Implications of Herbicide Tolerant Crops*. Publications from USDAARS / UNL Faculty. Paper 481.

DuPont Biotechnology. 2007. More Information on Herbicides, Herbicide Tolerant Crops and DuPont Product Development. *http://www2.dupont.com/Biotechnology/en US/science knowledge/herbicide resistance/moreinfo3.html.*

Economic Times. 2013. Cottonseed oil rules the kitchens of Gujarat as cheapest cooking oil. *Report on 14th April 2013.*

Economic Times. 2014. Cotton rises 10% on demand for exports and local consumption. *Report on Jan 28, 2014.*

Farrell T and Johnson A. 2005. *Cotton Pest Management Guide 2005/06*, NSW Department of Primary Industries, Orange.

Fawcett R and Towery D. 2002. *Conservation tillage and plant biotechnology: how new technologies can improve the environment by reducing the need to plow*. Conservation Technology Information Center,West Lafayette.

Frisvold GB, Hurley TM and Mitcell PD. 2009. Overview: Herbicide resistant crops – Diffuson, benefits, pricing and resistance management. *AgBioForum* **12**: 244-248.

FICCI report. 2012. Cotton 2020. Roadmap for sustainable production. February 01, 2012. New Delhi, In:*FICCI; Cotton 2020*. Strategic Thinking Session.

Gandhi VP and Namboodiri NV. 2009. Economics of BT cotton vis-à-vis non Bt cotton in India: A study across four major cotton growing states. *Final Report.* Centre for Management in Agriculture, IIM, Ahmedabad. pp 1-123.

GAIN Report (Global Agricultural Information Network), 2013. Cotton and products. *Report No. IN3028.*

Gianessi LP. 2005. Economic and herbicide use impacts of GT crops. *Pest Management Science* **61**: 241-245.

Green JM. 2012. The benefits of herbicide-tolerant crops. *Pest Management Science* **68**: 1323-1331.

Green JM and Owen MDK. 2011. Herbicide-tolerant crops: Utilities and limitations for herbicide tolerant weed management. *Journal of Agricultural Food Chemistry* **59**: 5819-5829.

Grunewald K, Schmidt W, Unger C and Hanshmann G. 2001. Behavior of glyphosate and AMPA in soils and water or reservoir Radebourg II catchment. *Journal of Plant Nutrition of Soil Science* **164**: 65-70.

Heap IM. 2010. The international survey of herbicide tolerant weeds. available at *http://www.weedscience.com, 2010.*

Hurley TM, Mitchell PD and Frisvold GB. 2009. Effects of weed resistance concerns and resistance management practices on the value of round up ready crops. *AgBioForum* **12**: 291-302.

Ikisan. 2015. http://www.ikisan.com/Cropper cent20S pecific / Eng/links/knt_cottonWeedpercent 20Management.shtml

Jain SC, Iyer BG, Jain HC and Jain NK. 1981.Weed management and nutrient losses in upland cotton under different ecosystems of Madhya Pradesh, pp. 131-135. In: *Proceedings of 8th Asian – Pacific Weed Science Society*.

James C. 2015. 20th Anniversary (1996 to 2015) of the Global Commercialization of Biotech Crops and Biotech Crop Highlights in 2015. ISAAA Brief No. 51. ISAAA: Ithaca, NY

James C. 2014. Global Status of Commercialized Biotech/GM Crops: 2014. ISAAA: Ithaca, New York. *ISAAA Brief No. 49*.

James C. 2013. Global status of commercializedbiotech/GM crops:2013. *ISAAA BriefNo. 46*. ISAAA: Ithaca, NY

Joel DM, Kleifeld Y, Losner-Goshen D, Herzlinger G, and Gressel J. 1995. Transgenic crops to fight parasitic weeds. *Nature***374**:220-221.

Knezevic SZ. 2002. *Use of Herbicide Tolerant Crops as a Component of an Integrated Weed Management Program*. University of Nebraska, Lincoln, USA.

Liu CA, Zhong H, Vargas J, Penner D and Sticklen M. 1998. Prevention of fungal diseases in transgenic, bialaphos- and glufosinate-tolerant creeping bentgrass (*Agrostis palustris*). *Weed Science* **46**: 139-146.

Manikandan KN. 2011. Weed Management in Summer Irrigated Cotton. In: *World Cotton Research Conference on Technologies for Prosperity*. Mumbai.

Mullner H, Eckes P and Donn G. 1993. *Engineering crop resistance to the naturally occurring glutamine synthetase inhibitor phosphinothricin in pest control with enhanced environmental safety,* pp. 38-47. In: American Chemical Society. (Eds. Duke SO, Menn JJ, Plimmer JR, Washington DC) Chap.

Nagrare VS, Kranthi S, Rishi Kumar, Dhara Jothi B, Amutha M, Deshmukh AJ, Bisane K D and Kranthi K R. 2011. *Compendium of Cotton Mealy Bugs*. Central Institute for Cotton Research, Nagpur, 42 p.

Owen MDK. 2008. Weed species shifts in glyphosate-tolerant crops. *Pest Management Science* **64**: 377-387.

Owen MDK and Zelaya I. 2004. Herbicide-resistant crops and weed resistant to herbicides. *Pest Management Science* **61**(3): 301-311.

Prabhu G, Halepyati AS, Pujari BT and Desai BK. 2012. Weed management in Bt cotton (*Gossypium hirsutum* L.) under irrigation. *Karnataka Journal of Agricultural Sciences* **25**: 183-186.

Preston C and Roush RT 1998. Variation in herbicide dose rates: risks associated with herbicide resistance. *Precision Weed Management in Crops and Pastures.* Proceedings of workshop at Wagga Wagga, NSW, R Medd and J Pratley.

Rajeshwari VR and Charyulu NR. 1996. Integrated weed control in cotton. *Annals of Agricultural Research* **17**: 438-440.

Riffle MS, Waller GR and Murray DS. 1987. Plant growth inhibitors extracted and steam distilled from unicorn plant (*Proboscidea louisianica*). *Proceedings of Weed Science Society* **40**: 315

Sadler J. 2012. Sustainable weed management and the use of genetically engineered herbicide tolerant crops. *A Report for Nuffield, Australia Farming Scholars.*

Sailaja KK and Satyaprasad K. 2006. Degradation of glyphosate in soil and its effect on fungal population. *Journal of Environmental Science and Engineering* **48**: 189-190.

Sankula S. 2006. *Quantification of the Impacts on US Agriculture of Biotechnology-Derived Crops Planted in 2005,* National Center for Food and Agricultural Policy, Washington, D.C.

Sankula S, Marmon G and Blumenthal E. 2005. *Biotechnology-Derived Crops Planted in 2004 - Impacts on US Agriculture,* National Center for Food and Agricultural Policy, Washington, D.C.

Seed News. 2011 *An Indian Farmers's View of Weed and Insect-Tolerant Cotton*. October 20, 2011.

Senseman SA. *Herbicide Handbook*, 9th ed.; Weed Science Society of America: Lawrence, KS, 2007. 458 p.

Shaner DL. 2000. The impact of glyphosate-tolerant crops on the use of other herbicides and on resistance management. *Pest Management Science* **56**: 320-326.

Shaik MA, Saleem A, Malik NA. 2006. Integrated weed management and its effect on the seed cotton yield in cotton (*Gossypium hirsutum* L) crop. *Pakistan Journal of Weed Sciences Research* **12**: 111-117.

Sharma R. 2008. Integrated weed management in field crops. *Crop Care* **35**: 41-46.

Sharma DK, Gupta A, Kashyap R and Kumar N. 2012. Spectrophotometric method for determination of Glyphosate in relation to its environmental and toxicological analysis. *Archives of Environmental Science* **6**: 42-49.

Sosnoskie L and Hanson B. 2013. Selection pressure, shifting populations and herbicide resistance. *CWSS Research Update and News* **9**: 1-5.

Swanton CJ, Shrestha A, Chandler K and Deen W. 2000. An economic assessment of weed control strategies in no-till glyphosate-tolerant soybean (Glycine max). *Weed Technology* **14**: 755-763.

The Crop Site. 2013. USDA GAIN: Oilseeds, Cotton, Sugar, Graina nd Feed. *http://www.thecropsite.com/reports/ ?id=1831.*

USDA, ERS 2015. Information generated using data from Fernandez-Cornejo and McBride (2002) for the years 1996-1999 and USDA, NASS, *June Agricultural Survey for the Years 2000-2015*.

Werth J, Preston C, Roberts G and Taylor I. 2006. Weed management practices in glyphosate tolerant and conventional cotton fields in Australia. *Australian Journal of Experimental Agriculture* **46**: 1177-1183.

Wright S, Orloff S and Shreshta A. 2013. Herbicide resistant weed issues and solutions in agronomic crops in the San Joaquin valley. *CWSS Research Update and News* **9**: 11-15.

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Tillage effects on weed biomass and yield of direct-seeded rice

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ABSTRACT

Field experiments were conducted during the rainy seasons of 2011 and 2012 in Odisha, India to evaluate the efficiency of different tillage practices at beausaning on weed flora and yield of direct-seeded rice (*Oryza sativa* L.). Two passes of ploughing at 5 cm depth and 15 cm spacing with country plough at 'beausaning' showed the highest yield of grain (4.06 t/ha) and straw (4.66 t/ha), which was associated with higher weed control efficiency, effective tillers/hill, panicle length, number of filled grains/panicle, 1000-grain weight and with lower number of non-bearing tillers/hill and sterile spikelet/panicle. The lowest value of all parameters was found in 1 and 2 passes with tractor. Two passes by power tiller was as good as 2 passes by country plough in controlling weeds and achieving higher yield. Though 1 and 2 passes with country plough and power-tiller showed statistically identical result, but the B:C ratio (2.25) was more in later treatment than the former (2.10).

Key words: Beusaning, Direct-seeded rice, Tillage practices, Weed control efficiency, Yield

Rice is the most important cereal grown under direct seeding and transplanting methods. Among this, direct-seeded rice under wet condition is less costly than transplanting due to lower requirement of labour and water (Singh *et al.* 2002, Sharma *et al.* 2007). In view of this, direct-seeded rice is gaining popularity in most of the rice growing countries including India due to its similar or even higher yields than that of transplanted rice (Sarkar *et al.* 2003, Bhusan *et al.* 2007, Farooq *et al.* 2009). The main disadvantage of direct-seeded rice is high weed infestation, because both weed and crop seeds emerge at the same time and compete with each other from germination, resulting yield reduction from 30-35% (Pillai 1977) to 50 to 100% (Rao *et al.* 2007), so effective and timely weed control is a key component for success of production of direct-seeded rice.

For controlling weed and better plant stand, 'beusaning' is done in direct-seeded rice. 'beusaning' (blind cultivation) is an indigenous practice developed by the farmers and largely practiced in Eastern India in 13 million hectares. In this practice, light ploughing is done between 20-30 days of emergence of crop followed by laddering and seedling redistribution (gap filling). This operations helps in loosening of soil, incorporate weeds into soil, thinning of seedling thereby optimize the plant stand.

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In 'beusaning', light ploughing is done with a bullock drawn narrow country plough maintaining a depth of 5±2 cm water in the field. Tillage operation by traditional wooden plough (country plough) pulled by draft animal for 'beusaning' is a slow process and requires more time to complete the operation. More over, draft power shortage is one of the major problems in cultivation. The number of draft animal is decreasing very rapidly among the farmers due to various reasons such as high cost of maintenance, high rate of slaughtering, slow rate of reproduction and reduced pasture areas (Sarkar 1993). In recent years, power tillers and tractors have emerged as good alternatives to meet the acute shortage of draft power. Use of these machineries in 'beusaning' operation kill the weeds and excess plants through pulverization. Therefore, an optimum tillage practice in terms of number of passes, depth and spacing of tillage are to be found for maintenance of optimum plant stand after 'beusaning' operation. The present work was therefore undertaken to find out suitable tillage practices at 'beusaning' on weed dynamics and productivity of direct-seeded rice.

MATERIALS AND METHODS

Field experiment was conducted at Seed Research Farm, Gambharipali, Odisha during rainy season (*Kharif*) 2010 and 2011. The soil of the experimental field was sandy clay loam with pH 6.5, organic carbon 0.43% and available N, P and K content of 272, 13.8 and 136 kg/ha, respectively. The experiment consisted of 7 treatments was laid out in randomized block design with three replications. Rice cultivar '*MTU 1001*' maturing in 135 days was sown in the field during 2nd week of June in both the years with a seed rate of 100 kg/ha. A common fertilizer dose of 80, 40 and 40 kg of N, P and K/ha, respectively was applied as full dose of P_2O_5 at seeding, 50% N and full K_2O at 'beusaning'. The rest 50% N was top dressed in 2 equal splits, *i.e.* 3 weeks after 1st application and at panicle initiation stage of crop. Plant protection measures and irrigations were provided as and when required. The total rainfall received during the crop season was 863.7 and 977.2 mm in 2012 and 2013, respectively.

In power tiller mounted rotavator and tractor mounted 9 tined cultivator, alternate tines were removed to maintain the spacing of 15 and 45 cm, respectively. In the bullock drawn country plough, rows were drawn at a spacing of 15 cm. A shallow submergence with 5±2 cm standing water was maintained during 'beusaning' operation. Laddering was done lightly after ploughing in 'beusaning' operation for making the rice plants unidirectional for workability and flattening the aged weeds.

Weed count (no./m^2) (numbers/0.5 m^2), weed dry weight (g/m^2) (g/0.5m^2) were sampled randomly at two places with the help of 0.50 m^2 quadrate at 4 weeks (before 'beusaning') and 7 weeks after sowing (after 'beusaning'). The 1st and 2nd weed counts were carried out from the same spots in each plot. For recording weed dry weight, weeds cut at ground level with sickle, were sun dried for 3 days followed by oven drying at 65± 5 ^{0}C. Weed population data were analysed after subjecting to square root transformation. Yield and yield attributes of rice were recorded at crop harvest. Weed control efficiency was also calculated on the basis of dry matter production of weeds. Economic analysis was done on the basis of prevailing market price of inputs used and output obtained from each treatment. Both the year's data were subjected for pooled analysis to obtain a trend among results over the years.

RESULTS AND DISCUSSION

Weed flora

Major weed flora in the experimental field were categorized in narrow-leaved (grass and sedges) and broad-leaved (monocot and dicot). The important species were: grasses *Digitaria sanguinalis* (L.) Scop., *Echinochloa crusgalli* (L.) P.Beauv., *Echinochloa colona* (L.) Link, *Panicum repens* (L.), *Cynodon dactylon* (L.) Pers; sedges *Cyperus rotundus* (L.), *Cyperus iria* (L.), *Cyperus difformis* (L.), *Fimbristylis miliacea* (L.) Vahal, *Paspalum distichum* (L.) and broad-leaved weeds (BLW) *Ammania baccifera* (L.), *Ludwigia parviflora* (L.), *Eclipta prostrata* (L.), *Eclipta alba* (L.), *Lippa nodiflora* Nich, *Marsilea quadrifolium* (L.), *Sphenoclea zeylanica* Gaertn., *Commelina benghalensis* (L.). The composition of narrow-leaved (grass and sedges) and broad-leaved weeds (BLW) in weedy check plot was 80.9 and 19.1%, respectively. Emergence of BLW was noticed earlier as compared to sedges and grasses.

Response of weeds to tillage practices

Both narrow-leaved and broad-leaved weeds and their biomass were found to be significant due to tillage in all counts (Table 1). Two passes with country plough, power-tiller and tractor reduced both narrow-leaved and broad-leaved in all counts in comparison to single pass. The lowest weed population (21.3 and 5.0) and dry weight (11.37 and 3.67) and highest weed control efficiency (86.3 and 81.8%) for narrow-leaved and broad-leaved, respectively was recorded in two passes with country plough which was at par with 2 passes by power tiller. In 2 passes, the soil become loose and more weeds were buried in the soil than that of single pass. The minimum weed population and dry weight of weed and weed control efficiency after 'beusaning' (7 WAS) was recorded in two passes with country plough at a spacing of 15 cm and depth of 5 cm, which was at par with 2 passes by power tiller at same spacing and depth. The reduced weed density in wet ploughing by 2 passes of country plough was due to incorporation of more weeds in to the soil. One and 2 passes with tractor at 45 cm spacing recorded higher weed population and dry weight. This was due to wider spacing (45 cm) which loosens the soil in less area and less weeds were uprooted, besides use of heavy machineries affected the tender seedling of rice. Plots without any tillage at 'beusaning' recorded the highest weed population and the dry weight.

Effect on crop

There were significant differences on effective tillers/hill, panicle length, grains/panicle, grain and straw yield due to tillage of rice variety '*MTU 1001*' (Table 2). Among the different tillage implements, 2 passes with country plough recorded the highest grain yield (4.06 t/ha), which was at par with 2 passes with power tiller. Two passes with country plough, power tiller and tractor increased the grain yield by 42.5, 36.8 and 28.1%, respectively over

Table 1. Narrow- and broad-leaved weeds as affected by tillage practices

Tillage	Weed density (no/0.5 m^2)				Weight g/m^2 (g/0.5 m^2)				WCE (%)	
	Narrow-leaved		Broad-leaved		Narrow-leaved		Broad-leaved		Narrow-leaved	Broad-leaved
	4 WAS	7 WAS	4 WAS	7 WAS	4 WAS	7 WAS	4 WAS	7 WAS	7 WAS	7 WAS
T1	11.0 (120)	13.14 (172.3)	5.58 (30.7)	6.12 (37.3)	49.2	83.1	8.3	20.2	0.0	0.0
T2	10.9 (119)	4.61 (21.3)	6.09 (36.6)	2.34 (5.0)	45.8	11.4	3.7	3.7	86.3	81.8
T3	10.7 (115)	4.94 (27.0)	5.64 31.6)	2.69 (6.8)	44.7	20.5	4.7	4.0	75.4	80.4
T4	10.8 (117)	5.61 (31.6)	5.95 (35.6)	2.64 (7.0)	45.7	26.3	5.2	5.4	68.4	73.3
T5	10.6 (112)	6.71 (45.0)	5.90 (34.0)	3.48 (11.7)	37.8	30.5	5.6	5.4	52.6	73.3
T6	10.9 (118)	7.07 (50.0)	5.81 (33.0)	3.48 (11.8)	45.4	35.5	6.3	7.3	57.3	64.0
T7	10.8 (116)	7.57 (57.3)	16.8 (36.0)	4.21 (17.3)	45.1	43.0	7.0	9.7	48.3	52.2
LSD (P=0.05)	NS	1.43	NS	0.62	NS	7.4	NS	3.4	-	-

T1- Tillage fallow (no 'beusaning'), T2- Two passes with country plough, T3- Two passes with power tiller, T4- Two passes with tractor, T5- One pass with country plough, T6- One pass with power tiller, T7- one pass with tractor; WAS- Weeks after sowing, WCE- Weed control efficiency, Figures in parentheses are original values

Table 2. Yield attributing characters, yield and economics of direct-seeded rice using various tillage practices (pooled data of two years)

Tillage	Effective tillers/ hill (no.)	Non - bearing tillers/ hill (no.)	Filled grain/ panicle (no.)	Sterile spikelet/ panicle (no.)	Grain yield (t/ha)			Straw yield (t/ha)			Harvest index (%)	Gross return (x10^3 ₹/ha)	Net return (x10^3 ₹/ha)	B:C ratio
					2012	2013	Mean	2012	2013	Mean				
T1	7.5	2.6	88	16.2	2.5	3.2	2.8	3.5	3.9	3.7	43.5	35.62	15.00	1.72
T2	10.3	2.7	107	20.1	3.9	4.2	4.1	4.4	4.92	4.66	46.5	50.75	26.63	2.10
T3	9.5	1.6	105	17.2	3.6	4.2	3.9	4.4	4.7	4.55	46.2	48.75	26.10	2.25
T4	9.5	1.9	104	17.2	3.2	4.1	3.6	4.3	4.54	4.42	45.2	45.62	23.67	2.07
T5	9.3	2.0	99	20.0	3.3	3.7	3.5	4.1	4.6	4.35	44.5	43.62	20.75	1.90
T6	9.3	2.2	98	18.0	3.2	3.4	3.3	4.1	4.18	4.14	44.4	41.37	19.74	1.91
T7	8.5	2.5	93	18.0	3.0	3.1	3.1	3.5	4.1	3.8	44.6	38.25	16.96	1.79
LSD (P=0.05)	0.19	0.21	2.8	0.26	0.4	0.3	0.2	0.6	0.5	0.3				

T1- Tillage fallow (no 'beusaning'), T2- Two passes with country plough, T3- Two passes with power tiller, T4- Two passes with tractor, T5- One pass with country plough, T6- One pass with power tiller, T7- one pass with tractor, WAS- Weeks after sowing, WCE- Weed control efficiency

unweeded check (tillage-fallow). The increased grain yield in these treatments were owing to reduced weed population and weed dry weight and better weed control efficiency (Table 1). Higher number of effective tillers/hill, panicle length, number of filled grain/panicle, 1000- grain weight and lower number of non-bearing tiller/hill and sterile spikelet/panicle were recorded in two passes with country plough followed by power tiller (Table 2).

The highest grain yield in 2 passes by country plough was due to 37.3% higher productive tiller, 15.4% higher panicle length, 21.4% higher filled grains/panicle compared to tillage-fallow. Positive effect of ploughing through country plough causes less number of weed and weed dry weight, optimize plant stand, making soil loosen, which might have permitted the roots to enter in to deep layer for better use of water and mineral nutrients.

The minimum yield and yield attributes in tillage fallow were the result of severe weed competition by uncontrolled weed growth. Straw yield followed almost similar trend as that of grain yield. Ranjit and Suwanketnikom (2005), Jain *et al.* (2006) and Jha *et al.* (2011) also reported increased grain yield of direct-seeded rice by different tillage practices.

The highest harvest index (46.5%) was found in 2 passes with country plough at 15 cm spacing (Table 2). The second highest harvest index was found in 2 passes with power tiller which was followed by 1 passes with tractor at 45 cm spacing. This might be due to higher grain yield in 2 passes with country plough as compared to other tillage operation. The lowest harvest index was found in 1 pass with country plough at 15 cm spacing.

Economics

Two passes with country plough at 'beausaning' in rice fetched higher gross return (₹ 50750/ha), net return (₹ 26630/ha) over tillage fallow. However, 2 passes with power tiller recorded higher B: C ratio (2.25) than that of country plough (2.10) indicating reduced cost in tillage operation of power tiller (Table 2). The tillage fallow recorded the lowest net return and B: C ratio.

Based on the study, it was concluded that two passes with country plough at 'beausaning' direct-seeded rice was superior in terms of improve tillering, grain filling and controling weeds over other method of tillage. However, tillage practice by power tiller are equally effective as compared to the country plough.

RERERENCES

Bhusan L, Ladha JK, Gupta RK, Singh S, Tirol, Padre A, Saharawat YS, Gathala M and Pathak H. 2007. Saving of water and labour in rice-wheat system with no tillage and direct-seeding technologies. *Agronomy Journal* **99**: 1288-1296.

Farooq M, Basra SMA, Ahmed N and Murtaza G. 2009. Enhancing the performance of transplanted coarse rice by seed priming. *Paddy Water Environmental* **7**: 55-63.

Jain N, Mishra JS, Kewat ML and Jain V. 2006. Effect of tillage and herbicides on weed seed bank dynamics in wheat (*Triticum aestivum*) under transplanted rice-wheat system. *Indian Journal of Weed Science* **38**(1&2): 161-164.

Jha AK, Kewat ML, Upadhyay VB and Vishwakarma SK. 2011. Effect of tillage and sowing method on productivity, economics and energetic of rice (*Oryza sativa*) – wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy* **56**(1): 35-40.

Pillai KG.1977. Integrated weed management in rice. *Indian Farming* **26**: 17-23.

Ranjit JD and Suwanketnikom R. 2005. Response of weeds and yield of dry direct-seeded rice to tillage and weed management. *Kasetsart Journal (Natural Science)* **39**: 165-173.

Rao AN, Johnson DE, Sivaprasad B, Ladha JK and Moritmer AM. 2007. Effect of nitrogen and weed management in direct-seeded rice. *Advances in Agronomy* **93**: 153-155.

Sarkar RI. 1993. Draft power constraint affecting irrigated crop diversification, pp. 100-115. In: *Irrigation Management for Crop Diversification in Bangladesh*. (Eds. Biswas MR and Mandal MAS), University Press, Dhaka, Bangladesh.

Sarkar RK, Sanjukta D and Das S. 2003. Yield of rainfed low land rice with medium water depth under anaerobic direct seeding and transplanting. *Tropical Science* **43**: 192-198.

Sharma RP, Pathak SK, Raman KR and Chattopadhyaya N. 2008. Resources conservation in rice (*Oryza sativa*) -wheat (*Triticum aestivum*) cropping system for enhancing productivity, profitability and soil health, pp. 236-237. In. *New Paradigms in Agronomic Research*, Proceedings of National Symposium of Indian Society of Agronomy, 9-21 November 2008, Navsari, Gujrat.

Singh G, Singh VP, Singh RK and Saxena A. 2002. Bio-efficacy of herbicides in zero till wheat in rice-wheat cropping system. *Indian Journal of Weed Science* **39**: 5-8.

Indian Journal of Weed Science **48**(2): 148–151, 2016
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Weed management and biofertilizer effects on productivity of transplanted rice

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ABSTRACT

Field experiment was conducted to evaluate the performance of weed management and biofertilizer on productivity of transplanted rice variety '*MTU-7029 (Swarna)*'. Experiment was laid out in factorial randomized block design with 24 treatments, comprising of twelve weed management practices and two nutrient management practices *viz.* No biofertilizer and biofertilizer (*Azotobacter* + PSB), replicated thrice. All the herbicidal treatment resulted in significant reduction in total weed dry weight and weed population than weedy check. The higher grain and straw yield was recorded in the plot where pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 50 g/ha was applied. In case of grain yield, it was statistically at par with application of pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 25 g/ha and weed free check during both the years. The highest net returns and benefit-cost ratio was realized under the application of pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 25 g/ha and also in biofertilizer applied plot.

Key words: Biofertilizer, Bispyribac-sodium, Yield, Pendimethalin, Rice, Weed management

Rice is a principal source of food for more than half of the world population. It is a dominating staple food crop of India as well as West Bengal. The only way to meet the future food requirements of ever increasing population and maintain self sufficiency is to increase the productivity per unit area by improved production technology. One of the major production constraints in rice production is the poor management of weeds. Hence, successful weed control is essential for obtaining optimum yield of rice (Hussain *et al.* 2008). Herbicides play a significant role in controlling the weeds and thereby increasing the production. Though many pre-emergence herbicides are available for controlling weeds, the need for post-emergence herbicide or sequential application of herbicides is often realized to combat the weeds emerged during later stages of crop growth. Nutrient management especially biofertilizer is important to maintain the soil fertility and plant nutrient supply to an optimum level for sustaining the desired crop productivity and provide food for ever increasing population. In this context, present experiment was carried out to study the performance of weed management and biofertilizer on productivity of transplanted rice.

MATERIALS AND METHODS

Field experiment was conducted during wet season of 2012 and 2013 at Chella, Kamarpara, Birbhum district of West Bengal to evaluate most effective weed control method and biofertilizer treatment for transplanted rice. The experiment was laid out in factorial randomized block design with 24 treatments in three replications, comprising of twelve weed management practices *viz.* pendimethalin 0.75 kg/ha at 3 DAT, pendimethalin 0.75 kg/ha at 3 DAT *fb* hand weeding at 50 DAT, bispyribac-sodium 25 g/ha at 30 DAT, pendimethalin 0.75 kg/ha at 3DAT *fb* bispyribac-sodium 25 g/ha at 30 DAT, bispyribac-sodium 50 g/ha at 30 DAT, pendimethalin 0.75 kg/ha at 3 DAT *fb* bispyribac-sodium 50 g/ha at 30 DAT, orthosulfamuron 50 g/ha at 12 DAT, pendimethalin 0.75 kg/ha at 3 DAT *fb* orthosulfamuron 50 g/ha at 12 DAT, orthosulfamuron 150 g/ha at 12 DAT, pendimethalin 0.75 kg/ha at 3 DAT *fb* orthosulfamuron 150 g/ha at 12 DAT, weed free check, weedy check and two nutrient management practices, *viz.* no biofertilizer and biofertilizer (*Azotobacter* + PSB). The recommended dose of fertilizers (N:P:K- 80:40:40) was used for the experiment. The seedlings of variety '*MTU-7029 (Swarna)*'were transplanted at 20 x 15 cm spacing. The experimental soil was sandy loam in texture, slight acidic in nature with 177.93 kg/ha available nitrogen, 30.67 kg/ha available phosphorus and 207.41 kg/ha available potassium, population of nitrogen fixing bacteria 66.45 x 10^4 cfu/g and phosphate solubilising bacteria 61.55 x 10^4 cfu/g. Herbicides were applied as foliar spray in the respective treatments as per schedule and for weed free check, hand weeding was done as and when required. Biofertilizer was applied by root dipping of

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seedlings. The data on weed population and dry weight of weeds were recorded at 45 and 60 DAT. The weed dry weight was expressed as g/m^2. The grain and straw yield of rice were recorded and economics was alsoworked out.

RESULTS AND DISCUSSION

Weed dry weight

Among the herbicidal treatment, lowest dry weight of weed was recorded in pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 50 g/ha during both the years at 45 DAT and 60 DAT. In 2012, at 45 DAT, it was statistically similar with pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 25 g/ha, pendimethalin 0.75 kg/ ha *fb* orthosulfamuron g/ha and pendimethalin 0.75 kg/ha *fb* orthosulfamuron 50 g/ha. In 2013, at 45 DAT, the lowest value was statistically at par with pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 25 g/ ha and pendimethalin 0.75 kg/ha *fb* orthosulfamuron 150 g/ha, which indicated that these herbicidal treatments are very much effective for weed control (Table 1).

Results also revealed that the sole application of herbicides were found least effective in minimizing the dry matter accumulation of weeds due to low weed control. The results confirm the findings of Maity and Mukherjee (2008). Pre-emergence application of pendimethalin controlled only grasses, few broad-leaved weeds but not sedges as reported by Yaduraju and Mishra (2004), whereas post-emergence application of bispyribac-sodium effectively controlled all three types of weeds. So, sequential application of these two herbicides was found to be the ideal combination for reducing weed dry weight. The results are in consonance with Brar and Bhullar (2012). In biofertilizer treatment, total weed dry matter at 45 and 60 DAT was not significantly affected by biofertilizer application which indicated that the use of biofertilizer did not influence the dry weight of total weed.

Weed population

Among the herbicidal weed management treatment, the lowest number of total weed/m^2 was recorded in pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 50 g/ha during both the years at 45 and 60 DAT, but at 45 DAT, it was statistically at par with pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 25 g/ ha and pendimethalin 0.75 kg/ha *fb* orthosulfamuron 150 g/ha (Table 1). This might be due to effective management of all categories of weeds by sequential application of pre- and post-emergence herbicide. So, these two combinations were found promising for controlling the weed population. Considering the total weed population at 60 DAT, in 2012, it was statistically at par with pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 25 g/ha and pendimethalin 0.75 kg/ha *fb* hand weeding at 50 DAT. During 2013, it was statistically at par with pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 25 g/ha. Effective management of weed by pre-emergence pendimethalin followed by post-emergence bispyribac-sodium was also reported by Narolia *et al.* (2014). In biofertilizer treatment, total weed density of 2013 at 45 and at 60 DAT during both years, were not significantly affected by biofertilizer application which indicated that the application of biofertilizer had neither positive nor negative outcome on the total weed population.

Grain yield

Grain yield varied significantly among the weed management practices. The lowest grain yield was registered in weedy check. However, the highest grain yield was recorded in the weed free check during both years. In 2012, it was statistically at par with all the doses of post-emergence application of bispyribac-sodium alone or in combination with pre-emergence application of pendimethalin, along with pendimethalin 0.75 kg/ha *fb* orthosulfamuron 50 g/ha and pendimethalin 0.75 kg/ha *fb* orthosulfamuron 150 g/ha. During 2013, it was statistically at par with pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 25 g/ ha and pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 50 g/ha. Chemical weed control by pre-emergence pendimethalin followed by post-emergence bispyribac-sodium application provides higher grain yield (Table 1). Timely and effective control of weeds with integrated use of pre and post-emergence herbicides resulted in increased grain yield. The similar results was reported by Walia *et al.* (2011). In biofertilizer treatment, grain yield was significantly affected by biofertilizer application. Biofertilizer applied plot were significantly superior in grain yield than no biofertilizer applied plot. The increase in yield is due to the inoculations with biofertilizers which might not be solely due to nitrogen fixation or phosphate solubilization, but because of several other factors such as release of growth promoting substances, control of plant pathogens, proliferation of beneficial organisms in the rhizosphere. These findings was in accordance with Kundu and Gaur (1984).

Straw yield

It was recorded that the highest straw yield in the weed free check and it was statistically at par with all the herbicidal weed management practices during

Table 1. Effect of weed management and biofertilizer on weed dry weight and weed population of transplanted rice

Treatment	Weed dry weight (g/m^2) 45 DAT 2012	45 DAT 2013	60 DAT 2012	60 DAT 2013	Weed population (no./m^2) 45 DAT 2012	45 DAT 2013	60 DAT 2012	60 DAT 2013
Weed management								
Pendimethalin 0.75 kg/ha at 3 DAT	4.05 (15.9)	4.27 (17.7)	5.06 (25.1)	5.12 (25.7)	5.65 (31.5)	5.70 (32.0)	5.06 (25.2)	5.13 (25.8)
Pendimethalin 0.75 kg/ha at 3 DAT *fb* hand weeding at 50 DAT	4.01 (15.6)	4.32 (18.2)	3.69 (13.1)	3.90 (14.7)	5.71 (32.2)	5.76 (32.8)	3.10 (9.2)	3.48 (11.7)
Bispyribac-sodium 25 g/ha at 30 DAT	3.68 (13.1)	3.65 (12.9)	4.01 (15.5)	4.11 (16.4)	4.59 (20.7)	4.63 (21.0)	3.99 (15.5)	4.22 (17.3)
Pendimethalin 0.75 kg/ha at 3 DAT *fb* bispyribac-sodium 25 g/ha at 30 DAT	2.99 (8.5)	3.12 (9.2)	3.58 (12.4)	3.73 (13.7)	3.35 (10.8)	3.36 (10.8)	3.10 (9.2)	3.24 (10.0)
Bispyribac-sodium 50 g/ha at 30 DAT	3.31 (10.5)	3.36 (10.8)	3.86 (14.4)	4.12 (16.5)	4.48 (19.7)	4.60 (20.7)	3.80 (14.0)	4.02 (15.7)
Pendimethalin 0.75 kg/ha at 3 DAT *fb* bispyribac-sodium 50 g/ha at 30 DAT	2.81 (7.4)	3.00 (8.5)	3.26 (10.5)	3.43 (11.3)	3.20 (9.8)	3.20 (9.8)	2.82 (7.5)	3.15 (9.5)
Orthosulfamuron 50 g/ha at 12 DAT	3.72 (13.4)	3.85 (14.4)	4.73 (21.9)	4.83 (22.8)	4.71 (21.7)	4.65 (21.2)	4.31 (18.2)	4.43 (19.2)
Pendimethalin 0.75 kg/ha at 3 DAT *fb* orthosulfamuron 50 g/ha at 12 DAT	3.10 (9.2)	3.46 (11.7)	4.20 (17.1)	4.55 (20.2)	3.57 (12.3)	3.60 (12.5)	4.15 (16.8)	4.34 (18.5)
Orthosulfamuron 150 g/ha at 12 DAT	3.57 (12.4)	3.77 (13.9)	4.43 (19.1)	4.69 (21.5)	4.56 (20.3)	4.62 (20.8)	4.11 (16.5)	4.37 (18.7)
Pendimethalin 0.75 kg/ha at 3 DAT *fb* orthosulfamuron g/ha at 12 DAT	2.87 (7.8)	3.02 (8.6)	3.86 (14.7)	4.29 (18.0)	3.31 (10.5)	3.28 (10.3)	4.00 (15.7)	4.20 (17.2)
Weed-free check	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)
Weedy check	11.19 (124.6)	11.72 (136.8)	13.89 (192.4)	14.29 (203.8)	8.68 (75)	8.98 (80.3)	8.23 (67.3)	8.29 (68.2)
LSD (P=0.05)	0.32	0.31	0.38	0.27	0.34	0.35	0.36	0.32
Biofertilizer								
No biofertilizer	3.82 (19.9)	4.03 (21.9)	4.63 (29.7)	4.84 (32.1)	4.47 (23.0)	4.48 (23.4)	4.02 (18.5)	4.16 (19.6)
Biofertilizer (*Azotobacter* + PSB)	3.84 (19.9)	4.01 (21.9)	4.58 (29.7)	4.78 (32.0)	4.28 (21.1)	4.37 (22.0)	3.88 (17.3)	4.10 (19.0)
LSD (P=0.05)	NS	NS	NS	NS	0.14	NS	NS	NS

*Figures in parentheses are the original values. The data were transformed to $\sqrt{x+0.5}$ before analysis. *fb*- followed by, DAT- Days after transplanting

both years.Among the chemical weed management treatments, highest straw yield was recorded in the plot where application of pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 50 g/ha was applied which was followed by pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 25 g/ha. These were owing to reduced weed density, weed dry weight resulted in higher straw yield in that experimental plot. However, unweeded control recorded lesser straw yield which might be due to higher weed competition to the crop plants which resulted in lower straw yield in control plot and this was in conformity with the findings of Singh *et al.* (2013). In biofertilizer treatment, straw yield was significantly affected by biofertilizer application. Biofertilizer applied plot was significantly superior in straw yield than no biofertilizer applied plot. This was in close conformity with the findings of wijebandara *et al.* (2009).

Economics

Application of pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 25 g/ha fetched the highest net return during 2012. It was statistically at par with all the herbicidal weed management practices along with weedy free check. In 2013, highest net return was obtained in the weed free check and it was statistically similar with that all the doses of post-emergence application of bispyribac-sodium alone or in combination with pre-emergence application of pendimethalin along with pendimethalin 0.75 kg/ha *fb* hand weeding at 50 DAT, pendimethalin 0.75 kg/ha *fb* orthosulfamuron 50 g/ha, orthosulfamuron 150 g/ha and pendimethalin 0.75 kg/ha *fb* orthosulfamuron 150 g/ha at 12 DAT. The lowest net returns obtained in weedy check were due to high infestation of weed resulting in lower yield. Benefit-cost ratio expressed that the highest economic benefit was realized under

Table 2. Effect of weed management and biofertilizer on yield and economics of transplanted rice

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Net returns ($x10^3$ `/ha)		B: C ratio	
	2012	2013	2012	2013	2012	2013	2012	2013
Weed management								
Pendimethalin 0.75 kg/ha	5.98	5.84	7.25	6.97	55.88	53.60	1.59	1.53
Pendimethalin 0.75 kg/ha *fb* hand weeding	6.07	6.19	7.33	7.04	55.22	56.56	1.49	1.52
Bispyribac-sodium 25 g/ha	6.18	6.11	7.28	6.92	57.39	56.06	1.58	1.54
Pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 25 g/ha	6.69	6.72	7.72	7.52	63.73	63.90	1.69	1.70
Bispyribac-sodium 50 g/ha	6.22	6.24	7.48	6.99	55.85	55.69	1.44	1.44
Pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 50 g/ha	6.72	6.79	7.81	7.59	60.75	61.28	1.47	1.53
Orthosulfamuron 50 g/ha	6.05	5.82	7.14	6.92	57.54	54.14	1.68	1.58
Pendimethalin 0.75 kg/ha *fb* orthosulfamuron 50 g/ha	6.17	6.12	7.54	7.27	58.26	57.50	1.64	1.62
Orthosulfamuron 150 g/ha	6.06	5.93	7.39	7.00	57.25	55.00	1.64	1.57
Pendimethalin 0.75 kg/ha *fb* orthosulfamuron g/ha	6.21	6.27	7.61	7.33	58.31	58.87	1.61	1.62
Weed free check	6.73	7.05	7.84	7.68	59.67	64.56	1.43	1.55
Weedy check	3.03	3.09	4.03	4.04	12.70	13.53	0.38	0.40
LSD (P=0.05)	0.61	0.66	0.86	0.80	9.21	9.57	0.25	0.26
Biofertilizer								
No biofertilizer	5.85	5.77	7.00	6.64	51.93	50.72	1.40	1.37
Biofertilizer (A*zotobacter* + PSB)	6.17	6.26	7.40	7.24	56.83	57.72	1.53	1.56
LSD (P=0.05)	0.25	0.27	0.35	0.33	3.76	3.91	0.10	0.11

fb= followed by, DAT= Days after transplanting

the application of pendimethalin 0.75 kg/ha *fb* bispyribac-sodium 25 g/ha. During 2012, it was statistically at par with all the herbicidal weed management practices. In 2013, it was statistically at par with all the herbicidal weed management practices along with weed free check. Among the chemical weed management treatments, though pre-emergence application of pendimethalin 0.75 kg/ha *fb* post-emergence application of bispyribac-sodium at 50 g/ha recorded slightly higher grain and straw yield, economically it was inferior than the application of pendimethalin 0.75 kg/ha *fb* post-emergence application of bispyribac-sodium at 25 g/ha. Similar result was also reported by Veeraputhiran and Balasubramanian (2013). Biofertilizer applied plot was significantly superior in net returns (₹/ha) and benefit-cost ratio than no biofertilizer applied plot. This might be attributed to better growth of plant under the condition adequate availability of nutrient, there by resulted in better grain and straw yield and caused higher net return and benefit-cost ratio.

It was concluded that application of herbicides and biofertilizer performed best than herbicide alone. Therefore, the application of pendimethalin 0.75 kg/ ha at 3 DAT *fb* bispyribac-sodium 25 g/ha at 30 DAT along with biofertilizer like *Azotobacter* and PSB can be recommended to the farmers.

REFERENCES

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

Hussain S, Ramzan M, Akhter M and Aslam M. 2008. Weed management in direct-seeded rice. *Journal of Animal and Plant Science* **18**: 2-3.

Kundu, BS and Gaur AC. 1984. Rice response to inoculation with N2 fixing and P-solubilizing microorganisms. *Plant and Soil* **79**: 227-234.

Maity SK and Mukherjee PK 2008. Integrated weed management in dry direct-seeded rice (*Oryza sativa*). *Indian Journal of Agronomy* **53**(2):116-120.

Narolia RS, Singh Pratap, Prakash Chandra and Meena Harphool. 2014. Effect of irrigation schedule and weed-management practices on productivity of direct-seeded rice (*Oryza sativa*) in South-eastern Rajasthan. *Indian Journal of Agronomy* **59**(3): 398-403.

Singh Arati, Singh RK, Kumar Pradeep and Singh Smita. 2013. Growth weed control and yield of direct seeded rice as influenced by different herbicides. *Indian Journal of Weed Science* **45**(4): 235-238.

Veeraputhiran R and Balasubramanian R. 2013. Evaluation of bispyribac-sodium in transplanted rice. *Indian Journal of Weed Science* **45**(1): 12-15.

Walia US, Gill G, Walia SS and Sidhu AS. 2011. Production of direct-seeded rice (*Oryza sativa*) under differential plant densities and herbicides in central plains of Punjab. *Journal of Crop and Weed* **7**(2): 1-5.

Wijebandara Iranie DMD, Dasog GS, Patil GS and Hebbar Manjunath. 2009. Response of rice to nutrients and biofertilizers under conventional and system of rice intensification methods of cultivation in Tungabhadra command of Karnataka. *Karnataka Journal of Agricultural Sciences* **22**(4): 741-750.

Yaduraju NT and Mishra JS. 2004. Weed management in rice with special orientation to export, pp. 111-115. In: *SAARC RICE EXPO 2004*, Maharashtra Chamber of Commerce and Industry and Rice Exporters Association of Pakistan, Mumbai, India.

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Integrated weed management in aerobic rice

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ABSTRACT

Field experiment was carried out to study the effect of integrated weed management in aerobic rice (*Oryza sativa* L.) for consecutive two *Kharif* seasons in 2011 and 2012 at Karaikal, Puducherry Union Territory with seven treatments in three replications. Grassy weeds dominated the weed flora, with *Echinochloa colona* as the major weed. Weed free condition maintained throughout the crop growth recorded significantly lower weed density, dry weight and higher weed control efficiency. Though the highest gross monetary returns (₹ 56,000/ha) and net returns (₹ 25,360/ha) was recorded in weed free condition, maximum B: C ratio (1.94) was recorded in pre-emergence application of pendimethalin 1.0 kg/ha along with a hand weeding at 30 days after sowing (DAS). Uncontrolled weeds accounted for 86.3% yield loss in aerobic rice under coastal ecosystem of Puducherry UT, India.

Key words: Aerobic rice, B:C ratio, Coastal ecosystem, IWM, Yield loss

Rice is the world's most important irrigated crop. The looming global water crisis threatens the sustainability of irrigated rice, which is the biggest water user in Asia. Aerobic rice is the new concept of growing rice in non-puddled and non-flooded aerobic soil. Aerobic system of rice production saved irrigation water by more than half compared to flooded system and can possibly mitigate water scarcity in future (Singh *et al*. 2008). However, weeds are one of the main constraints in aerobic rice cultivation. Yield loss from 50 to 100% has been reported in aerobic rice (Mishra and Singh 2007).

Nowadays, the use of herbicides is gaining popularity in rice fields due to their rapid effects and the lower costs compared with the traditional methods. But continuous use of herbicides alone at higher dose may lead to the problems of residual toxicity, besides causing a shift in weed flora. Dependence on manual weed control alone is time consuming and costly. Hence, integrated weed management practices offers most practical and cost effective means of reducing weed competition in aerobic rice (Mahajan and Chauhan 2013). Considering the above facts, a field experiment was conducted to study the effect of integrated weed management in aerobic rice under coastal ecosystem of Puducherry UT, India.

MATERIALS AND METHODS

Field experiment was conducted during *Kharif* (June to September) 2011 and 2012 at Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, (11° 56' N latitude,79° 53' E longitude, 8 m above mean level), Puducherry (Union Territory), India. The soil of the experimental field was sandy clay loam in texture, near neutral in reaction (pH: 6.94), low in available N (119 kg/ha) and high in available P (24 kg/ha) and K (366 kg/ha).

The experiment was laid out in randomized block design with seven treatments in three replications. The treatments were *viz.* butachlor 1.25 kg/ha +1 hand weeding at 30 DAS, pendimethalin 1.0 kg/ha + 1 hand weeding at 30 DAS, pretilachlor with safener 0.45 kg/ha + 1 hand weeding at 30 DAS, anilophos 0.4 kg/ha +1 hand weeding at 30 DAS, hand weeding twice at 15 and 30 days after sowing (DAS), weed free throughout and unweeded control. The rice cultivar '*PMK 3*' was sown on 3rd June, 2011 and 5th June, 2012 with 20 cm spacing between rows. Recommended dose of fertilizers and irrigations were given uniformly. Herbicides for concerned treatments were applied with knapsack sprayer with a spray volume of 500 l/ha. Rest of the management practices were in accordance with the recommended package of practices for individual crop.

Weed counts (monocots and dicots) were recorded at flowering stage with the help of 50 x 50 cm quadrates at two random places in each plot. The data on weed density and dry weight was transformed using $\sqrt{x + 0.5}$ to normalize their distribution before analysis. The weed control efficiency and weed index was calculated by using the standard

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formulae. For economic study, prevailing market prices was used for different inputs and outputs. The experimental data were subjected to statistical scrutiny as per the procedures given by Panse and Sukhatme (1967).

RESULTS AND DISCUSSION

Weed flora

Important weeds observed in experimental field were *Echinochloa colona* L., *Leptochloa chinensis* L., *Panicum repens* L., *Dactyloctenium aegyptium* Beauv., *Cynodon dactylon* L. Pers., *Cyperus rotundus* among monocots; *Commelina benghalensis* L., *Aeschynomene indica* L., *Trianthema portulacastrum* L., *Eclipta alba* L., and *Cleome viscosa* L., among dicot weeds.

Weed biomass

Weed free treatment recorded lowest monocot, dicot, total weed biomass as 27.2, 5.5 and 32.7 no./m^2, respectively and dry weight 7.1, 0.6 and 7.7 g/m^2, respectively during both the years (Table 1). It was followed by hand weeding twice, integrated weed management under pendimethalin and pretilachlor with safener. Chauhan and Yadav (2013) observed that pendimethalin has been found to be effective against *Echinochloa* spp., *D. aegyptium* and *L. chinensis*. The herbicidal effect of pendimethalin might be due to the inhibition of cell division by tubulin inactivation and thus curtailed the seed germination of weeds (Das and Duary 1998). Better weed control under pre-emergence application of pendimethalin and pretilachlor with safener in aerobic rice was earlier observed by Ramesh *et al.* (2009). Application of other pre-emergence herbicides like butachlor and anilophos was found ineffective in controlling weed germination and its growth under non-flooded condition of aerobic rice. Unweeded control produced significantly higher number of weeds (357.7 no./m^2) as well as dry weight (430.3 g/m^2).

Weed control efficiency

Pre-emergence application of butachlor and anilophos along with a hand weeding in non-flooded soil resulted in weed control efficiencies of 42.9 and 47.3%, respectively. Lower weed control efficieny under these treatments were due to ineffective weed control (Jhon *et al.* 2012). However, maintaining weed free condition throughout the crop period in aerobic rice recorded highest weed control efficiency of 98.2%.

Effect on crop

Uncontrolled weeds cause stunted crop growth with reduced plant height (53.1 cm), productive tillers (4.8), filled grain percentage (50.6), rice grain yield (0.4 t/ha) and yield reduction to the magnitude of 86.3% due to severe weed competition. However, all the weed management treatments improved the growth, yield parameters and grain yield over unweeded control (Table 2). Significantly higher rice grain yield was recorded with weed free condition (2.93 t/ha). It was followed by the hand weeding twice at 15 and 30 DAS and pendimethalin1.0 kg/ha + 1 hand weeding at 30 DAS (2.52 and 2.51 t/ha, respectively). Singh *et al.* (2005) observed that effective weed control by the use of herbicides during critical weed competition period results in better availability of resources for the growth and development of rice crop.

Table 1. Effect of weed management practices on weed density and dry weight in aerobic rice (pooled data of two years)

Treatment	Monocot weed density (no./m^2)	Dicot weed density (no./m^2)	Total weed density (no./m^2)	Monocot weed dry weight (g/m^2)	Dicot weed dry weight (g/m^2)	Total weed dry weight (g/m^2)	Weed control efficiency (%)
Butachlor 1.25 kg/ha+ 1 HW	13.8 (178)	7.0 (51.3)	15.4 (230)	15.4 (224)	3.8 (21.0)	16.1 (245)	42.9
Pendimethalin 1.0 kg/ha + 1 HW	12.5 (151)	3.2 (8.3)	12.8 (160)	11.7 (136)	3.3 (13.0)	12.4 (149)	65.3
Pretilachlor with safener 0.45 kg/ha + 1 HW	13.2 (163)	5.4 (38.8)	14.5 (202)	12.9 (168)	1.5 (3.6)	13.1 (172)	60.0
Anilophos 0.4 kg/ha + 1 HW	13.0 (159)	7.9 (60.5)	15.2 (220)	13.6 (182)	4.6 (44.2)	15.5 (227)	47.3
Hand weeding twice (15 and 30 DAS)	11.5 (123)	5.0 (31.2)	12.8 (154)	12.6 (149)	0.8 (0.2)	12.6 (149)	65.3
Weed free	5.1 (27)	2.3 (5.5)	5.7 (32)	2.5 (7)	0.8 (0.6)	2.5 (8)	98.2
Unweeded control	17.9 (307)	7.0 (50.3)	19.3 (358)	19.7 (374)	5.7 (56.2)	20.9 (430)	0.0
LSD (P=0.05)	2.42	3.10	2.64	2.56	2.62	2.75	-

Data subjected to $\sqrt{x+0.5}$ transformation. Figures in parentheses are original values. HW=Hand weeding

Table 2. Effect of weed management practices on growth, yield and economics in aerobic rice (pooled data of two years)

Treatment	Plant height (cm)	Productive tillers (no)	Filled grain (%)	Rice yield (t/ha)	Weed index	Gross returns (x10^3 `/ha)	Net returns (x10^3 `/ha)	B:C ratio
Butachlor 1.25 kg/ha+1 HW	86.1	6.7	67.6	1.33	54.4	27.00	3.69	1.14
Pendimethalin 1.0 kg/ha+1 HW	91.4	8.6	78.3	2.51	14.3	48.03	23.10	1.94
Pretilachlor with safener 0.45 kg/ ha + 1 HW	85.6	6.5	75.2	1.92	34.3	38.35	13.43	1.49
Anilophos 0.4 kg/ha + 1 HW	84.4	7.1	70.7	1.38	52.7	27.81	4.69	1.18
Hand weeding twice (15&30 DAS)	90.5	9.1	78.5	2.52	14.1	48.13	22.81	1.92
Weed free	93.0	10.7	79.1	2.93	-	56.00	25.36	1.84
Unweeded control	53.1	4.8	50.6	0.40	86.3	8.83	-11.18	0.40
LSD (P=0.05)	8.67	1.6	10.3	0.32	-	-	-	-

Economics

Higher gross and net returns was realized with maintaining weed free condition throughout crop growth (₹56,000 and ₹25,360/ha, respectively). However, integration of pre-emergence pendimethalin 1.0 kg/ha application with a hand weeding at 30 DAS resulted in higher B: C ratio (1.94) followed by two hand weeding at 15 and 30 DAS (1.92) compared to other treatments (Table 2).This was possible because of the lesser cultivation cost under these treatments when compared to maintaining weed free condition throughout the crop growth.

It was concluded that pre-emergence application of pendimethalin 1.0 kg/ha integrated with one hand weeding at 30 DAS was effective in reducing weed growth and increase rice yield with better benefit-cost ratio in coastal ecosystem of Karaikal, Puducherry UT.

REFERENCES

Chauhan BS and Yadav A. 2013.Weed management approaches for dry-seeded rice in India: a review. *Indian Journal of Weed Science* **45**(1): 1-6.

Das TK and Duary B. 1998. Pendimethalin; An excellent herbicide for weed control in crops. *Intensive Agriculture* **36**(5-6): 18-20.

John DPS, Poonguzhalan R, Mohan R and Suburayalu E. 2012.Weed management for enhanced production of aerobic rice. *Indian Journal of Weed Science* **44**(4): 270–273.

Mahajan G and Chauhan BS. 2013. The role of cultivars in managing weeds in dry-seeded rice production systems. *Crop Protection* **49**: 52–57.

Mishra JS and Singh VP. 2007. Integrated weed management in zero till direct seeded rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping system. *Indian Journal of Agronomy* **52**:198-203.

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

Ramesh T, Sathiya K, Padmanaban PK and James Martin G. 2009. Optimization of nitrogen and suitable weed management practice for aerobic rice. *Madras Agricultural. Journal* **96**(7-12): 344-348.

Singh S, Ladha JK, Gupta RK, Bushan L and Rao AN. 2008.Weed management in aerobic rice systems under varying establishment methods, *Crop Protection* **27**(3-5): 660-671.

Singh VP, Singh G, Singh RK, Singh SP, Kumar A, Dhayani VC, Kumar M and Sharma G. 2005. Effect of herbicides alone and in combination on direct seeded rice. *Indian Journal of Weed Science* **37**(3&4): 197–201.

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Herbicide combinations for control of complex weed flora in transplanted rice

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ABSTRACT

A field experiment was conducted to evaluate the bioefficacy of some potent low dose herbicides of sulfonylurea group in conjunction with other traditional recommended herbicides for control of broad spectrum of weeds in transplanted rice (*Oryza sativa* L) during the wet season of 2012 and 2013. Pretilachlor 750 g/ha as pre-emergence (PE) *fb* ethoxysulfuron 18.75 kg/ha as post-emergence or pretilachlor 750 g/ha followed by metsulfuron-methyl + chlorimuron-ethyl 4 g/ha or pyrazosulfuron 20 g/ ha (PE) followed by manual weeding were better options for efficient weed control, higher grain yield and B:C ratio in transplanted rice.

Key words: Transplanted rice, Herbicides, Weed flora

Rice (*Oryza sativa* L) is an important food crop contributing major share in the total food grain production. Generally, low rice production is attributed to infestation of pests and diseases, weeds, poor water quality and its management, fertility management besides low yield potential of varieties. Weed management is one of the major factors, which affect rice yield. Uncontrolled weeds cause grain yield reduction up to 76% under transplanted conditions (Rao *et al.* 2007). Therefore, timely weed control is imperative for realizing desired level of productivity. Therefore, an efficient and economic weed management program is necessary to control different types of weeds throughout the cropping period. Hand weeding though efficient is expensive, time consuming, difficult and often limited by scarcity of labour in time. On the other hand, herbicides offer economic and efficient weed control if applied at proper dose and stage. However, the continuous use of single herbicide or herbicides having the same mode of action may lead to the weed resistance problem and also weed shifts. Hence it is necessary to test some high efficacy herbicides to control mixed weed flora in transplanted rice. Keeping this in view, a field experiment was carried out to evaluate the performance of pre- and post-emergence herbicides alone and in combination in transplanted rice

MATERIALS AND METHODS

Experiment was conducted at college farm, Rajendranagar, Hyderabad, during rainy season of 2012 and 2013. Twelve treatments *viz*., bispyribac-Na 25 g/ha at 25 DAT, pretilachlor 1000 g/ha at 3 DAT, pyrazosulfuron 20 g/ha at 0-3 DAT, bispyribac + ethoxysulfuron 25 + 18.75 g/ha, bispyribac + metsulfuron-methyl + chlorimuron-ethyl (Almix) 20 + 4 g/ha, pretilachlor *fb* ethoxysulfuron 750 + 18.75 g/ha, pretilachlor *fb* Almix 750 + 4 g/ha at 25 DAT pyrazosulfuron 20 g/ha (PE) *fb* manual weeding at 0-3 *fb* 25 DAT, pretilachlor (6%) + bensulfuron (0.6%) 6.6%) 660 g/ha at 0-5 DAT, weedy, hand weeding at 25 and 45 DAS were taken. Experiment was laid out in randomised block design with three replications. All herbicides were applied using knapsack sprayer fitted with flatfan nozzle at spray volume of 500 l/ha. Thirty days old seedlings of rice variety '*MTU 1010*' were transplanted at a spacing of 15x15 cm. Recommended dose of 120: 60: 40 kg/ha of NPK was applied uniformly. Half of the nitrogen and whole of phosphate and potash were applied at the time of final puddling and the remaining quantity of nitrogen was applied at panicle initiation stage. Weed dry weight were sampled randomly at two places with the help of a 0.25 m^2 sized quadrate at 60-day growth stage. Yield was recorded at crop harvest. Weed control efficiency was also calculated on the basis of dry matter production by weeds.

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RESULTS AND DISCUSSION

Weed flora

Major weed flora on weedy plot at 60 days stage of crop growth comprised of *Echinochloa colona*, *Echinochloa crusgalli*, *Eclipta alba*, *Commelin* , *Celosia* sp., *Ammania baccifera*, *Panicum repens, Bacopa monneri* and *Cyperus difformis*, *Cyperus* spp, *Scirpus supinus,Cyperus rotundus*, *Cyperus iria*. In weedy plot, grassy weeds constituted 52.8%, sedges 24.2% and broad-leaf weeds 22.9% of the total weed population. Different herbicidal treatments expressed differential influence on weed control in transplanted rice during both the years. Similar results were also recorded by Halder and patra (2007).

Effect on weed dry matter

All the weed control measures caused significant reduction in the density of all the weeds over weedy check. Weed dry matter was highly influenced by differential application of herbicides, their combinations and integration with manual weeding. Significantly lowest weed dry matter was recorded (18.8 g/m^2) in weed free treatment *i.e.* hand weeding at 25 and 45 DAT and was at par with pyrazosulfuron-ethyl 20 g/ha (PE) *fb* manual weeding (19.9 g/m^2 and 19.1% g/m^2 in 2012 and 2013, respectively) and it was at par with pretilachlor 750 g/ha (PE) *fb* Almix 4 g (POE) (21.8 g/m^2 and 20.8 g/m^2 in 2012 and 2013, respectively), pretilachlor 750 g/ha (PE) *fb* ethoxysulfuron 18.75 g/ha (POE) (22.5 and 22.67 g/m^2 in 2012 and 2013, respectively), bispyribac-sodium 20 g/ha + almix 4 g (POE) (22.9 and 23.6 g/m^2 in 2012 and 2013, respectively) and bispyribac sodium + ethoxysulfuron (POE) (23.2 and 25.4 g/m^2 in 2012 and 2013, respectively) were at par with each other indicating the significant influence of sequential application of pre-emergence and post-emergence herbicides (Table 1). These were significantly superior to lone application of bispyribac-sodium, pretilachlor 1000 g/ha and pyrazosulfuron-ethyl 20 g/ha or pretilachlor + bensulfuron-methyl. Similar trend has also been observed by Mandal (1995).

Weed control efficiency (WCE) ranged from 73.3-76.8% and 75.2-80.6% in respective years with various herbicide combinations. Highest WCE was recorded (86.6 and 88.0% in 2012 and 2013, respectively) with weed free conditions. Among herbicdes treamtents, highest WCE was recorded (76.8 and 80.6% in 2012 and 2013, respectively), while lowest was recorded with pyrazosulfuron 20 g/ha (48.1 and 52.0 in 2012 and 2013, respectively). The results were in conformity with the findings of Saini (2003) Yadav (2009) and Suganthi *et al.* (2010).

Effect on yield

Data revealed that significantly higher grain yield was recorded with weed free twice at 25 and 45 DAT (5.85 and 7.35 t/ha in 2012 and 2013, respectively), and was at par with the grain yield obtained with sequential application of pre- and post-emergence herbicides, *viz.* pyrazosulfuron-ethyl 20 g/ha (PE) *fb* manual weeding (5.83 and 7.34 t/ha in 2012 and 2013, respectively) during both the years This trend indicated the significance of integrated weed management. Grain yield recorded from pretilachlor (PE) *fb* Almix (5.59 and 7.05 t/ha in 2012 and 2013, respectively), pretilachlor *fb* ethoxys-ulfuron (POE) (5.47 and 7.09 t/ha in 2012 and 2013, respectively), bispyribac-sodium + Almix (POE) (5.28 and 6.78 t/ha in 2012 and 2013, respectively) and bispyribac sodium + ethoxysulfuron (POE) (5.16 and 6.65 t/hain 2012 and 2013, respectively) and all these treatment were significantly superior to grain yield obtained from lone application of bispyribac-sodium or pretilachlor or pyrazosulfuron or pretilachlor + bensulfuron-methyl (Table 2) indicating the importance of weed management in the critical growth period of crop by herbicide application, which facilitated the efficient use of resources. The findings of this investigations were in line with Kathirvelan and Vaiyapuri (2003) and Dhiman Mukerjee (2005).

Table 1. Effect of different pre- and post-emergence herbicides on weed dry matter (WDM) and weed control efficiency in transplanted rice

Treatment	WDM (g/m^2)		Weed control efficiency (%)	
	2012	2013	2012	2013
Bispyribac-Na 25 g/ha (POE)	5.50 (29.3)	5.51 (30.7)	65.9	68.9
Pretilachlo 1000 g/ha (PE)	6.36 (39.5)	6.59 (43.6)	53.9	55.8
Pyrazosulfuron 20 g/ha (PE)	6.74 (44.5)	6.88 (47.3)	48.1	52.0
Bispyribac + ethoxysulfuron 25 + 18.75 g/ha (POE)	4.91 (23.2)	4.94 (24.4)	67.1	75.2
Bispyribac 20 g/ha + Almix 4 g/ha (POE)	4.87 (22.9)	4.86 (23.6)	73.3	76.0
Pretilachlor 750 g/ha (PE) *fb* ethoxysulfuron 18.75 g/ha (POE)	4.85 (22.5)	4.76 (22.7)	73.8	77.0
Pretilachlor 750 g/ha (PE) *fb* Almix 4 g/ha (POE)	4.77 (21.8)	4.56 (20.8)	74.6	78.9
Pyrazosulfuron 20 g/ha (PE) *fb* manual weeding	4.56 (19.9)	4.37 (19.1)	76.8	80.6
Pretilachlor + bensulfuron 660 g/ha	5.58 (30.2)	5.68 (32.3)	64.8	67.3
Weed free (hand weeding at 25 and 45 DAS)	3.53 (11.5)	4.34 (18.8)	86.6	88.0
Weedy check	9.31 (85.8)	9.93 (98.5)	-	
LSD (P=0.05)	0.48	0.51		

*Figures in parantheses are original values and data are square root transformed

Table 2. Yield and economics as influenced by different weed control treatments in transplanted rice

Treatment	Grain yield (t/ha)		2012			2013		
	2012	2013	Gross returns (x10³ ₹/ha)	Net returns (x10³ ₹/ha)	BCR	Gross returns (x10³ ₹/ha)	Net returns (x10³ ₹/ha)	BCR
Bispyribac-Na 25 g/ha (POE)	4.48	5.96	58.24	20.18	1.82	78.03	39.98	2.05
Pretilachlo 1000 g/ha (PE)	4.27	5.77	55.57	18.35	1.78	75.56	38.28	2.03
Pyrazosulfuron 20 g/ha (PE)	4.37	5.83	56.87	19.96	1.84	76.42	39.54	2.07
Bispyribac + ethoxysulfuron 25 + 18.75 g/ha (POE)	5.16	6.65	67.14	28.40	2.05	87.16	48.42	2.25
Bispyribac 20 g/ha + Almix 4 g/ha (POE)	5.28	6.78	68.64	30.18	2.11	88.84	50.39	2.31
Pretilachlor 750 g/ha (PE) *fb* ethoxysulfuron 18.75 g/ha (POE)	5.47	7.09	71.17	33.11	2.22	92.87	54.82	2.44
Pretilachlor 750 g/ha (PE) *fb* Almix @4 g/ha (POE)	5.59	7.05	72.73	35.04	2.29	92.35	54.59	2.45
Pyrazosulfuron 20 g/ha (PE) *fb* manual weeding	5.83	7.34	75.85	35.97	2.24	96.13	56.26	2.41
Pretilachlor + bensulfuron 660 g/ha	4.57	6.07	59.47	21.44	1.86	79.49	41.49	2.09
Weed free (hand weeding at 25 and 45 DAS)	5.85	7.35	76.05	33.61	2.09	96.33	53.98	2.27
Weedy check	2.97	4.45	38.67	2.47	1.28	58.29	22.19	1.61
LSD (P=0.05)	0.67	0.41						

Economics

Economics of different herbicides their combinations and integrated weed managment were calculated on the basis of cost of cultivation and gross returns (₹/ha) accrued from the treatment and based on this, benefit cost ratio was calculated (BCR). Hand weeding at 25 and 45 DAT, pyrazosulfuron-ethyl 20 g/ha *fb* manual weeding, though was effective in efficient weed control and higher yield but its higher cost pulled down the profit with low B.C ratio of 2.27 and 2.41, respectively in 2013. Based on BCR it was reported that for transplanted paddy, pre-emergence application of pretilachlor 750 g/ha (PE) *fb* Almix 4 g/ha (POE) was the best as it gave highest BCR (2.29 and 2.45 in 2012 and 2013, respectively). The next best treatment was pretilachlor 750 g/ha (PE) *fb* ethoxysulfuron 18.75 g/ ha (POE) as it gave B: C ratio 2.24 and 2.44 in 2012 and 2013, respectively.

It was concluded that pretilachlor 750 g/ha (PE) *fb* ethoxysulfuron (POE) or Almix 4 g/ha and pyrazosulfuron 20 g/ha (PE) *fb* manual weeding were better options for efficient weed control, higher grain yield and profit in transplanted rice.

REFERENCES

Dhiman Mukerjee and Singh RP. 2005. Relative performance of new generation herbicides on weed density yield and N,P uptake behavior in transplanted rice. *Indian Journal of Agricultural Sciences* **75**: 820-822.

Halder J and Patra AK. 2007. Effect of chemical weed control methods in transplanted rice. *Indian Journal of Agronomy* **52**: 111-113.

Kathirvelan P and Vaiyapuri V. 2003. Relative efficacy of herbicides in transplanted rice. *Indian Journal of Weed Science* **35**(3&4): 257-258.

Mandal S. 1995. *Efficacy of sulfonylurea herbicides alone and in combination with anilofos in transplanted rice.* M.Sc. Ag. (Agronomy), Thesis, G.B. Pant University of Agriculture and Technology, Pantnagar.

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

Saini JP. 2003. Efficacy of pyrazosulfuron-ethyl against mixed weed flora in transplanted rice. *Pesticide Research Journal* **15**(2): 157-159.

Suganthi M, Kandasamy OS, Subbian P and Rajkumar R. 2010. Effect of new herbicides for weed control in transplanted rice. *Madras Agricultural Journal* **97**: 138-141.

Yadav DB, Ashok Yadav K and Punia SS. 2009. Evaluation of bispyribac–sodium for weed control in transplanted rice. *Indian Journal of Weed Science* **41**: 23-27.

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Long-term impact of crop establishment methods on weed dynamics, water use and productivity in rice-wheat cropping system

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ABSTRACT

An experiment consisting of five establishment techniques in rice-wheat cropping sequence with different combinations of conventional tillage (CT), zero-tillage (ZT) and minimum tillage (MT) *viz*. CT-CT, ZT-CT, CT-ZT, ZT-ZT and MT-ZT) was conducted during 2003-2007 at the farm of a farmer in Haryana on a larger plot size of 0.4 ha under each treatment. During first year, grain yield of wheat did not differ significantly among different treatments but during 2004-05 to 2007-08, grain yield of wheat in ZT method of planting was either higher or at par with conventional ploughed method of planting but CT transplanting of rice was significantly more than ZT transplanted treatments except during first year when rains were very good at transplanting time. Weed dynamics after 4 years revealed that in rice crop, weed density of *Echinochloa colona, E. crusgalli, Leptochloa chinensis,Cyperus* spp. and broad-leaf weeds such as *Ammania baccifera* and *Eclipta alba* was more when rice was transplanted under ZT or MT conditions but in wheat, weed density of grassy weed *Phalaris minor* was less under ZT-ZT or MT-ZT treatments. After 4 years of continuous ZT in both rice and wheat crops, weed flora changed in favour of broad-leaf weeds. Bulk density of soil did not vary after 5 years of ZT-ZT conditions. Soil temperature of root zone in wheat crop planted under ZT conditions was more (0.7-1.7 ^{O}C) in first week of February and less (2.1-.3.8 ^{O}C) in first week of April as compared to conventional CT-CT practice of rice and wheat crops resulting in more grain yield of wheat due to temperature moderation and also due to a bit addition of organic matter in ZT conditions. Grain yield of rice planted under ZT or MT conditions was less mostly due to more weed infestation and it also consumed 4.8-184% more water as compared to CT method of puddle transplanted rice.

Key words: Crop establishment**,** Conventional tillage, Minimum tillage, Soil properties, System productivity, Weed dynamics, Water requirement, Zero tillage

Rice-wheat is the most important cropping system practised in an area of 13.5 million hectare in the Indo-Gangetic Plains of South Asia (Gupta and Seth 2007). Planting of wheat crop by zero-drill machine after harvest of rice is well documented and has been largely accepted by farmers of Haryana, Punjab, Uttar Pradesh, Uttaranchal and Bihar. The multifold benefits of this resource conservation technology realized during experimentation at farmers' fields is well documented (Malik *et al.* 2002). Similarly implications and benefits of long term trials under ZT wheat have been outlined earlier also (Yadav *et al.* 2002). In irrigated low land rice cultivation commonly practiced by farmers, puddling is done that makes transplanting of rice easy, checks weeds and leads to incorporation of organic matter (De Datta 1981). Puddling not only consumes much energy and time from the tillage point of view but also consumes a large quantity of the total water requirement in rice (Sharma *et al.* 1995). So, an alternative method of planting is needed which may provide effective weed control, prepare a good seed bed for rice seedling and also helps to conserve water. Therefore, no tillage system was presumed most convenient in such conditions. Puddling condition on certain type of low land soil could be achieved by irrigation water without intensive tillage (Hakim 1986). Shallow tillage with herbicide application has been found to reduce the impact of weed to crop in 2-3 years, 50% of irrigation water and increased crop yield compared to that of zero-tillage system (Xin *et al.* 2001). Application of glyphosate herbicide before transplanting may take care of weeds and ratoon decay or decomposition without any residual effects on rice crop (Lamid *et al.*1995). Results of experiments conducted by Reddy *et al.* (2005) in

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rice-wheat cropping zone of Haryana and Lamid *et al.* (2001) in Indonesia showed feasibility of successful cultivation of Zero-tilled transplanted rice with slight yield gain and water saving. No-till rice technique in rice-wheat cropping system has been largely accepted by farmers of sichuan province of China (Au 2001). Encouraged with success of ZT sowing of wheat, experiments on feasibility of ZT or MT rice were initiated. In order to be ready to tackle expected implications in future related to impact of different establishment techniques (ZT-ZT/MT-ZT/ZT-CT) in both rice-wheat cropping systems on soil compactness, crop productivity, weed dynamics, water requirement and grain yield of both rice and wheat crops, long-term tillage trials were considered appropriate. Keeping aforesaid facts in view, the present investigation was planned to study the feasibility of double zero or minimum till - zero tillage options in rice-wheat cropping system and also to study the effects of various tillage practices on weed dynamics, soil physical properties and grain yield of rice and wheat.

MATERIALS AND METHODS

To investigate the long-term effect of different tillage treatments on crop productivity, soil health and weed dynamics, an experimental trial consisting of five combinations tillage (conventional tillage-CT, zero tillage-ZT and minimum tillage-MT) treatments *i.e.* CT-CT, ZT-CT, CT-ZT, ZT-ZT and MT-ZT in rice-wheat cropping system was conducted consistently for five years during 2003-04 to 2007-08. Experiment was initiated during *Rabi* season of 2003-04 on a large plot size of one acre for each treatment in village Pirthala of district Fatehabad (Haryana) and continued until up to *Rabi* season of 2007-08. Every year wheat crop var. '*PBW 343*' was grown after harvesting of rice by following all recommended package of practices except tillage practices (as per treatment). During all the years, rice and wheat crops were raised as per recommended practices of CCS HAU Hisar.

Data on density of different weeds in weedy check were recorded at 35 DAS in wheat and 30 DAT in rice. After harvest of wheat crop by combine harvester, loose straw left was burnt and fields were left as such but in case of rice, it was retained up to 30-40% on soil surface under ZT. Prescribed tillage practices (as per treatment) were adopted before *Kharif* season crop. In treatments of ZT (zero till transplanted rice), weeds emerged if any due to rains in month of May were controlled by spraying non-selective herbicide glyphosate (1.5% on product basis). In MT treatment, one slight disking was given to control the weeds and then field was irrigated and planked. In CT (conventional tillage treatment), field was prepared after harrowing twice and then puddling and removal of weeds with cultivator. Every year, rice crop was transplanted in last week of June and wheat in first week of November in all the fields under treatment. Pre-emergence application of pretilachlor at 1000 g/ha common to all treatments was made to control weeds. To control grassy weeds emerged in later stages, post-emergence use of fenoxaprop 9 EC (Whip Super) at 56.25 g/ha was incorporated in treatments where rice was transplanted by ZT method. Tubewell water with flow of 0.623 Cu sec was used for irrigating the crop and number of hours taken to irrigate under a particular treatment were counted and considered for calculating water consumption. Data on grain yield and bulk density of soil after harvesting were recorded from all the treatments. After harvest of rice in *Kharif* 2004, soil samples from different soil depths *i.e.* 0-5, 5-10 and 10-15 cm were collected from all treatments to study weed seed dynamics as influenced by tillage practices.

RESULTS AND DISCUSSION

Weed studies

Weed density studies conducted at 30 DAT in rice revealed significantly higher density of grassy weeds as well as broad-leaf weeds in treatments of ZT and MT methods of rice transplanting as compared to CT (conventional puddled method of rice transplanting). *Echinochloa crusgalli*, *E. colona* and *Leptochloa chinensis* were major grassy weeds, while broad-leaf weed *Ammania baccifera* and sedges *Cyperusiria* and *C. rotundus* were other prominent weeds (Table 1). During *Kharif*, 2007 (7^{th} crop in sequence) total number of weeds were more when rice was transplanted by ZT and MT methods. Higher density of broad-leaf weeds in zero till rice was also reported by Lamid *et al.* (2001). Density of *P. minor* was more in wheat planted by CT method but broad-leaf weeds such as *Chenopodium album, Melilotus indica* and *Rumex dentatus* dominated the weed flora planted by ZT method. Density of *R. dentatus* was significantly higher in plots of ZT-ZT and CT-ZT (data not given). After five years of continuous zero till wheat, weed flora changed in favour of broad-leaf weeds particularly *R. dentatus* and *C. album* during *Rabi* 2007 (Table 3). During first year, density of *P. minor* in field at 35 DAS was almost same in all tillage treatments and decreased in next two seasons but density of broad-leaf weeds particularly *C. album* increased every year and was more in wheat planted by ZT method.

Weed seed bank and its dynamics in soil

Grow out tests of soil samples collected from different soil depths in permanent tillage trial before *Kharif* 2007 (after 4 years of completion of trial) showed that in rice *E. colona, L. chinensis, E. crus-galli, C. difformis, A. baccifera* and *Dactyloctenium aegyptium* were the major weeds emerged from soil at different soil depths. Number of weed seeds emerged were more in ZT-ZT and MT-ZT treatments as compared to CT-CT. Weed density was maximum in upper 0-5 cm soil layer in all treatments(Fig. 1). Grow out test of soil samples collected during *Rabi* 2007-08 (after 5 years of trial) from different soil depths under different treatments before wheat sowing, revealed pre-dominance of *P. minor, C. album* and *M. indica* in all treatments. Density of weeds was maximum in CT-CT treatment and it was distributed in all soil depths being more in 0-5 and 5-10 cm soil depths. In ZT-ZT and CT-ZT (rice-wheat) treatments, density of weeds was minimum and that was mainly concentrated in 0-5 and 5-10 cm soil depth. *P. minor* population was very low in ZT-ZT or CT-ZT treatments as compared to CT-CT in 0-5 cm and 5-10 cm soil depth. Density of broad-leaf weeds particularly *C. album* was more in CT-ZT treatment followed by ZT-ZT and MT-ZT treatments at both soil depths (Table 3 and Fig. 2).

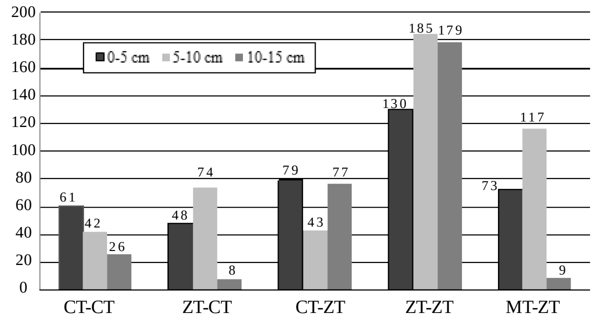

Fig. 1. Weed seeds emergence at different depths as affected by tillage methods (*Kharif* 2007)

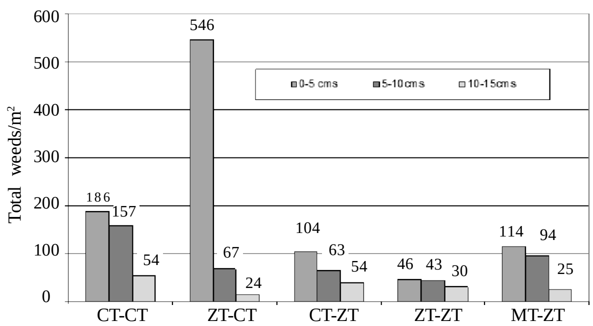

Fig. 2. Weed dynamics in different soil layers as affected by tillage practices (*Rabi* 2007-08)

Grain yield

Grain yield of rice and wheat varied significantly among treatments every year except *Rabi* 2003-04. During 2004-05, 2005-06 and 2007-08, maximum grain yield (4.98, 4.87 and 5.45 t/ha) of wheat was obtained under MT-ZT treatment which was significantly higher over CT-CT method during second and third years (Table 4). More grain yield of wheat under ZT-ZT planting method as compared to other tillage treatments in long term trial in pearl millet – wheat cropping system has been reported by Yadav *et al*. (2005). Grain yield of rice also differed significantly due to different tillage practices. During first year, grain yield of rice was maximum in MT-ZT and ZT-ZT but during 2nd, 3rd and 4th years, maximum grain yield (7.52, 7.71 and 7.20 t/ha) was recorded in CT-CT practices which was significantly higher than ZT-ZT and MT-ZT tillage practices. Higher grain yield of rice under MT and ZT during *Kharif* 2004 could be due to quick growth of seedling transplanted in shallow position in ZT and MT due to good rains occurred at transplanting time. Adhikari *et al* (2003) also reported grain yield of ZT rice at par with conventional transplanted rice.

Bulk density

Bulk density of the soil did not vary much even after five years of experimentation. Bulk density of soil increased with soil depth but did not vary much even after ninthcropharvest. In CT-CT, bulk density in 0-5 cm was around 1.37-1.39 g cm^3, whereas corresponding values for ZT-ZT were 1.38-1.42 g cm^3 (Table 5).

Soil temperature

The data on soil temperature (0-10 cm soil layer) recorded during first week of February and April (2004-08) in wheat have been given Table 6. It indicates that soil temperature in early February was 0.7-1.7 ^{O}C higher under ZT/MT method compared to CT. This increase in temperature under ZT might have facilitated better crop growth by better uptake and utilization of nutrients and also by avoiding crop from possible cold injury. Whereas lower temperature (2.1-3.8 ^{O}C) under ZT or MT compared to CT in first week of April might be helpful in uniform crop maturity by avoiding crop from terminal heat which usually results in forced maturity leading to shriveled grains and lower yields. Similar findings have been reported earlier also in wheat under ZT method in rice-wheat cropping system (Yadav *et al.* 2002).

Table 1. Effect of tillage practices on the density of different weeds in rice at 30 DAT

Tillage (Rice- wheat)	Weed density (no./m^2)							
	Echinochloa spp.				BLW			
	2004	2005	2006	2007	2004	2005	2006	2007
CT-CT	2.04(3.7)	2.04(2.9)	2.44(5)	1.73(2)	2.17(3.7)	1(0)	1.71(2.6)	1.91(2.7)
ZT-CT	4.67(22)	4.67(19)	4.54(19.8)	4.39(18.3)	2.94(7.6)	2.15(3.6)	2.62(6)	2.70(6.3)
CT-ZT	1(0)	1(0)	2(3)	1.71(2)	1.51(1.3)	1(0	1(0)	1(0)
ZT-ZT	5.06(28)	5.06(27)	5.25(26.7)	4.72(21.3)	3.46(11)	2.30(4.3)	3.49(15)	3.94(14.7)
MT-ZT	3.21 (9)	3.21(10)	2.47(5)	5.19(26)	1.92(2.7)	2.30(4.3)	2.62(6)	4.68(21)
LSD (P=0.05)	0.35	0.35	0.24	0.34	0.17	0.18	0.42	0.35

Figures in the parentheses indicate $(\sqrt{x+1})$ transformed data

Table 2. Density of different weeds in wheat as influenced by tillage practices at 35 DAS

Tillage (Rice-wheat)	Weed density (no./m^2)									
	P. minor					BLW				
	2003-04	2004-05	2005-06	2006-07	2007-08	2003-04	2004-05	2005-06	2006-07	2007-08
CT-CT	4.2(16.7)	2.1(3.3)	1(0)	2.2(44)	3.6(12.5)	3.3(9.6)	3.2(9.3)	1.6(1.7)	1.8(1.2)	1.9(3.7)
ZT-CT	4.5(19.0)	2.5(5.4)	1.7(2.2)	7.3(52.3)	4(15)	3.7(13.0)	3.2(9.1)	1.5(1.3)	2.1(3.3)	2.1(3.4)
CT-ZT	4.3(17.6)	2.4(5.0)	1.8(2.4)	6.6(42.6)	3(8.3)	4.3(17.9)	4.1(16.2)	8.9(79)	5.5(29)	5.3(28)
ZT-ZT	4.1(16.3)	2.4(4.7)	1(0)	4.5(19.3)	2.5(5.4)	4.1(16)	5.3(27.2)	8.4(70.4)	7(48.3)	6.3(38.4)
MT-ZT	4.2(17.5)	2.6(6.0)	1.7(1)	6.6(43)	1.9(2.7)	3.7(12.9)	4.1(15.7)	2.6(5.7)	4.9(22.7)	4.7(21.3)
LSD (P=0.05)	NS	NS	0.13	0.32	0.52	0.34	0.31	0.83	0.63	0.46

Figures in the parentheses indicate $(\sqrt{x+1})$ transformed data

Table 3. Weed dynamics in wheat as affected by planting methods (*Rabi* 2007-08)

Tillage	*P. minor*	*C. album*	*R. dentatus*	*M. indica*	*Total*
0-5 cm soil depth					
CT-CT	166	4	0	16	186
ZT-CT	546	0	0	0	546
CT-ZT	8	80	0	16	104
ZT-ZT	33	12	0	1	46
MT-ZT	85	22	0	7	114
5-10 cm soil depth					
CT-CT	133	3	0	21	157
ZT-CT	54	0	0	13	67
CT-ZT	31	33	0	0	64
ZT-ZT	9	28	2	4	43
MT-ZT	69	16	8	2	95
10-15 cm soil depth					
CT-CT	40	4	0	12	54
ZT-CT	5	1	0	8	14
CT-ZT	3	57	1	8	39
ZT-ZT	2	13	7	8	30
MT-ZT	11	7	4	3	25

Soil carbon

Data on soil carbon recorded after 7thcrop of wheat harvest in May, 2007 from different soil layers (0-5, 5-10, 10-15 and 15-20 cm) varied significantly in different soil layers. In general, it was maximum in treatments of ZT-ZT and MT-ZT method of planting and significantly more than CT- CT method at all soil depths (Table 7). In 0-5 cm soil layer, soil organic carbon was maximum(1.01-1.03%) in ZT-ZT and MT-ZT method of planting as compared to 0.85% in CT-CT method. Similarly, the soil organic carbon content was reported more in soil that had been more under zero tillage/reduced tillage for longer periods (Doran 1987, Havlin *et al.* 1990, Franzluebebbers *et al.* 1995).

Microbial population

Microbial population after harvest of 6th crop (rice) in sequence as shown in (Table 8), ranged from 219-242 mg/kg soil in treatments of zero tillage (MT-ZT and ZT-ZT) which was more than CT-CT treatment (168 mg/kg soil). Dehydrogenase activity

Table 4. Effect of tillage practices on grain yield (t/ha) of wheat and rice

Tillage (Rice-wheat)	Wheat					Rice			
	2003-04	2004-05	2005-06	2006-07	2007-08	2004	2005	2006	2007
CT-CT	5.50	4.80	4.81	5.25	5.42	7.52	7.98	7.71	7.20
ZT-CT	5.55	4.82	4.80	5.16	5.20	7.53	6.96	7.60	7.16
CT-ZT	5.60	4.90	4.70	5.02	5.38	7.45	7.11	7.65	7.18
ZT-ZT	5.54	4.92	4.81	5.20	5.40	7.97	6.72	6.70	6.60
MT-ZT	5.55	4.98	4.87	5.18	5.45	8.13	6.88	6.94	6.30
LSD (P=0.05)	NS	0.07	0.06	0.06	0.03	0. 24	0.24	0.31	0.24

Table 5. Bulk density of soil as influenced by various tillage practices in rice-wheat cropping system (2005-2008)

Tillage (Rice-wheat)	Bulk density (g/cm^3) *Kharif* 2005	2006	2007	2008	*Rabi* 2004-05	2005-06	2006-07	2007-08
Soil depth 0-5 cm								
CT-CT	1.37	1.39	1.38	1.38	1.39	1.38	1.38	1.39
ZT-CT	1.37	1.37	1.38	1.39	1.39	1.37	1.38	1.39
CT-ZT	1.40	1.39	1.40	1.40	1.41	1.40	1.39	1.40
ZT-ZT	1.42	1.38	1.41	1.41	1.42	1.39	1.40	1.40
MT-ZT	1.43	1.39	1.42	1.42	1.41	1.41	1.41	1.41
LSD(P=0.05)	0.02	NS	0.02	0.02	NS	0.021	NS	NS
Soil depth 5-10 cm								
CT-CT	1.46	1. 47	1. 50	1.48	1.47	1.47	1.48	1.47
ZT-CT	1.51	1.48	1.54	1.50	1.51	1.48	1.48	1.48
CT-ZT	1.50	1.49	1.51	1.51	1.50	1.49	1.49	1.49
ZT-ZT	1.50	1.50	1.49	1.49	1.50	1.50	1.50	1.51
MT-ZT	1.47	1.49	1.51	1.50	1.47	1.50	1.50	1.50
LSD(P=0.05)	0.03	NS	0.02	NS	0.023	NS	NS	0.027
Soil depth 10-15 cm								
CT-CT	1.66	1.66	1.66	1.67	1.66	1.66	1.67	1.67
ZT-CT	1.66	1.68	1.66	1.68	1.68	1.68	1.69	1.66
CT-ZT	1.65	1.65	1.63	1.63	1.63	1.63	1.63	1.65
ZT-ZT	1.63	1.63	1.61	1.64	1.63	1.63	1.63	1.65
MT-ZT	1.64	1.63	1.64	1.63	1.64	1.64	1.64	1.67
LSD(P=0.05)	NS	0.03	0.03	0.03	0.04	0.03	0.04	NS

Table 6. Impact of tillage practices on soil temperature in the root zone of wheat

Tillage (Rice-wheat)	Soil temperature (^0C) January 2004	2005	2006	2007	2008	April 2004	2005	2006	2007	2008
CT-CT	8.72	8.64	8.32	8.42	8.46	26.5	27.2	27.6	27.6	27.3
ZT-CT	8.70	8.70	8.69	8.50	8.65	26.5	26.9	27.8	28.0	26.8
CT-ZT	8.72	8.76	9.48	9.45	9.46	26.2	24.3	25.0	25.3	24.5
ZT-ZT	8.98	9.48	9.56	9.56	9.52	25.9	23.5	24.6	23.0	23.4
MT-ZT	9.16	9.46	9.54	9.55	9.54	25.7	23.3	24.0	23.8	23.8
LSD (P=0.05)	0.04	0.03	0.06	0.2	0.03	NS	1.2	2.2	1.8	2.3

Table 7. Soil organic carbon (%) at various soil depths in different tillage treatments after 4 years (before 7th crop of rice *i.e.* after wheat harvest, 2006)

Planting (Rice-wheat)	Soil depth (cm) 0-5	5-10	10-15	15-20
CT-CT	0.85	0.68	0.35	0.35
ZT-CT	0.81	0.64	0.32	0.31
CT-ZT	0.87	0.68	0.43	0.38
ZT-ZT	1.01	0.86	0.54	0.46
MT-ZT	1.03	0.82	0.62	0.45
LSD(P=0.05)	0.11	0.12	0.14	0.6

Table 8. Microbial population as affected by tillage practices in rice and wheat after wheat harvest (2006)

Tillage (Rice-wheat)	MBC (mg/kg soil)	Dehydrogenase activity (µg TPF/µg soil/24 hrs	Phosphate activity (µg PNP/g dry soil/hr
CT-CT	168	77	80
ZT-CT	212	115	90
CT-ZT	223	114	98
ZT-ZT	242	117	104
MT-ZT	219	87	90

in ZT-ZT treatment was 117 µg TPF/µg soil/24 as compared to CT-CT treatment whereas phosphate population in ZT-ZT method was 104 µg PNP/g dry soil/hr as compared to 80 µg PNP /g dry soil/hr in CT-CT method. Results of experiments conducted at CCS HAU Hisar by Kumar *et al*. (2003) also have clearly reflected that microbial count, soil organic carbon and DHA were higher in ZT field followed by mould board plough and CT soil. The greater number of microorganisms and their activity closure to soil surface under zero till system could be associated primarily with some residues retained.

Water consumption

During *Kharif* 2004 and 2005, rains were very good but even then water requirement of ZT transplanted rice was more (4.9-27.9%) as compared to conventional transplanted rice. During 2006, due to poor rains rice crop consumed more water and in ZT-ZT method of planting, Tube well had to run for 685 hours which was 184% more than CT-CT method due to higher percolation of water in unpuddled conditions (Table 9).

Conclusion

Transplanted zero till rice would provide lowland farmers with some flexibility in the timeline of the rice planting and its establishment in accordance to the onset of monsoon rains as does the normal farmer practice. Non-puddled rice transplanting method could be a viable technology

Table 9. Water requirement of rice under different tillage systems in *Kharif*

Tillage (Rice-wheat)	2004 Total time consumed for irrigations (h)	2004 Percent increase /decrease over conventional method	2005 Total time consumed for irrigations (h)	2005 Percent Increase /decrease over conventional method	2006 Total time consumed for irrigations (h)	2006 Percent increase over conventional method
CT-CT	143	-	91.6	-	241	-
ZT-CT	167	+16.6	100.7	+10.3	526	118
CT-ZT	112	-21.7	77.4	-15.5	244	1.2
ZT-ZT	184	+27.9	96.0	+4.8	685	184
MT-ZT	152	+5.8	90.0	-1.75	562	133

and an alternative to puddled transplanted rice particularly in the years of heavy rainfall. Therefore, puddled transplanting of rice followed by zero till sowing of wheat was the most promising option for improving productivity and profitability while sustaining the natural resources and addressing the emerging challenges in rice-wheat cropping system of north-west India.

REFERENCES

Adhikari U, Justice S, Tripathi J and Bhatta MR. 2007. Performance evaluation of non-puddled rice transplanting methods. In: *25th National Summer Crops Workshop* June 21-23, 2007 at National Agriculture Research Institute, NARC, Khumaltar,Lalitpur, Nepal.

Au J. 2001. The no tillage technique with grammaxone in rice and wheat production in the water saving and conservation agriculture, pp. 836-842. In: *Proceedings of 18th Asian-Pacific Weed Science Society Conference,* May 28-June 2 2001, Beijing, China.

De Datta SK. 1981. *Principles and Practices of Rice Production.* A Wiley Inter Science Publication, John Wiley& Sons, Inc, 605 Third Avenue, New York. 618 p.

Doran JW. 1987. Microbial biomass and mineralizable nitrogen distributionin no tillage and plowed soils. *Biology and Fertility of Soils* **5**: 68-75.

Franzluebbers AJ, Hons FM and Zuberer. 1995. Soil organic carbon, microbial biomass and mineralizable carbon and nitrogen in sorghum. *Soil Science Society of America Journal* **59**: 460-466.

Gupta RK and Seth A. 2007. A review of resource conserving technologies for sustainable management of the rice–wheat cropping systems of the Indo-Gangetic plains (IGP), *Crop Protection* **26:** 436-447.

Hakim N. 1986. *Fundamentals of Soil Science.* Univ. Lampung, Bander Lampung. (Indonesia). 480 p.

Havlin JL, Kissel DE, Maddux LD, Claassen MM and Lang JH. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. *Soil Science Society of America Journal* **59:** 467-470.

Hobbs P. and Morris M. 1996. Meeting South Asia's future food requirement from rice-wheat cropping systems: Issues facing researchers in the post-green revolution era. *NRG Paper 96-01 Mexico,* DF: CIMMYT.

Kumar S. 2003. *Influence of tillage in wheat (*Triticum aestivum*) on soil microbial population and its activities.* MSc Thesis, CCS HAU Hisar.

Lamid, Z, Saraigih ES and Tambijo AD. 2001. Effect of continuous no-tillage applied glyphosate herbicide on weed community of irrigated low land rice, pp. 43-48. In: *Proceedings of 18th Asian-Pacific Weed Science Society Conference*. 28 May - 2 June, 2001, Beijing,China.

Sharma SK, Tomar RK and Gangwar KS. 1995. Effect of crop establishment and tillage practices on yield and economic of irrigated rice (*Oryza sativa*)-wheat (*Triticum aestivum*) system. *Indian Journal of Agricultural Sciences* **65**(9): 636-638.

Reddy CV, Malik RK and Yadav Ashok. 2005. Evaluation of double zero tillage in rice-wheat cropping system. pp. 118-121. In: *Accelerating the adoption of Resource Conservation Technologies in Rice-Wheat Systems of the Indo-Gangetic plains,* Proceedings of Project Workshop, June 1-2, 2005 at Hisar (Haryana), India.

Xin CY, Guo QY and Qin XL. 2001. Effect of shallow tillage on weed seed, soil moisture and crop yield,pp 324-327. In: *Proceedings of 18th Asian-Pacific Weed Science Society Conference.* 28 May - 2 June, 2001. Beijing, China.

Yadav Ashok, Malik RK, Balyan RS, Singh S. Chauhan BS, Yadav Dharambir, Murti Ram and Malik RS. 2002. Long term effects of zero tillage in rice-wheat cropping system, pp 158-161. In: *Herbicide Resistance Management and Zero Tillage in rice-wheat Cropping System*. Proceedings of International Workshop March 4-6, 2002, CCS Haryana Agricultural University, Hisar-125004(Haryana), India.

Yadav Ashok, Malik RK, Punia SS, Malik RS and Singh Sher. 2005. Studies on the impact of long term zero tillage in pearl millet-wheat cropping sequence, pp. 23-31. In: *Accelerating the adoption of Resource Conservation Technologies in Rice-wheat cropping systems of Indo-Gangetic Plains.* Proceedings of the Project Workshop, June 1-2, 2005, Directorate of Extension Education, CCS HAU Hisar (Haryana), India.

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Efficacy of different clodinafop-propargyl formulations against littleseed canarygrass in wheat

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ABSTRACT

Field experiments were conducted in three successive seasons (*Rabi* 2010–11, 2011-12 and 2012–13) to evaluate the efficacy of clodinafop-propargyl formulations (wettable powder and emulsifiable concentrate) applied as post-emergence against *Phalaris minor* in wheat crop. All formulations of herbicide reduced the density of *Phalaris minor* over the weedy check however treated plots yielded below than the state average yield of wheat crop. These new clodinafop formulations/brands failed to provide effective control of resistant *P. minor* prevailing in wheat field during all years, and gave only 27-32% control of *Phalaris minor* over the weedy check. These new formulations also yielded similar to clodinafop-p-propargyl applied as standard check. Per cent control of *Phalaris minor* was found to be reduced from 60 to 40% over unsprayed check with delay in application time of clodinafop from 35 to 60 DAS.

Key words: Application time, Clodinafop, Formulations, *Phalaris minor*, Resistance

Littleseed canarygrass (*Phalaris minor* Retz.) is the most common and predominant weed of wheat under rice-wheat cropping system in the North-Western Indo-Gangetic Plains (IGP) of India. In Punjab, *P. minor* is a major weed of wheat crop. The crop suffers a yield loss of 25-30% due to infestation of this weed (Yadav and Malik 2005). *P. minor* is the predominant weed species found in wheat with importance value index of 34.80 in Kapurthala and 28.45 in Ludhiana districts in *Rabi* 2007-08 and Importance value index (IVI) of this weed has been found to increase to 94.40 in Kapurthala and 75.90 in Ludhiana districts, in *Rabi* 2011-12, demonstrating its supremacy as a major weed in wheat crop (Anonymous 2008, 2012).

Resistance to isoproturon–a substituted urea herbicide is the most serious case of herbicide resistance in the world (Malik and Singh 1995), spread in more than 10 lakh ha of the rice-wheat cropping system (Singh 2007) and cause complete wheat crop failure, particularly under heavy infestation of 2000-3000 *P. minor* plants/m^2, posing a serious threat to the sustainability of this system. Resistant biotypes from Haryana have been reported to require up to eleven times the pre-susceptible dose of isoproturon to achieve 50% growth reduction (Yadav and Malik 2005) and this resistance was also found to be of metabolic in nature.

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Alternative herbicides belonging to group I [(acetyl co-A carboxylase (ACCase) inhibitors] and group II [acetolactate synthase (ALS) inhibitors] were recommended for management of *P. minor*. Clodinafop-propargyl, an aryloxyphenoxy propionates applied as post-emergence was recommended for for grass control, *viz. P. minor and A. fatua etc.* in spring hexaploid and tetraploid wheat. Clodinafop-propargyl is absorbed by the leaves and rapidly translocated to the growing points of leaves and stems. It interferes with the production of fatty acids needed for plant growth in susceptible grassy weeds. It has been used extensively in wheat for the last several years. The new herbicides brought the *P. minor* infestation under control and restored yields to their previous levels. But red signals of resistance against these alternate herbicides have also been speculated in 2002 and thereafter.

Recently, poor or no control of *P. minor* by application of clodinafop-propargyl has been observed in large areas, which could be related to cross-resistance or multiple resistance (Das *et al.* 2014) but new formulations are coming in market. Farmers delay application of clodinafop-propagy after two months of sowing either owing to late emergence of weed after first irrigation or to control two flushes of *P. minor* by one spray. Keeping this in mind, different new brands and formulations of clodinafop-propargyl and its time of application have been evaluated in respect to its bio-efficacy against *P. minor* in wheat crop.

MATERIALS AND METHODS

Field experiment was conducted at Research Farm Punjab Agricultural University, Ludhiana, Punjab during three successive winter seasons of 2010-11, 2011-12 and 2012-13. The experimental site was situated in Trans-Gangetic Agro-Climatic zone, representing the Indo-Gangetic Alluvial plains (IGP) at 30° 56' N latitude, 75° 52' E longitude and at an altitude of 247 m above mean sea level. The soil of the experimental site was loamy sand (coarse loamy, mixed hyperthermic, Typic ustipsamments) with normal soil reaction (pH=7.8) and electrical conductivity (0.17 dS/m). The soil was low in organic carbon (0.32 %) and available N (251.7 kg/ ha) and medium in available P (13.9 kg/ha) and K (167.3 kg/ha).

Experiment was laid out in randomized complete block design with 3 replications. Wheat cv. '*PBW 343*' in 2010-11, '*PBW 621*' in 2011-12 and '*HD 2967'* in 2013-14 were sown in mid-November in all three seasons. '*PBW 343*' was withdrawn from package of practices of Punjab and so, new variety, '*PBW 621*' was used in second year of study. In third year of study, variety "*HD 2967*" was taken for study due to its wide adaptability and acceptability at farmers' field. The new herbicide brands (Columbus and Markclodina in 15% wettable powder form) of coldinafop-propagyl 60 g/ha and variable doses of new formulation of clodinafop-propagyl (26.7% EC) 53.4, 66.75, 80.10 and 133.5 g/ha were applied at 30 days after sowing (DAS) using 375 litre of spray solution per hectare with hand operated knapsack sprayer fitted with flat fan nozzle. The crop was raised with recommended package of practices. *Phalaris minor* density and its biomass data was recorded at 30 days after spray or at 60 DAS with 50 x 50 cm quadrat.

In third year of study, application time of clodinafop-propargyl was also evaluated and late application at 60 days after sowing (DAS) was tested against recommended time of 35 DAS and unsprayed check during *Rabi* 2013-14. Per cent control of weed was reported over unsprayed check at 30 days after spray application or at 90 DAS. The weed data were subjected to square root transformation before analysis. Data on yield attributes and yield were determined at harvest. The data were statistically analyzed by using statistical procedures and comparisons were made at 5% level of significance.

RESULTS AND DISCUSSION

The experimental field contained only *P. minor* as grassy weed. Columbus, a brand formulation was evaluated for its bio-efficacy against *P. minor* in wheat crop in 2010-11. The application of clodinafop-propargyl (both brands- Columbus and Topik 15 WP) yielded significantly higher grain yield (3.46 and 3.43 t/ha) over the weedy check (2.80 t/ha) and recorded 31 and 25% control of *P. minor* over the weedy check. However, the new brand of clodinafop-propargyl (Columbus) recorded grain yield statistically at par with earlier recommended brand of clodinafop-propargyl (Topik) (Table 1). The new brand of clodinafop (Columbus) also failed miserably at Agronomy Research Farm as wheat average yield was much below the state average yield of 5.50 t/ha.

Another emulsifiable concentrate formulation of clodinafop-propagyl was evaluated for its bioefficacy against *P. minor* in wheat in 2011-12. Different doses of clodinafop from 53.4 to133.5 g/ha (commercial formulation dose of 200-500 ml/ha) also resulted statistically similar density of *P. minor* as well as grain yield at all the doses. Clodinafop-propargyl 26.7 EC provided only 58-64% control of *P. minor* over the weedy check (Table 2). All the doses of emulsifiable concentrate formulation of clodinafop-propargyl recorded statistically similar grain yield over the weedy situation as well as earlier recommended wettable powder formulation of clodinafop-propargyl (Topik) and both yielded below the state average yield of wheat crop. Markclodina- another brand of clodinafop-propargyl recorded statistically similar

Table 1. Effect of clodinafop on weeds and other yield attributing characters of wheat during *Rabi* 2010-11

Treatment	Dose (g/ha)	*P. minor* at 60 DAS		Effect on crop at harvest		
		Population (no./m^2)	Dry matter (g/m^2)	Plant height (cm)	Effective tillers/m^2	Grain yield (t/ha)
Columbus 15 WP (clodinafop)	60	8.9 (97)	9.4 (87)	76.7	241.1	3.46
Topik 15 WP (clodinafop)	60	11.2 (126)	9.8 (95)	76.5	239.6	3.43
Weedy check	-	13.6 (185)	11.4 (127)	71.6	226.7	2.80
Weed free	-	1.0 (0)	1.0 (0)	80.5	321.7	5.63
LSD (P=0.05)		2.9	1.1	3.0	7.7	0.45

Data is square root transformed, Figure within parentheses is original means

Table 2. Bio-efficacy of new formulation of clodinafop for control of grass weeds in wheat during *Rabi* 2011-12

Treatment	Dose (g/ha)	*P. minor* at 60 DAS		Effect on crop at harvest		
		Population (no./m^2)	Biomass (g/m^2)	Plant height (cm)	Effective tiller/m^2	Grain yield (t/ha)
Clodinafop 26.7% EC	53.40	6.2 (38)	6.0 (36)	72.2	255	3.95
Clodinafop 26.7% EC	66.75	5.4 (31)	5.6 (31)	66.2	256	4.00
Clodinafop 26.7% EC	80.10	5.4 (31)	5.4 (29)	74.7	257	4.13
Clodinafop 26.7% EC	133.50	5.8 (33)	5.5 (31)	70.1	262	4.28
Clodinafop 15% WP	60	6.0 (36)	5.1 (26)	69.7	261	3.99
Weedy		8.4 (69)	9.2 (85)	67.5	221	3.49
Weed free		1.0 (0)	1.0 (0)	75.5	341	5.93
LSD (P=0.05)		2.2	1.39	NS	36	0.82

Data is square root transformed, Figure within parentheses are original means

Table 3. Effect of clodinafop for control of grassy weeds in wheat during *Rabi* 2013-14

Treatment	Dose (g/ha)	*Phalaris minor* at 60 DAS		Effect on crop at harvest		
		Population (no./m^2)	Dry matter (g/m^2)	Plant height (cm)	Effective tillers/m^2	Grain yield (t/ha)
Markclodina 15 WP (clodinafop)	60	4.3 (18)	4.5 (19)	84.3	294	43
Topple 15 WP (clodinafop)	60	4.3 (17)	4.6 (20)	78.9	294	42
Unsprayed check	-	4.8 (23)	5.2 (26)	77.7	221	36
Weed free	-	1.0 (0)	1.0 (0)	86.0	330	57
LSD (P=0.05)		0.3	0.2	5.0	42	3

Data is square root transformed. Figure within parentheses are original means.

grain yield (4.27 t/ha) with earlier recommended brand of clodinafop-propargyl namely Topple (4.20 t/ha), which recorded 27% control of *P. minor* as compared to unweeded check during *Rabi* 2013-14 (Table 3). These results were in conformity to findings by Hamada *et al.* (2013).

Some farmers in Punjab have started using higher dose (2 to 3 times) than the recommended dose or used tank-mix of these herbicides for effective control of *P. minor* in wheat. The multiple herbicide-resistant populations had a low level of sulfosulfuron resistance but a high level of resistance to clodinafop-propargyl and fenoxaprop-p-ethyl (Chhokar and Shar 2008). From weed survey conducted during *Rabi* 2012-13 and 2013-14 in Moga, Patiala, Ropar, Sangrur, Kapurhala, Jalandhar and Ludhiana districts, it was found that the farmers were using either tank-mix application of 600 g/ha (1.5 times higher than the recommended dose 400 g/ha) of clodinafop-propargyl with recommended dose (32.5 g/ha) of sulfosulfuron for controlling *P. minor* or spraying sulfosulfuron before first irrigation and application of 1600 g/ha (four times higher than the recommended dose) of clodinafop at 60 DAS and moreover, farmers delayed this spray up to 60 DAS (Table 4).

Probable reason for poor control of weed at farmers fields were identified as adoption of faulty spray techniques, use of inappropriate nozzle, to and fro movement of spray lance while spraying, *etc*. or there was presence of clodinafop resistant population of *P.minor*. Clodinafop used for 4 years increased the chance of resistance evolving, whereas its rotation with sulfosulfuron reduced the chance of resistance evolving (Das *et al*. 2014). The further use of clodinafop would lead to the spread of resistance in larger areas through the dispersal of resistant seeds. Repeated use of same group of herbicide and either lower or higher application dose of herbicides with low volume of water used by farmers than recommended package and practices were the major causes of rapid evolution of herbicide resistance in *P. minor* populations of North West region of India. Navjyot-Kaur *et al*. (2015) also reported that the application of clodinafop, fenoxaprop-p-ethyl and

Table 4. Control of *P. minor* with clodinafop in different districts during *Rabi* 2012-13 and 2013-14 at farmers' field

District	No. of locations with poor control of *Phalaris minor*
Moga	12 (12)*
Patiala	10 (15)
Ropar	12 (20)
Sangrur	6 (20)
Kapurthala	8 (15)
Jalandhar	12 (20)
Ludhiana	20 (30)

*Figures in parentheses denote total number of locations.

pinoxaden is giving <40% control of *P. minor.* There was significant reduction in grain yield and per cent control of *P. minor* over unsprayed check which was reduced from 60 to 40% with delay in application time of clodinafop from 35 to 60 DAS (Table 5).

Table 5. Effect of time of application of clodinafop on control of *P. minor* and wheat grain yield during *Rabi* 2013-14

Treatment	Control of *P. minor* over unsprayed check (%)	Grain yield (t/ha)
Clodinafop 60 g/ha at 35 DAS	60.0[a]	4.85[a]
Clodinafop 60 g/ha at 60 DAS	40.0[b]	4.26[b]
Unsprayed check	-	3.22[c]

Figures with the different letters are significantly different from each other at 5% probability.

So, for effective control of *P. minor*, clodinafop group of herbicides should be replaced with alternate herbicides-sulfosulfuron 25 g/ha or pinoxaden 5.0 t/ha in areas where *P. minor* has developed resistance against clodinafop-propargyl. Besides, where *P. minor* has not evolved resistance, the yearly rotation of sulfosulfuron with clodinafop-propargyl or pinoxaden might delay the evolution of resistance.

REFERENCES

Anonymous. 2008. *Annual Report.* All India Coordinated Project on Weed Control, Department of Agronomy, PAU Ludhiana.

Anonymous. 2012. *Annual Report.* All India Coordinated Project on Weed Control. Department of Agronomy, PAU Ludhiana.

Das TK, Ahlawat IPS and Yaduraju NT. 2014. Littleseed canarygrass (*P. minor*) resistance to clodinafop-propagyl in wheat fields in north-western India: Appraisal and management. *Weed Biology and Management* **14**: 11-20.

Hamada SHE, Abdel-Lateef MF, Abdelmonem AE, El-Kholy RMA, Helalia AAR. 2013. Efficiency of certain clodinafop-propargyl formulations in controlling annual grassy weeds in wheat. *Annals of Agricultural Science* **58**(1): 13-18.

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

Navjyot-Kaur, Tarundeep-Kaur, Simerjeet-Kaur and Bhullar Makhan S. 2015. Development of cross resistance in *Phalaris minor* Retz. in Punjab. (unpublished data).

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

Yadav A and Malik RK. 2005. *Herbicide Resistant Phalaris minor in wheat–Sustainability issue*. Resource Book. Department of Agronomy and Directorate of Extension Education, CCSHAU, Hisar, India.

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Weed management in maize under rainfed organic farming system

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ABSTRACT

Field experiment was conducted under organic farming for three consecutive years during 2008-09 to 2010-11 to study the effect of different non-chemical weed management practices on productivity and weed infestation in maize in mid altitude (950 m MSL) of Meghalaya, India. Total eight treatment in three replication were evaluated on maize. Grain weight/cob of maize was maximum under mulching with fresh *Eupatorium* sp. biomass after earthing up at 30 days after sowing (DAS). The highest maize yield was recorded under mulching with fresh *Eupatorium* 10 t/ha, but it was statistically at par with two hand weeding (HW) at 20 and 40 DAS, weed free check and soybean green manure incorporation in situ + one HW. Two HW, soybean green manure incorporation + one HW and mechanical weeding (20 DAS) + one HW (after earthing up) were found to be effective in weed reduction in maize. Weed control efficiency was recorded maximum under two HW which was at par with mechanical weeding (20 DAS) + one HW. Available N, P, K and soil organic carbon concentration after 3-croppoing cycles were maximum under mulching with fresh *Eupatorium* 10 t/ha treatment followed by soybean green manuring + one HW (45 DAS) than those under other weed management practices. Thus, mulching with fresh *Eupatorium* (after earthing up) and soybean green manuring + one HW were the recommendable options for sustainable organic maize production under high rainfall hill ecosystem of North-East India.

Key words: Hill ecosystem, Mulching, Maize, Organic farming, Rainfed, Weeds control efficiency

Maize (*Zea mays* L.) is the second most important crop after rice in North East region (NER) of India and maize is predominant crop in the upland ecosystem of the region (Das *et al.* 2010). Maize is among the high yielding crops and has great economic importance to the hill and mountain ecosystem as food, feed and fodder. Maize is cultivated as rainfed crop in subtropical mid hills ecosystem. Although yield potential of maize varieties is high but it has so far could not been realized upto its potential due to several constraints.

Weed infestation is a major factor in pulling down the yield of crop. Rainy season maize suffers from severe weed competition. Weed infestation causes yield losses varying from 28-100% depending upon the intensity, nature and duration. The losses caused by weeds exceed the losses from any other category of agricultural pests (Sharma *et al.* 2010). Weeds compete with the crop plants for sunlight, moisture and nutrients (Kumar *et al.* 2013 and Saeed *et al.* 2013) and deprive the crops from vital resources (Lehoczkyand Reisinger 2003). As a wide spaced crop, maize suffers from heavy weed infestation during *Kharif* season. The climate (high rainfall, congenial temperature and humidity) of the NER is favourable for luxuriant weed growth especially during rainy season. Maize is sensitive to weeds especially in early stages of development and thus, weed infestation during germination to 45 days after sowing (DAS) causes maximum reduction in yield. Weeds not only decrease crop yield but also harbour insect-pest and diseases and in some cases, they serve as an alternate host for these pest. In organic farming, the weed problems are further high mainly due to application of organic manure, mulches, biomass which exacerbates the weed multiplication and growth.

Thus, it was necessary to devise organic system of weed control comprising of cultural, mechanical, biological and physical practices to manage weeds without synthetic herbicides and chemicals which promote weed suppression, rather than weed elimination. Hand Weeding (HW) is the most popular method of removing weeds in NER of India. However, HW is tedious, time consuming and labour demanding. Mulching is an effective method of weed control without using chemicals. The use of biomass from facultative weed such as *Eupatorium* as mulch has been reported a good source of organic matter

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and weed suppressor for several upland crops in Himachal Pradesh (Acharya *et al.* 1998). Application of *Eupatorium* mulch along with HW gave significantly higher yield of upland rice compared to control in Nepal (Gaire *et al.* 2013). A promising way to use allelopathy in weed control is using extracts of alleloopathic plants as natural herbicides (Ankita and Mittal 2012). Keeping in view the importance of weed management in organic crop production, the present investigation was carried out to study the effect of various non-chemical weed management practices on weed population, dry weight, yield of maize and soil properties at mid-altitude of eastern Himalayas.

MATERIALS AND METHODS

Field experiments were carried out for consecutive three years in the mid hills of Meghalaya under rain-fed terrace condition during rainy seasons (*Kharif)* of the year 2008-09 to 2010-11. The soil of the experimental site was sandy clay loam in texture, acidic in reaction (pH 4.9) with 1.80% soil organic carbon (SOC). The soil was low in available N (180.0 kg N/ha) and P (9.5 kg P/ha) and medium in available K (175.1 kg K/ha).

Field experiment was laid out in randomized block design with eight treatment in three replications. Treatments were, mechanical weeding at 20 DAS + one HW at 45 DAS, mulching with fresh biomass of *Eupatorium adhenophorum* 10 t/ha after earthing up at 30 DAS, aqueous leaf extract (10%) spray of *Lantana* and pine (*Pinus kesiya*), two HW - 1st before earthing up (20 DAS) and 2nd after earthing up (45 DAS), aqueous leaf extract spray of *Lantana* and pine + one HW after earthing-up (35 DAS), soybean green manure incorporation in situ during earthing up + one HW (45 DAS), weed free check (HW at 10, 25, 40, 55 and 70 DAS) and weedy check.

Mechanical weeding was performed with the help of wheel hoe and leaf extract was sprayed directly in the inter row spaces of maize. One row of soybean was grown simultaneously in between two rows of maize as green manure crop and incorporated into the soil at 30 days after germination during earthing up. FYM was applied on N equivalent basis and P requirement was compensated through rock phosphate. Neem cake was applied 150 kg/ha as general dose in all the treatments to control soil borne pathogens. A uniform dose of organic manure to supply recommended dose of N and P in maize (60:26.2 kg/ha) was used. Data on weeds (density, dry weight) were recorded at 30 and 60 DAS from two randomly selected quadrants (0.5 x 0.5 m) from each treatment during maize growing period. Weeds were uprooted gently, roots washed and their counts were recorded. Weeds were oven dried at 70^{0}C for 48 hours after sun drying for recording dry weight. Weed control efficiency (WCE) was calculated by using following formulae given by Mani *et al.* (1973). Yield attributes and yield of maize were recorded from each treatment at harvesting stage.

The initial and post-harvest soil samples (after 3 years) were collected (500 g composite sample, one sample from each plot) from 0-15 cm depth for analyzing the available N, P, K status, SOC and soil microbial biomass carbon (SMBC). The soil samples were air dried, processed and passed through 2 mm sieve, and used for analyzing soil fertility parameters such as available N by the alkaline permanganate method (Subbiah and Asija 1956), available P by $NaHCO_3$ extraction method (Olsen and Sommers 1982) and available K by neutral normal NH_4OAC extraction method (Knudsen *et al.* 1982). SMBC was estimated by soil fumigation technique **(**Anderson and Ingram 1993**)**. Bulk density (ñb) was determined by the core method (Blake and Hartge 1986) using cores of 5.8 cm height and 5.4 cm diameter at 0-15 cm depth and oven dried at 105^{0}C (one sample per plot).

Experimental data pertaining to each parameter were subjected to statistical analysis by using technique of analysis of variance and their significance was tested by "F" test (Gomez and Gomez, 1984). Standard error of means (SEm+) and least significant difference (LSD) at 5% probability (P=0.05) were worked out for each parameter studied to evaluate differences between treatment means.

RESULTS AND DISCUSSION

Effect on weeds

The predominant weed species observed in the experimental field during rainy season were *Ageratum conizoides, Alternanthera phyloxiroides, Bidens pilosa, Borrevia hispida, Galinsoga parviflora* and *Spilanthus acemella* among broad-leaved weeds*; Cynodon dactylon, Digitaria marginata, Digitaria sanguinalis*, *Panicum repens* and *Eleusine indica* among grasses and *Cyperus rotundus* and *Fimbristylis miliacea* among sedges. Number of broad-leaved weeds were found maximum followed by grasses and sedges irrespective of weed management practices. All the weed management practices were effective in suppressing total weed density and dry matter as compared to weedy check. Minimum weed population and dry weight at 30 and 60 DAS were recorded under weed free check (Table 1). Two HW, soybean green manure incorporation + one HW and mechanical weeding (20 DAS) + one HW (after earthing up) was also found effective in reducing weed population to the extent of 72, 67 and 68% in 30 DAS and 77, 78 and 80% in 60 DAS as compared to weedy check, respectively. This result was in line with the findings of Syawal (1998) who reported that HW effectively controlled weeds.

In general, weed dry weight was found higher at 30 DAS compared to 60 DAS in all the treatments except weedy check and aqueous leaf extract spray of *Lantana* and pine which may be due to suppression of weed growth by maize canopy at later growth stages (Table 1). Lower weed biomass during 60 DAS than 30 DAS indicated that increasing plant canopy covered the open niches which otherwise might have been utilized by weeds (Gul *et al.* 2009). Pooled weed control efficiency (WCE) of different treatments ranged from 71.33-91.97 and 31.59-72.90% in 30 and 60 DAS, respectively. Among all the treatments, two HW at 20 and 45 DAS and mechanical weeding at 20 DAS and one HW at 45 DAS was recorded maximum WCE compared to other treatments. The finding confirms the results of Gul *et al.* (2009).

Yield attributes and yield

Although the cob length in maize did not vary significantly across the treatments, highest cob length was recorded under mulching with fresh *Eupatorium* 10 t/ha and soybean green manuring + one HW as compare to rest of treatment except weed-free check (Table 2). It might be due to addition of nutrients and moisture conservation through application of *Eupatorium* as mulch. The number of seeds/cob were the highest under weed free check, however it was statistically at par with mulching with weed biomass. The grain weight/cob was also highest under mulching with weed biomass. Three years average grain yield of maize was maximum (3.87 t/ha) under fresh *Eupatorium* mulching followed by two HW at 20 and 40 DAS (3.64 t/ha) and soybean

Table 1. Population density, dry weight and weed control efficiency as influenced by various organic weed management practices (pooled mean of 3 years)

Treatment	Population density (no./m^2)		Dry weight (g/m^2)		Weed control efficiency (%)	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Mechanical weeding at 20 DAS + one HW at 45 DAS	158	75	9.41	4.2	86.1	94.8
Mulching with fresh *Eupatorium* 10 t/ha after earthling up at 30 DAS	225	90	12.9	17.5	74.6	78.6
Aqueous leaf extract (10%) spray of *Lantana* and pine	359	235	26.0	44.6	48.6	34.2
Two HW -1st before earthing up (20 DAS) and 2nd after earthing up (45 DAS)	145	88	7.2	4.2	85.9	94.9
Aqueous leaf extract spray of *Lantana* and pine + one HW after earthing up (35 DAS)	185	91	11.7	6.7	76.9	91.7
Soybean green manure incorporation in situ + one HW (45 DAS)	156	84	10.5	4.9	79.2	94.0
Weed free check (HW at 10, 25, 40, 55 and 70 DAS)	4	2	0.8	0.2	98.4	99.8
Weedy check	493	392	50.7	81.6	-	-

HW: Hand weeding; DAS: Days after sowing

Table 2. Yield attribute and yield of maize as affected by organic weed management practices (pooled mean of 3 years)

Treatment	Maize		
	Cob length (cm)	Seeds /cob	Grain weight /cob (g)
Mechanical weeding at 20 DAS + one HW at 45 DAS	14.5	262	127
Mulching with fresh *Eupatorium* 10 t/ha after earthling up at 30 DAS	15.1	281	137
Aqueous leaf extract (10%) spray of *Lantana* and pine	14.3	263	126
Two HW -1st before earthing up (20 DAS) and 2nd after earthing up (45 DAS)	14.5	281	119
Aqueous leaf extract spray of *Lantana* and pine + one HW after earthing up (35 DAS)	14.5	268	105
Soybean green manure incorporation in situ + one HW (45 DAS)	15.1	280	126
Weed free check (HW at 10, 25, 40, 55 and 70 DAS)	15.4	285	129
Weedy check	14.1	244	81
LSD (P=0.05)	NS	5.2	4.4

HW: Hand weeding; DAS: Days after sowing

Table 3. Effect of soil properties as influenced by various weed management practices after 3-cropping cycles

Treatment	Bulk density (g/cm^3)	SOC (g/kg)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	SMBC (µg/g dry soil)
Mechanical weeding at 20 DAS + one HW at 45 DAS	1.25	22.9	256	24.1	275	232
Mulching with fresh *Eupatorium* 10 t/ha after earthling up at 30 DAS	1.19	23.6	278	30.8	280	272
Aqueous leaf extract (10%) spray of *Lantana* and pine	1.27	22.5	245	21.7	264	199
Two HW -1st before earthing up (20 DAS) and 2nd after earthing up (45 DAS)	1.24	23.0	260	23.9	263	250
Aqueous leaf extract spray of *Lantana* and pine + one HW after earthing up (35 DAS)	1.23	22.8	253	22.5	266	251
Soybean green manure incorporation in situ + one hand weeding (45 DAS)	1.21	23.9	280	29.0	274	258
Weed free Check (HW at 10, 25, 40, 55 and 70 DAS)	1.28	23.0	226	18.8	259	241
Weedy check	1.18	24.4	270	20.3	277	271
Initial value	-	19.6	219	12.5	245	-
LSD (P=0.05)	0.03	1.7	17	4.6	13	15

HW: Hand weeding; DAS: Days after sowing; SOC - Soil organic carbon

green manure incorporation in situ+ one HW (3.64 t/ha). Mulched biomass added large quantity of nutrients and the additional nutrients over that applied through manure might have contributed to the increased yield of maize (Sharma and Acharya 2000 and Sharma *et al.* 2010).

Soil fertility

At the end of three cropping cycles, mulching with fresh *Eupatorium* (after earthing up) 10 t/ha resulted in higher SOC (23.6 g/kg), available N (278.0 kg/ha), P (30.80 kg/ha) and K (280.1 kg/ha) in soil followed by soybean green manure incorporation in situ + one HW than other treatments (Table 3). Percentage increase of SOC, available N, P and K were 20.4, 27.1, 76.0 and 14.3% respectively, under mulching with fresh *Eupatorium* (after earthing up) 10 t/ha relative to respective initial values (Table 3). Whereas, these enhancement in relation to two HW were 2.6, 6.8, 28.8 and 6.6%, respectively. Bulk density was recorded the lowest and soil SMBC was the highest under mulching with fresh *Eupatorium* (after earthing up) 10 t/ha treatments. Long term application of organic amendments were reported to improvement in SOC, available N, P and K in soil, thereby sustaining the soil health (Panwar *et al*. 2010). The use of weed biomass (shrubs) such as *Eupatorium adhenophorum* as mulching material for soil and moisture conservation and fertility build up in crop production has been also reported by other researchers (Acharya *et al.* 1998 and Gaire *et al.* 2013).

It can be concluded that mulching with weed biomass such as fresh *Eupatorium* (after earthing up) and soybean green manuring in maize + one HW are the recommendable options for organic maize production under high rainfall hill ecosystem of North-East India.

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REFERENCES

Acharya CL, Kapur OC and Dixit SP. 1998. Moisture conservation for rainfed wheat production with alternative mulches and conservation tillage in hills of north-west India. *Soil and Tillage Research* **46**: 153-163.

Anderson JM and Ingram JSI. 1993. *Tropical Soil Biology and Fertility*, CAB, UK.

Ankita G and Chabbi M. 2012. Effect of allelopathic leaf extract of some selected weed flora of Ajmer district on seed germination of *Triticum aestivum* L. *Science Research Reporter* **2**(3): 311-315.

Gul B, Marwat KB, Hassan G, Khan A, Hasim S and Khan IA. 2009. Impact of tillage, plant population and mulches on biological yield of maize. *Pakistan Journal of Bot*any **41**(5): 2243-2249.

Blake GR and Hartge KH. 1986. Bulk density. pp. 363-376. In: *Methods of Soil Analysis, Part I*, (Ed. A. Klute) ASA Monograph No. 9. Madison, WI.

Das A, Patel DP, Munda GC and Ghosh PK. 2010. Effect of organic and inorganic sources of nutrients on yield, nutrient uptake and soil fertility of maize (*Zea mays*)- mustard (*Brassica campestris*) cropping system. *Indian Journal of Agricultural Sciences* **80**(1): 85–88.

Dayan FE. 2002. Natural pesticides. pp. 521–525. In: *Ncylopedia of Pest Management.* (Ed. D. Pimentel), Inc., New York.

Gaire R, Dahal K R and Amgain L P.2013. Effect of different mulching materials on weed dynamics and yield of direct seeded rice in Chitwan, *Agronomy Journal of Nepal* **3**: 73-81.

Gomez KA and Gomez AA. 1984. *Statistical Procedure for Agricultural Research*. 2nd Ed. International Rice Research Institute, John Wiley and Sons, New York, Singapore.

Knudsen D, Peterson G A and Pratt P F. 1982. Lithium, sodium, and potassium. In: Methods of soil analysis, part 2: Chemical and microbiological properties, (Eds. Page AL, Miller RH and Keeney DR), American Society of Agronomy Wisconsin, USA.

Kumar B, Kumar R, Kalyani S and Haque M. 2013. Integrated weed management studies on weed flora and yield in *Kharif* maize. *Trends in Biosciences* **6**(2): 161-164.

Lehoczky E and Reisinger P. 2003. Study on the weed-crop competition for nutrients in maize. *Communications in Agricultural and Applied Biological Sciences* **68**: 373-80.

Mani VS, Gautam KC and Chakraborthy. 1973. Losses in crop yield due to weed growth. *Proceedings of the National Academy of Sciences* **14**: 142-158

Olsen SR and Sommers LE. 1982. Phosphorus. In: *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties,* (Eds. Page AL, Miller RH and Keeney DR), Agronomy Monograph 9,ASA and SSSA, Madison, Wisconsin, USA

Padhi AK and Panigrahi RK. 2006. Effect of intercrop and crop geometry on productivity, economics, energetic and soil fertility status of maize based intercropping systems. *Indian Journal of Agronomy* **51**(3): 65-67.

Panwar NR, Ramesh P, Singh AB and Ramana S. 2010. Influences of organic, chemical and integrated management practices on soil organic carbon and soil nutrient status under semi-arid tropical conditions in central India. *Communication in Soil Science and Plant Analysis* **41**: 1073-1083.

Sharma AR, Singh R, Dhyani SK and Dube RK. 2010. Moisture conservation and nitrogen recycling through legume mulching in rainfed maize (*Zea mays*) – wheat (*Triticum aestivum*) cropping system. *Nutrient Cycling in Agroecosystems* **87**(2): 187-197.

Sharma PK and Acharya CL. 2000. Carry- over effect of residual soil moisture with mulching and conservation tillage practices for sowing of rainfed wheat (*Triticum aestivum* L) in North-West India. *Soil and Tillage Research* **57**: 43-52.

Subbiah BV and Asija GL. 1956. A rapid procedure for the estimation of available N in soils. *Current Science* **25**:259-260.

Syawal Y. 1998. Composition shift and other characteristics of weeds and yield of sweet corn on Andisols with N fertilization and weeding at critical period of the crop. *Publikasi Berkala Penelitian Pascasarjana Universitas Padjadjaram* **9**(2): 18-33.

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Weed management in blackgram under rainfed conditions

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ABSTRACT

Field study was conducted at Dryland Farming Research Station in Bhilwara, Rajasthan during *Kharif* seasons of 2010 and 2011 to study the weed control efficiency of different weed management practices including pre- and post-emergence herbicides in blackgram [*Vigna mungo* (L.) Hepper]. Among herbicidal weed control treatments, the lowest weed density and dry matter, and highest yield attributes, seed yield and economic return with B:C ratio was recorded with quizalofop-ethyl 50 g/ha 30 DAS and it was statistically at par with interculture at 15 DAS *fb* imazethapyr 100 g/ha 30 DAS, interculture at 15 DAS *fb* quizalofop-ethyl 50 g/ha 30 DAS, imazethapyr 100 g/ha 20 DAS and weed free. Whereas, highest weed control efficiency was recorded with alachlor 1.0 kg/ha PRE *fb* imazethapyr 100 g/ha 30 DAS. All herbicidal treatments reduced weed biomass and improved seed yield and yield attributing parameters as compared to weedy check. Weedy check registered the highest values of weed count and biomass and lowest seed yield and yield attributing characters. Rainfall was directly related to weed count and weed dry matter accumulation with the coefficient of 0.65 and 0.61, respectively.

Key words: Blackgram, Quizalofop-ethyl, Rainfed, Weed control efficiency, Weed, Yield

Black gram (*Vigna mungo* L.) is an important legume crop cultivated worldwide in tropical and subtropical regions of the world and is valued for high protein in its seeds. India is the world's largest producer as well as consumer of blackgram. It produces about 1.5 to 1.9 million tons of blackgram annually from about 3.5 million hectares of area, with an average productivity of 500 kg/ha (Anonymous 2014). Blackgram output accounts for about 10% of India's total pulse production. In Rajasthan, blackgram is grown on about 16,000 hectares area mostly under rainfed conditions.

Blackgram is usually accompanied by luxuriant weed growth during the rainy (*Kharif*) season owing to abundant rainfall received during monsoons leading to serious crop losses. The crop is not a very good competitor against weeds (Choudhary *et al.* 2012). Therefore, weed-control initiatives are essential to ensure proper crop growth particularly in the early growth period. The losses caused by weeds exceed the losses from any other category of agricultural pests in semi arid areas of south east Rajasthan. Farmers do not follow chemical weed control in pulses, except few farmers who use pre-emergence herbicides followed by one or two hand weedings. Singh *et al.* (2014) raised a need of post-emergence herbicide to control the second flush of weeds in pulses and to reduce human labour.

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Recently some of the post-emergence herbicides such as quizalofop and imazethapyr have been found effective in controlling weeds in pulses. Imazethapyr applied as post-emergence at 50 to 75 g/ha showed season-long control of many weeds without injuring soybean (Ram *et al.* 2013). In blackgram, Nandan *et al.* (2011) reported that post-emergence application of imazethapyr at 25 g/ha had no adverse effects on rain-fed blackgram growth characters and resulted in statistically similar grain yield to that of two hand weeding (20 and 40 days after sowing).

Control of the weeds by using herbicides could be an alternative to manage the weeds and thereby increasing the yield of blackgram. Since application of single herbicide may not be effective in providing broad spectrum weed control, application of pre- and post-emergence herbicides in sequence or integrated with manual weeding may be more beneficial. Keeping these facts in view, the present investigation was undertaken to test the performance of various post-emergence herbicides along with one pre-emergence and hand weeding for providing weed control during critical period of crop weed competition in blackgram under dry land conditions.

MATERIALS AND METHODS

A field study was conducted during *Kharif* seasons of 2010 and 2011 at Dryland Farming

Research Station, Arjia, Bhilwara, Rajashthan. The soil of the experimental site was sandy clay loam, having 0.48% organic carbon, 245, 41 and 465 kg/ha available N, P and K, respectively. The mean maximum and minimum temperature recorded were in the range of 31.8 to 37.4 °C and 16.1° to 25.3 °C, respectively (mean of two years). The mean sunshine hours among different weeks were 5.7 to 8.6 h in a day. The total evaporation observed was 393.1 mm, while total rainfall recorded 789.1 mm during both the years of study. The relative humidity in morning (RH1) and evening (RH2) were recorded in the range of 95 to 90 and 42 to 75%, respectively.

Experiments consisted of 15 treatments with three replication was undertaken in randomized bloack design (Table 1). Blackgram was sown at 30 cm row-to-row spacing using 20 kg seed/ha. Recommended dose of fertilizers (20 kg N + 30 kg P_2O_5/ha) was applied to blackgram crop at the time of sowing through di-ammonium phosphate (DAP) and urea. Pre-emergence application of pendimethalin and alachlor was done on next day of sowing and post-emergence application of other herbicides was done 30 DAS. Weed population was recorded by using 0.25 m quadrate at 60 DAS in all the treatments and then converted into number of weeds/m^2. The weeds were dried in oven till a constant weight was achieved and then transformed into g/m^2. Growth and yield parameters and yield of blackgram were recorded for both the years.

The data on total weed count and weed dry matter were subjected to square root transformation ($\sqrt{x+0.5}$) normalize their distribution (Gomez and Gomez 1984). Weed control efficiency and different indices were calculated as per method given by Mani *et al.(*1973) and Devasenapathy *et al.* (2008).

Biological yield and grain yield were recorded on a plot basis and harvest index was calculated. Gross returns were calculated by taking the sale price of blackgram as 36 per kg. Net returns (per ha) was calculated as: Net returns = Gross returns - cost of cultivation including the cost of individual treatments. Benefit: cost ratio was calculated after dividing net returns with the cost of cultivation. All the data were subjected to analysis of variance (ANOVA) as per the standard procedures. The comparison of treatment means was made by critical difference (LSD) at P=0.05.

RESULTS AND DISCUSSION

Effect on weeds

The common weeds at the experimental site were *Cynodon dactylon (*bermuda grass*),Commelina bengalensis* (Bengal dayflower), *Cyperus rotundus* (purple nut sedge), *Ageratum conyzoides* (billygoat-weed) *Setaria glauca (*foxtail grass), *Euphorbia hirta* (*g*arden spurge), *Echinochloa colonum* (jungle rice), *Echinochloa crusgalli* (sawan grass), *Tribulus terrestris* (puncture vine), *Trianthema monogynya* (horse purselane), *Ipomoea pestigridis*, *Fimbristylis penera etc.*

The highest weed density (17.20/m^2 and 11.05/m^2) and weed dry matter production (15.60 g/m^2 and 9.82 g/m^2) at 30 and 60 DAS were recorded in weedy check plots (Table 1). Among post-emergence herbicides, quizalofop-ethyl 50 g/ha at 30 DAS was significantly superior in reducing weed density both at 30 and 60 DAS while remained at par with the treatments of interculture 15 DAS *fb* imazethapyr 100 g/ha 30 DAS, interculture 15 DAS *fb* quizalofop-ethyl 50 g/ha at 30 DAS, and imazethapyr 100 g/ha 20 DAS treatments and remained statistically superior over all other weed management practices except weed free treatment. Application of pendimethalin 1.0 kg/ha as pre-emergence also reduced the weed density to a level of 11.26/m^2 and 6.99/m^2 as compared to weedy check level of 17.20/m^2 and 11.05/m^2 at 30 and 60 DAS (Table 1). Results were in conformity with the Tan *et al.* 2005 that quizalofop-ethyl, chlorimuron and imazethapyr are new generation post-emergence herbicides used in many leguminous crops. These herbicides provide broad spectrum of weeds control, flexibility in application time, low usage rates and low mammalian toxicity.

Weed dry matter production was reduced significantly (4.40 g/m^2 and 2.13 g/m^2) both at 30 and 60 DAS with interculture at 15 DAS *fb* quizalofop-ethyl 50 g/ha at 30 DAS over weedy check, pendimethalin 1.0 kg/ha as pre-emergence (PE), alachlor 1.0 kg/ha PE, pendimethalin 1.0 kg/ha PE *fb* interculture 30 DAS, and alachlor 1.0 kg/ha PE *fb* interculture at 30 DAS, except weed free treatment and remained at par among all other weed management practices (Table 1). The results were in conformity with the findings of Kantar *et al.* (1999), where about 84.6% weed biomass was controlled with application of imazethapyr. Papiernik *et al.* (2003) also recommended use of imezathapyr in legumes which inhibit acetohydroxy acid synthase and the synthesis of branched chain amino acids. Application of pendimethalin 1.0 kg/ha as PE also reduced the weed dry matter to a notable level of 9.98 g/m^2 and 5.18 g/m^2 at 30 and 60 DAS, respectively.

The highest value of weed control efficiency at 60 DAS (Table 1) was recorded under weed free treatment. Among herbicides, it was recorded highest

Table 1. Effect of different weed control treatments on weed density and dry weight at different growth stages of blackgram (pooled value)

Treatment	Weed density (no./m^2) (*TAV)		Weed dry matter (g/m^2) (*TAV)		Weed control efficiency (%) 60 DAS	Weed persistence Index (%) 60 DAS
	30 DAS	60 DAS	30 DAS	60 DAS		
Pendimethalin 1.0 kg/ha (PE)	11.36 (126.9)	6.99 (48.3)	9.98 (100.0)	5.18 (26.7)	54.9	19.43
Alachlor 1.0 kg/ha (PE)	11.14 (125.0)	7.67 (58.3)	10.02 (100.3)	5.30 (27.8)	55.9	17.69
Pendimethalin 1.0 kg/ha (PE) *fb* interculture 30 DAS	9.24 (85.2)	4.48 (19.7)	8.20 (70.4)	4.02 (16.3)	64.5	10.53
Alachlor1.0 kg/ha (PE) *fb* interculture 30 DAS	8.95 (79.9)	4.50 (19.8)	7.50 (57.6)	3.95 (15.5)	72.0	7.63
Pendimethalin 1.0 kg/ha (PE) *fb* imazethapyr 100 g/ha 30 DAS	6.69 (44.5)	3.44 (11.3)	4.90 (24.4)	2.83 (8.0)	88.3	1.74
Pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha 30 DAS	6.90 (47.4)	3.45 (11.5)	5.42 (29.7)	3.18 (10.3)	86.0	2.38
Alachlor 1.0 kg/ha (PE) *fb* imazethapyr 100 g/ha 30 DAS	6.56 (43.5)	3.71 (13.3)	4.81 (23.0)	2.83 (7.7)	89.8	1.51
Alachlor 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha 30 DAS	6.51 (42.8)	3.60 (12.5)	5.06 (26.0)	2.27 (5.3)	87.6	1.70
Interculture 15 DAS *fb* imazethapyr 100 g/ha 30 DAS	5.88 (34.2)	2.73 (7.0)	4.55 (22.8)	2.29 (5.0)	87.7	1.47
Interculture 15 DAS *fb* quizalofop-ethyl 50 g/ha 30 DAS	5.59 (31.2)	2.79 (7.3)	4.40 (21.0)	2.13 (4.7)	89.1	1.18
Imazethapyr 100 g/ha 20 DAS	5.68 (32.0)	2.85 (7.7)	4.51 (21.5)	2.87 (8.5)	89.3	1.22
Quizalofop-ethyl 50 g/ha 30 DAS	5.57 (30.8)	2.58 (6.2)	4.89 (25.4)	2.79 (7.8)	86.6	1.58
Farmer's practice	12.94 (171.4)	10.56 (111.0)	13.42 (186.0)	8.04 (66.7)	26.3	44.55
Weed-free	4.57 (20.5)	2.76 (7.2)	3.29 (11.0)	1.68 (2.7)	94.6	0.40
Weedy check (control)	17.20 (295.8)	11.05 (121.7)	15.60 (249.4)	9.82 (96.2)	0.0	100.00
LSD (P=0.05)	0.60	0.30	0.94	0.69	7.9	4.13

*TAV- Angular Transformation Values

with alachlor 1.0 kg/ha (PE) *fb* imazethapyr 100 g/ha at 30 DAS, which was at par with pendimethalin 1.0 kg/ha PE *fb* imazethapyr 100 g/ha at 30 DAS, pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha at 30 DAS, alachlor 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha at 30 DAS, interculture 15 DAS *fb* imazethapyr 100 g/ha at 30 DAS, interculture 15 DAS *fb* quizalofop-ethyl 50 g/ha at 30 DAS, imazethapyr 100 g/ha at 20 DAS, quizalofop-ethyl 50 g/ha at 30 DAS and statistically superior over all other management practices. Singh and Chandel (1995) also reported higher weed control efficiency with two hand weeding. Kantar *et al.* (1999) also reported 84.6% weed control with imazethapyr. However, the other herbicides quizalofop-p-ethyl, fenoxaprop-p-ethyl and chlorimuron-p-ethyl alone or in combination also registered notable values of weed control efficiency in the range of 78.8 to 89.3%. Vyas and Jain (2003) also reported higher weed control efficiency, seed yield with application of imezathapyr over quizalofop-p-ethyl in soybean crop.

The highest weed index (98.8%) was recorded with interculture at 15 DAS *fb* quizalofop-ethyl 50 g/ha at 30 DAS, which was at par with pendimethalin 1.0 kg/ha PE *fb* imazethapyr 100 g/ha at 30 DAS, pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha at 30 DAS, alachlor 1.0 kg/ha PE *fb* imazethapyr 100 g/ha at 30 DAS, alachlor 1.0 kg/ha PE *fb* quizalofop-ethyl 50 g/ha at 30 DAS, interculture 15 DAS *fb* imazethapyr 100 g/ha at 30 DAS, imazethapyr 100 g/ha at 20 DAS, and quizalofop-ethyl 50 g/ha at 30 DAS and lowest weed index was found in manual weeding at 15 and 30 DAS (55.45%) (Table 1). These results were in conformity of Arya *et al.* (2007) who have recorded good yield of chickpea and mustard due to quizalofop-ethyl 60 g/ha.

Yield

Different weed management practices had significant positive impacts on yield attributes and yield (Table 2). Lowest values of plant height (59.38 cm), branches/plant (3.57), pods/plant (40.33), grains/pod (6.33), pod length (4.90 cm), and 1000-seed weight (43.82 g) were recorded under weedy check. The highest values for plant height (64.68 cm), branches/plant (4.67), pods/plant (48.67), grains/pod (8.07), pod length (5.48 cm), and 1000-seed weight (45.90 g) were recorded under interculture at 15 DAS *fb* quizalofop-ethyl 50 g/ha at 30 DAS due to reduced crop-weed competition. Mundra and Maliwal (2012) also reported that among the herbicidal treatments, application of quizalofop-ethyl 50 g/ha recorded maximum number of branches, pods/plant and seeds/pod. The increase in growth and yield attributes might be due to the

Table 2. Effect of different weed control treatments on growth parameters and yield attributes of blackgram (pooled value)

Treatment	Plant height (cm)	Branches/ plant (no.)	Days to 50% bloom	Pods/ plant (no.)	Grains/ pod (no.)	Pod length (cm)	1000-seed wt. (g)
Pendimethalin 1.0 kg/ha (PE)	63.1	4.03	54.8	43.3	7.50	5.15	45.8
Alachlor 1.0 kg/ha (PE)	63.2	4.10	54.8	42.5	7.57	5.48	45.6
Pendimethalin 1.0 kg/ha (PE) *fb* interculture 30 DAS	64.8	4.60	55.0	45.5	7.37	5.07	46.0
Alachlor 1.0 kg/ha (PE) *fb* interculture 30 DAS	64.5	4.47	54.7	46.8	7.77	5.25	46.5
Pendimethalin 1.0 kg/ha (PE) *fb* imazethapyr 100 g/ha 30 DAS	64.1	4.17	54.3	46.0	7.03	5.30	46.0
Pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha 30 DAS	64.5	4.13	54.3	44.7	8.03	5.32	46.2
Alachlor 1.0 kg/ha (PE) *fb* imazethapyr 100 g/ha 30 DAS	63.9	3.97	54.7	44.0	7.70	5.40	46.4
Alachlor 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha 30 DAS	64.1	3.97	53.5	45.0	7.17	5.20	45.8
Interculture 15 DAS *fb* imazethapyr 100 g/ha 30 DAS	64.0	4.33	55.0	44.7	7.42	5.27	46.5
Interculture 15 DAS *fb* quizalofop-ethyl 50 g/ha 30 DAS	64.7	4.67	54.8	48.7	7.37	5.38	45.9
Imazethapyr 100 g/ha 20 DAS	61.8	4.40	55.2	47.7	8.03	5.47	46.5
Quizalofop-ethyl 50 g/ha 30 DAS	62.2	4.23	54.5	48.7	7.87	5.38	46.4
Farmer's practice	60.9	3.73	54.5	40.3	7.17	5.00	45.0
Weed free	65.8	4.53	53.8	50.2	7.53	5.52	47.3
Weedy check (control)	59.4	3.57	54.7	40.3	6.33	4.90	43.8
LSD (P=0.05)	2.02	0.56	0.88	3.19	0.73	0.24	1.39

Table 3. Effect of different weed control treatments on yield and economics of blackgram (pooled value)

Treatment	Seed yield (t/ha)	Haulm yield (t/ha)	Harvest index	Gross returns (x10^3 `/ha)	Net returns (x10^3 `/ha)	B:C ratio
Pendimethalin 1.0 kg/ha (PE)	0.97	4.18	19.3	44.08	36.69	5.19
Alachlor 1.0 kg/ha (PE)	0.98	4.13	19.7	44.45	36.65	4.87
Pendimethalin 1.0 kg/ha (PE) *fb* interculture 30 DAS	1.03	4.54	19.0	47.05	38.05	4.52
Alachlor 1.0 kg/ha (PE) *fb* interculture 30 DAS	0.95	4.06	19.3	43.26	33.86	3.77
Pendimethalin 1.0 kg/ha (PE) *fb* imazethapyr 100 g/ha 30 DAS	0.99	4.33	19.1	45.08	36.10	4.29
Pendimethalin 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha 30 DAS	1.03	4.21	20.1	46.22	37.16	4.36
Alachlor 1.0 kg/ha (PE) *fb* imazethapyr 100 g/ha 30 DAS	0.99	4.51	18.8	45.63	36.24	4.11
Alachlor 1.0 kg/ha (PE) *fb* quizalofop-ethyl 50 g/ha 30 DAS	1.00	4.26	19.7	45.43	35.97	4.07
Interculture 15 DAS *fb* imazethapyr 100 g/ha 30 DAS	1.08	4.49	20.2	48.75	39.51	4.63
Interculture 15 DAS *fb* quizalofop-ethyl 50 g/ha 30 DAS	1.07	4.56	19.7	48.39	39.06	4.47
Imazethapyr 100 g/ha 20 DAS	1.10	4.56	20.1	49.62	41.98	5.83
Quizalofop-ethyl 50 g/ha 30 DAS	1.13	4.60	20.4	50.53	42.80	5.92
Farmer's practice	0.94	4.17	18.9	42.93	35.62	5.30
Weed free	1.05	4.48	19.7	47.94	37.64	4.01
Weedy check (control)	0.88	3.77	19.2	39.79	33.98	6.22
LSD (P=0.05)	0.09	0.43	1.22	3.772	3.77	0.48

reduction in weed competitiveness with the crop which ultimately favored better environment for growth and development of crop.

Economics

Seed and biological yield recorded with quizalofop-ethyl 50 g/ha at 30 DAS were 28.53 and 21.84%, respectively, which were higher than weedy check. The corresponding figure in case of imazethapyr 100 g/ha at 20 DAS were 25.8 and 21.0% higher. However, herbicides along with other weed management practices registered significant increase in seed yield with quizalofop-ethyl 50 g/ha at 30 DAS (1.13 t/ha) over weedy check (0.88 t/ha), while remained statistically at par with interculture at 15 DAS *fb* imazethapyr 100 g/ha at 30 DAS, interculture at 15 DAS *fb* quizalofop-ethyl 50 g/ha at 30 DAS, imazethapyr 100 g/ha at 20 DAS including weed free treatment (Table 3). Mundra and Maliwal (2012) reported that the highest seed yield and stover yield of blackgram was recorded with quizalofop-ethyl 50 g/ha. The results were also in conformity with the findings of Rajput and Kushwah (2004).The highest value of net return (₹ 42803) and B:C ratio (5.92) was recorded with application of quizalofop-ethyl 50 g/ha at 30 DAS, followed by net return (₹

41976) and B:C ratio (5.83) with imazethapyr 100 g/ ha 20 DAS (Table 3). The minimum net return and B:C ratio among other herbicidal treatment was obtained with alachlor 1.0 kg/ha PRE *fb* interculture 30 DAS.

REFERENCES

Anonymous 2014. *Agricultural Statistics at a Glance*, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India.

Arya RL, Varshney JG and Kumar L. 2007. Effect of integrated nutrient application in chickpea + mustard intercropping system in the semi arid tropics of North India. *Communications in Soil Science and Plant Analysis* **38**: 229-240.

Choudhary VK, Kumar SP and Bhagawati R. 2012. Integrated weed management in blackgram (*Vigna mungo*) under mid hills of Arunachal Pradesh. *Indian Journal of Agronomy* **57**: 382-385.

Devansathpathy P, Ramesh T and Gangwar H. 2008. Weed management studies, pp. 55-64. In: *Efficiency Indices for Agriculture Management Research*.

Gomez KA and Gomez AA. 1984. *Statistical Procedures for Agricultural Research* (2nd edition). A Wiley-Interscience Publication, John Wiley and Sons, New York, USA.

Kantar F, Elkoca E and Zengin H. 1999. Chemical and agronomical weed control in chickpea (*Cicer arietinum* L.). *Tropical Journal of Agriculture and Forestry* **23**: 631-635.

Mani VS, Pandita ML, Gautam KC and Das B. 1973. Weed killing chemicals in potato cultivation. *Proceedings of the National Academy of Sciences of the United States of America (PANS)* **23**: 17-18.

Mundra SL and Maliwal PL. 2012. Influence of quizalofop-ethyl on narrow-leaved weeds in blackgram and its residual effect on succeeding crops. *Indian Journal of Weed Science* **44**(4): 231-234.

Nandan B, Sharma BC, Kumar A and Sharma V. 2011. Efficacy of pre- and post- emergence herbicides on weed flora of urdbean under rainfed subtropical Shiwalik foothills of Jammu & Kashmir. *Indian Journal of Weed Science* **43**: 172-174.

Papiernik SK, Grieve CM, Yates SR and Lesch SM. 2003. Phytotoxic effects of salinity, imazethapyr and chlorimuron on selected weed species. *Weed Science* **51**: 610-617.

Rajput PL and Kushwah SS. 2004. Integrated weed management in soybean on farmer field. *Indian Journal of Weed Science* **36**: 210-212.

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.

Singh M and Chandel AS. 1995. Effect of weed control methods on soybean (*Glycine max*). *Indian Journal of Agronomy* **40**(1): 55-58.

Singh S and Sheoran P. 2008. Studies on integrated weed management practices in rainfed maize under sub-montaneous conditions. *Indian Journal of Dryland Agricultural Research and Development,* **23**: 6-9.

Singh RP, Verma SK, Singh RK and Idnani LK. 2014. Influence of sowing dates and weed management on weed growth and nutrients depletion by weeds and uptake by chickpea (*Cicer arietinum*) under rainfed condition. *Indian Journal of Agricultural Sciences* **84**(4): 468-472.

Tan S, Evans RR, Dahmer ML, Singh BK and Shaner DL. 2005. Imidazolinone-tolerant crops: History, current status and future. *Pest Managmeant Science* **61**: 246-257.

Vyas MD and Jain AK. 2003. Effect of pre and post-emergence herbicides on weed control and productivity of soybean (*Glycine max*). *Indian Journal of Agronomy* **48**(3): 309-311.

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Weed management in blackgram with pre-mix herbicides

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ABSTRACT

Pre-mix combination of imazethapyr + pendimethalin at 1000 g/ha had maximum weed kill efficiency over alone application of herbicides applied as pre- or post-emergence. Similarly, the maximum grain yield (1.38 t/ha) was achieved with pre-mix combination of imazethapyr + pendimethalin at 1000 g/ha plot followed by its lower dose applied at 900 g/ha and both doses were found significantly superior over other herbicidal treatments. Supremacy of this treatment was proved by increment of grain yield to the tune of 63.3% over the weedy check and only 3.7% lesser than the hand weeding (20 and 40 DAS). Pre-mix combination of imazethapyr + pendimethalin also proved to be effective in improving other parameters like plants/m^2, pods/plant, seed/pod and 100 seed weight (g).

Key words: Blackgram, Herbicides, Herbicide efficiency index, Weed persistence, Weed control,Yield

Blackgram (*Vigna mungo*), is a bean grown in the Indian subcontinent. Blackgram is very nutritious as it contains high level of carbohydrate (60 g/100 g), protein (20-25 g/100 g), phosphorus (385 mg/100 g), calcium (145 mg/100 g) and iron (7.8 mg/100 g). It has been shown to be useful in mitigating elevated cholesterol levels (Indira and Kurup 2013). Blackgram is usually accompanied by luxuriant weed growth during rainy *(Kharif)* season owing to abundant rainfall received during monsoon leading to serious crop losses by weeds. The crop is not very good competitor against weeds (Choudhary*et al.* 2012) and therefore, weed control initiatives are essential to ensure proper growth of crop particularly in the early growth period.

Weeds compete for water, nutrient and space and cause up to 45% yield loss in Blackgram (Yadav*et al.* 1997). Among the different methods of weed control, the chemical method is becoming popular among farmers due to non-availability of cheap labour. Blackgram is less competitive against many weeds during early stage of crop as most sensitive period of weed competition is between 15 to 45 days after sowing. Unchecked weeds have been reported to cause a considerable reduction in seed yield of Blackgram, which in case of summer Blackgram could be 46-53% (Bhandari *et al.* 2004, Kumar and Tewari 2004), whereas, in *Kharif* Blackgram the losses could be 43.2-64.1%. (Chand *et al.* 2004, Rathi*et al.* 2004).

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Imazethapyr, a broad-spectrum herbicide, has soil and foliar activity that allows flexibility in its application timing and has low mammalian toxicity (Tan *et al.* 2005). In blackgram, Nandan *et al.*(2011) reported that post-emergence application of imazethapyr at 25 g/ha had no adverse effect on growth characters and resulted statistically similar grain yield to that of twice hand weeding (20 and 40 DAS). Pendimethalin is basically pre-emergence herbicide. In rainfed condition, if weeds have not yet germinated, this herbicide may be effective when applied after first shower.

Hence, the present study was conducted to determine the tolerance of the herbicides on blackgram at different doses and find out the efficacy of post-emergence of herbicides against the weeds and yield of blackgram.

MATERIALS AND METHODS

An experiment was conducted to evaluate the bioefficacy of pendimethalin and imazethapyr alone and their combination as pre-mix against mixed flora of weeds in blackgram during *Kharif* seasons of 2012 and 2013 at N.E.Borlaug Crop Research Centre of G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand India. The experiment was laid out in a randomized block design with 10 treatments in three replications. Treatments were comprised of pendimethalin 1000 g/ha, two doses of imazethapyr at 50 and 70 g/ha, pre-mix combination of pendimethalin and imazethapyr (Velor/Squaroz) at

800, 900 and 1000 g/ha and imazethapyr + imazamox (Odissay) at 60 and 70 g/ha, twice hand weeding at (20 and 40 DAS) and weedy check. Among the herbicidal treatment, pendimethalin and imazethapyr + pendimethalin were applied as pre-emergence (2 DAS) while remaining herbicides were applied as post-emergence (19 DAS) with knapsack sprayer using flat fan nozzle with 500 liters of water volume per hactare. Blackgram variety '*Pant Urd-19*' was sown on September 5, 2012 and August 20, 2013 with a row spacing of 30 cm. All other recommended package of practices was adopted to raise the crop.

The weed samples were collected randomly at two places in each plot with 0.25 m^2 quadrate after 30 days of sowing and total weed density was calculated. The weeds inside each quadrate were uprooted, cleaned and dried. After drying, weight and weed control efficiency was calculated by using slandered formula. Herbicide efficiency index and weed persistence index determined as per formula given by Walia (2003). At maturity, the blackgram crop was harvested and air dried for 72 h. Besides, pod/plant (no./m^2), seed/pod and 100-seed weight were determined. Increase in yield over weedy check and per cent increase was also calculated for all the treatments. Data recorded were statistically analyzed according to Gomez and Gomez (1984). Means were compared at 5% levels of significance by the least significant difference (LSD) test. Data on weed population were subjected to square root transformation.

RESULTS AND DISCUSSION

Weed flora

The weed flora of the experimental site was pooled over the years and comprised of *Echinochloa colona* (18.5%), *Eleusine indica* (17.1%), *Dactyloctenium aegyptium* (4.9%), *Digitaria sanguinalis* (1.8%), *Panicum maximum* (1.8%), among the grasses, *Digera arvensis* (1.4%), *Cleome viscosa* (0.5%), *Celosia argentia* (3.9%), *Malugo stricta* (2.5%), *Trianthema monogyna* (2.5%) were major broad-leaf weeds (BLWs). *Cyperus rotundus* (44.9%) was most dominating among all the weeds species.

Effect on weeds

All the herbicidal treatments convincingly suppressed the weeds growth and were superior over the weedy check (Table 1). Among the herbicides applied alone, application of pendimethalin at 1000 g/ha resulted in lowest density of grassy weeds while lowest density of BLWs and sedges was obtained with post-emergence application of imazethapyr at 70 g/ha. Among various pre-mix, imazethapyr + pendimethalin 1000 g/ha was the most effective and recorded 89.7 and 87.2% suppression of grassy and BLWs, respectively as compared to weedy check. Higher flushes of *C. argentia* and *E. indica* were observed during crop growth period. Among the alone herbicides, total minimum weed density was recorded with pre-emergence application of pendimethalin at 1000 g/ha and was at par with application of imazethapyr at 70 g/ha applied as post-emergence. On the other hand, imezathapyr + pendimethalin (pre-mix) 1000 g/ha (12.1 weeds/m^2) was the best of all followed by imazethapyr + imazamox (pre-mix) 70 g/ha (12.3 weeds/m^2) as compared to weedycheck (19.9 weeds/m^2). These two pre-mix reduced total weed population by 63.2 and 62.3%, respectively over the weedy check. The better performance of combination of herbicides might be due to synergistic effect between the two herbicides reducing the population as well as dry matter accumulation of different weed species.

Table 1. Effect of herbicidal treatment on density and dry weight of weeds and weed control efficiency at 30 DAS

Treatment	Weed density (no./m^2)			Total weed density (no./m^2)	Total weed dry weight (g/m^2)	WCE (%)
	Grassy	BLWs	Sedges			
Pendimethalin PE (1000 g/ha)	3.4(11.3)	4.7(25.7)	11.7(139)	13.1(176)	5.8(33.1)	57.5
Imazethapyr PoE (50 g/ha)	10.4(107.7)	5.1(29.0)	11.1(126)	16.1(262)	6.5(41.4)	46.9
Imazethapyr PoE (70 g/ha)	9.4(88.7)	4.5(21.0)	10.1(104)	14.5(214)	5.9(34.3)	55.9
Imazethapyr + pendimethalin (pre-mix) PE (800 g/ha)	6.3(39.3)	5.0(33.3)	11.8(140)	14.5(212)	5.7(32.0)	58.9
Imazethapyr + pendimethalin (pre-mix) PE (900 g/ha)	5.1(25.3)	4.6(21.0)	11.3(126)	13.1(172)	5.3(28.6)	63.3
Imazethapyr + pendimethalin (pre-mix) PE (1000 g/ha)	4.3(17.7)	2.9(9.3)	10.9(122)	12.1(149)	4.9(23.3)	70.1
Imazethapyr + imazamox (pre-mix) PoE (60 g/ha)	6.9(48.9)	4.9(25.7)	10.5(110)	13.5(185)	6.5(41.6)	46.6
Imazethapyr + imazamox (pre-mix) PoE (70 g/ha)	5.6(31.7)	3.7(15.7)	10.2(105)	12.3(152)	6.0(34.6)	55.6
Hand weeding at 20 and 40 DAS	4.0(15.0)	3.7(14.0)	7.3(53)	9.0(82)	4.9(22.8)	70.7
Weedy	2.9(171.0)	8.2(72.7)	12.6(160)	19.9(404)	8.9(77.9)	-
LSD (P=0.05)	0.9	0.6	1.4	1.4	0.4	-

PE: Pre-emergence; PoE: Post-emergence; DAS - Days after sowing; Value in parentheses was original and transformed to square root $(\sqrt{x+1})$ for analysis, WCE - weed control efficiency

Table 2. Effect of herbicidal treatments on herbicidal efficiency index and weed persistence index

Treatment	Herbicide efficiency index (%)	Weed persistence index (%)
Pendimethalin PE (1000 g/ha)	3.0	0.97
Imazethapyr PoE (50 g/ha)	2.1	0.80
Imazethapyr PoE (70 g/ha)	2.2	0.84
Imazethapyr + pendimethalin (pre-mix) PE (800 g/ha)	3.0	0.78
Imazethapyr + pendimethalin (pre-mix) PE (900 g/ha)	4.4	0.85
Imazethapyr + pendimethalin (pre-mix) PE (1000 g/ha)	5.8	0.81
Imazethapyr + imazamox (pre-mix) PoE (60 g/ha)	1.9	1.2
Imazethapyr + imazamox (pre-mix) PoE (70 g/ha)	2.7	1.2
Hand weeding at 20 and 40 DAS	6.3	1.5
Weedy	-	-
LSD (P=0.05)	-	-

PE: Pre-emergence, PoE: Post-emergence, DAS- Days after sowing

Among alone application of herbicides, minimum weed dry matter accumulation was achieved with application of pendimethalin at 1000 g/ha which was at par with imazethapyr applied as post-emergence at 70 g/ha. Whereas, among various pre-mix application of imazethapyr + pendimethalin at 1000 g/ha followed by its respective lower dose applied at 900 g/ha was found more effective in reducing the dry matter accumulation of weeds. Twice hand weeding was also found comparable with combination of imazethapyr + pendimethalin at 1000 g/ha in reducing the dry matter accumulation of weeds. However, all the weed control treatments were proved to be significantly superior to weedy check.

Among various pre-mix herbicidal application, the higher weed control efficiency was obtained with pre-mix combination of imazethapyr + pendimethalin applied at 1000 g/ha followed by its respective lower dose applied at 900 g/ha, while it was low with application of imazethapyr + imazamox at 60 g/ha. Weed control efficiency (WCE) was higher with application of pendimethalin 1000 g/ha among the alone application of herbicides (Table 1). This might be due to better control of grassy weeds which led to less dry matter accumulation by weeds. Pre-emergence application of imazethapyr + pendimethalin (pre-mix) at 1000 g/ha resulted in 70.1% WCE which was followed by imazethapyr + imazamox (pre-mix) applied at 70 g/ha (63.3%) which might be due to broad spectrum control of weeds.

WPI and HEI

Weed persistence index (WPI) and herbicide efficacy indices (HEI) express the tolerance of weeds to different herbicide treatments as well as their efficacy to eradicate the weeds (Table 2). Among the various pre-mix combination of imazethapyr + pendimethalin applied at 800 g/ha recorded lowest WPI (0.78%) followed by its highest dose applied at 1000 g/ha. Among all treatments, highest WPI was recorded with twice hand weeding followed by post-emergence application of imazethapyr + imazamox (pre-mix) at 60 and 70 g/ha. Regarding HEI, pre-mix combination of imazethapyr + pendimethalin applied at 1000 g/ha produced higher HEI than all other herbicidal treatments followed by its respective lower dose applied at 900 g/ha. However, twice hand weeding (20 and 40 DAS) proved to be superior to all the herbicidal treatments.

Effect on yield attributes and yield

Pooled data of two years indicated that pre-mix combination of imazethapyr + pendimethalin at 1000 g/ha recorded higher number of plant/m^2 followed by its respective lower dose applied at 900 g/ha. Among different herbicidal treatments, higher pods/plant was obtained with pre-mix combination of imazethapyr + pendimethalin at 1000 g/ha which was at par with alone application of pendimethalin applied at 1000 g/ha and pre-mix combination of imazethapyr + pendimethalin at 800 and 900 g/ha. With an increase in doses of imazethapyr + pendimethalin (pre-mix) from 800 to 1000 g/ha, the yield and yield attributing characters increased but the differences were not significant.

Among the different pre-mix, maximum grain/pod was recorded with the pre-emergence application of imazethapyr + pendimethalin at 1000 g/ha which was at par with all other pre-mix combinations. Alone application of pendimethalin at 1000 g/ha as well as twice hand weeding (20 and 40 DAS) were also found comparable with imazethapyr + pendimethalin (pre-mix) applied at 1000 g/ha. Maximum 100-seed weight was achieved with the application of imazethapyr + pendimethalin (pre-mix) applied at 900 and 1000 g/ha as well as twice hand weeding whereas post-emergence application of imazethapyr + imazamox (pre-mix) applied at 60 and 70 g/ha recorded minimum 100-seed weight.

Table 3.Effect of herbicidal treatments on yield and yield attributes of blackgram

Treatment	Plants (no./m^2)	Pods / plant	Seed / pod	100 seed weight (g)	Seed yield (t/ha)
Pendimethalin PE (1000 g/ha)	49.5	26.7	3.6	3.1	1.15
Imazethapyr PoE (50 g/ha)	47.5	23.2	3.2	3.1	0.96
ImazethapyrPoE (70 g/ha)	50.7	23.0	3.3	3.1	1.00
Imazethapyr + pendimethalin (pre-mix) PE (800 g/ha)	49.5	24.3	3.4	3.2	1.13
Imazethapyr + pendimethalin (pre-mix) PE (900 g/ha)	53.7	24.9	3.5	3.3	1.31
Imazethapyr + pendimethalin (pre-mix) PE (1000 g/ha)	53.8	27.0	3.6	3.3	1.38
Imazethapyr + imazamox (pre-mix) PoE (60 g/ha)	48.3	23.2	3.5	3.0	1.02
Imazethapyr + imazamox (pre-mix)PoE (70 g/ha)	50.2	23.3	3.4	3.0	1.11
Hand weeding at 20 and 40 DAS	53.3	26.6	3.6	3.3	1.43
Weedy	40.5	17.2	2.4	2.7	0.50
LSD (P=0.05)	6.8	2.9	0.3	0.3	0.10

PE: Pre-emergence, PoE: Post-emergence, DAS- Days after sowing

Among alone application of herbicide, higher seed yield (1.15 t/ha) was recorded with the application of pendimethalin at 1000 g/ha, which showed 56.1% increment over the weedy check. Among the various pre-mix combination, imazethapyr + pendimethalin at higher dose (1000 g/ha) performed best by recording the highest seed yield (1.38 t/ha) which was at par with its respective lower dose applied at 900 g/ha and was significantly superior to all other pre-mix combinations as well as other herbicidal treatments (either applied pre- or post-emergence) and was comparable with twice hand (20 and 40 DAS) (1.43 t/ha). Per cent increase in seed yield of blackgram was reported higher (63.3%) with the pre-mix combination of imazethapyr + pendimethalin at 1000 g/ha over the weedy check. It was followed by the application of same herbicide at 900 g/ha resulting in increment of seed yield with the tune of 61.6% over the weedy check.The seed yield was negatively associated with total weed density, weeds biomass and positively associated with plants (no./m^2), pods/plant, seed/pod and 100-seed weight (g). This might be due to effective control of weeds, less crop weed competition throughout the crop growth period which resulted in improved growth parameters of the crop (Table 3).

Rao *et al*. (2010) also reported that alone application of pendimethalin and among different combinations, imazethapyr + pendimethalin were found better in reduction of the dry matter accumulation of weeds with maximum seed yield.

REFERENCES

Bhandari V, Singh B, Randhawa JS and Singh J. 2004. Relative efficacy and economics of integrated weed management in blackgram under semi-humid climate of Punjab. *Indian Journal of Weed Science* **36**: 276-277.

Chand R, Singh NP and Singh VK. 2004. Effect of weed control treatments on weeds and grain yield of late sown urdbean (*Vigna mungo* L.) during *Kharif* season. *Indian Journal of Weed Science* **36**: 127-128.

Choudhary VK, Kumar SP and Bhagawati R. 2012. Integrated weed management in blackgram (*Vigna mungo*) under mid hills of Arunachal Pradesh. *Indian Journal of Agronomy* **57:** 382–85.

Gomez KA and Gomez AA. 1984. *Statistical Procedures for Agricultural Research*, 2nd Ed., John Wiley and Sons Inc., New York.**).**

Indira M and Kurup PA. 2013.Blackgram: A hypolipidemic pulse. *Natural Product Radiance* **2**(5): 240-242.

Kumar A and Tewari AN. 2004**.** Crop-weed competition studies in summer sown blackgram (*Vigna mungo L.). Indian Journal of Weed Science* **36**: 76-78.

Nandan B, Sharma BC, Kumar A and Sharma V. 2011**.** Efficacy of pre- and post-emergence herbicides on weed flora of urdbean under rain-fed subtropical Shiwalik foothills of Jammu & Kashmir. *Indian Journal of Weed Science***43**:172-74.

Rao AS, Subba Rao G, and Ratnam M. 2010. Bio-efficacy of sand mix application of pre-emergence herbicides alone and in sequence with imazethapyr on weed control in relay crop of blackgram. *Pakistan Jorrnal of Weed Science and Research* **16** (3):279-285.

Rathi JPS, Tewari AN and Kumar M. 2004. Integrated weed management in blackgram (*Vigna mungo* L.). *Indian Journal of Weed Science* 36: 218-220.

Vaishya RD,Srivastava BK and Singh G. 2003. Integrated weed management in summer urd bean. *IndianJournal of Pulses Research* **16**: 161-162.

Tan S, Evans RR, Dahmer ML, Singh BK and Shaner DL. 2005.Imidazolinone-tolerant crops: history, current status and future. *Pest Management Science***61**: 246–57.

Walia US. 2003**.** *Weed Management*. Kalyani Publishers, B-I/292, Rajinder Nagar. 396p.

Yadav RP, Yadav KS and Srivastava UK. 1997**.** Integrated weed management in blackgram. *Indian Journal of Agronomy* **42**(2): 24-26.

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Influence of different herbicides on growth, yield and economics of lentil

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ABSTRACT

A field experiment was conducted during *Rabi* season of 2011-12 and 2012-13 at Raipur, Chhattisgarh to find most effective herbicides for weed management in lentil. Best result was found in hand weeding twice at 20 and 40 DAS closely followed by pre-mix application of pendimethalin + imazethapyr 1.0 kg/ha as pre-emergence wherein lowest weed dry weight was recorded at 60 DAS with maximum weed control efficiency, tallest plant, maximum branches/plant, highest plant dry matter accumulation, highest pods/ plant, seeds/plant, test weight, maximum grain and stover yield, maximum net return and B:C ratio over all the treatments.

Key words: Chlorimuron-ethyl, Imazethapyr, Lentil, Pendimethalin, Quizalofop-ethyl, Seed yield, Weed management

Lentil *(Lens culinaris* Medikus) is an important winter season pulse crop in India. It is hardier and capable of withstanding extremes of weather and soil condition. However, due to its short stature, slow initial growth and long duration, its productivity is adversely affected by the presence of weeds. The prominent weed species infesting lentil crop are *Cynodon dactylon, Chenopodium album, Euphorbia hirta, Melilotus alba, Anagallis arvensis* and *Xanthium strumarium*. The concept that high input in high yield also means is high risk, if weeds are not controlled. A weed free crop environment is therefore important both for increasing yield and income for the security of crop. There are number of reasons of low production and productivity of lentil out of which weeds, being serious negative factors in crop production are responsible for reduction in the yield of lentil to a tune of 84% (Mohamed *et al.* 1997). Loss in seed yield may go to the extent of 45-65% under unweeded condition. During winter season, broad-leaved weeds may become dominant in the early stages of crop growth because of their fast growth and deep root system.

To control weeds, generally hand weeding is in practice that is now costly as well as difficult because of non-availability of labour in peak period. With the advancement of agro techniques, chemical weed control has become an effective and cheap alternative to control weeds. It is effective and economical measures to control weeds as compared to manual weeding. Earlier a few studies have been done using herbicdes like quizalofop-ethyl and imazethapyr as post-emergence (Singh *et al.* 2014) and pendimethalin as pre-mergence and isoproturon as post emergence (Yadav *et al.* 2013, Dhuppar *et al.* 2013) with good control of weeds in lentil but there are scanty reports on pre-mix application of herbicides available in the market. Therefore, this study has been done to evaluate this aspect.

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MATERIALS AND METHODS

A field experiment was conducted at Indira Gandhi Krishi Vishwavidyalaya, Raipur ($21^0$4 N latitude, $81^0$39 E longitude and 298 m above mean sea level), Chhattisgarh during *Rabi* season of 2011-12 and 2012-13 to find out the most effective herbicide, their appropriate dose and time of application for lentil. The soils of the experimental plot was sandy loam in texture (Inceptisol) with pH 7.69 (neutral), low in organic carbon (0.48%), low in available N (181 kg/ha) and P (7.74 kg/ha) and high exchangeable K (311 kg/ha) with normal electrical conductivity.

The experiment was laid out in randomized complete block design (RCBD) comprising of 8 treatments, *viz.* quizalofop-ethyl at 50 g/ha at 30 DAS, imazethapyr at 37.5 g/ha at 30 DAS, chlorimuron- ethyl at 4 g/ha at pre-plant incorporation, pendimethalin 1.0 kg/ha at pre-emergence, pre-mix pendimethalin + imazethapyr 0.75 kg/ha as pre-emergence, pre-mix pendimethalin + imazethapyr 1.0 kg/ha at pre-emergence, hand weeding twice at 20 and 40 DAS and weedy check. Crop was sown at a seed rate of 40 kg/ha with a row spacing of 25 cm and plant spacing 5 cm in line during last week of November in 2011 and 2012, respectively. Recommended dose of N (20 kg/ha), P (17 kg/ha) and K (16 kg) through urea, diammonium phosphate and murate of potash were drilled in the soil before sowing. The crop was raised under irrigated condition with recommended package of practices for the zone.

All the herbicides were sprayed as per their time of application by knapsack sprayer using a flat fan nozzle at 500 l/ha volume by diluting with water. The economics of treatments was computed on the basis of prevailing market prices of inputs and outputs under each treatment. Pooling was made on the basis of two years data as similar trend was noticed during all the years.

RESULTS AND DISCUSSION

Floristic composition

The predominant weeds observed in the experimental field were *Cynodon dactylon* among grasses, *Chenopodium album*, *Cirsium arvense*, *Melilotus alba*, *Euphorbia hirta*, *Anagallis arvensis*, *Xanthium strumarium*, *Convolvulus arvensis* among broad-leaf and *Cyperus rotundus* among sedges during two years. Similarly, weed flora have also been reported by Chandrakar (2011). Thus, broad-leaved weeds were dominant compared to grassy and sedges during both year.

Effect on weeds

All the weed control treatments significantly curtailed weed dry weight compared to weedy check (Table 1). However, hand weeding twice at 20 and 40 DAS recorded lowest weed biomass compared to other treatments. Amongst the herbicides, lowest weed biomass 31.2 and 38.9 g/m^2 was recorded at 40 and 60 DAS in pendimethalin + imazethapyr 1.0 kg/ha at pre- emergence, respectively. It was closely followed by pendimethalin + imazethapyr 0.75 kg/ha as pre-emergence over rest of the treatments and weedy check. Combination of pendimethalin + imazethapyr and imazethapyr alone effectively controlled germinating broad-leaved as well as grassy weeds. This might be due to inhibition of weed seedling emergence, resulting in least weed biomass and higher crop growth. Similar findings were reported in field pea (Ram *et al.* 2011) and in Rajmash (french bean) (Ram *et al.* 2012). On the other hand, hand weeding twice at 20 and 40 DAS recorded the lowest weed biomass (19.87 g/m^2 at 40 DAS and 24.00 g/m^2 at 60 DAS) over all the herbicide treatments including weedy check by controlling weed population to the extent of 74.59 % (Table 1).

On efficiency factor, pre-emergence application of pendimethalin + imazethapyr at 1.0 kg/ha had maximum weed control efficiency (58.86%) recorded at 60 DAS and was closely followed by pre-emergence application of pendimethalin + imazethapyr at 0.75 kg/ha whereas, it was the least under chlorimuron-ethyl at 4 g/ha applied at pre plant incorporation. This might be due to the lower weed biomass and higher efficiency of weed control under combination of pendimethalin + imazethapyr against both broad-leaved and grassy weeds (Table 1). Imazethapyr at 25 as well as 40 g/ha at either 25 or 35 DAS showed promise in improving the grain yield of lentil (Singh *et al.* 2014). Similarly, minimum weed index (21.06 %) was recorded with pre-emergence application of pendimethalin + imazethapyr at 1.0 kg/ha over rest of the herbicide treatments and weedy check (Table 1) as this treatment effectively controlled both broad-leaved and grassy weeds. Similar findings were reported by Godara and Deshmukh (2002).

Table 1. Influence of different herbicides on weed biomass, weed control efficiency at 60 DAS and per cent reduction in yield due to presence of weeds of lentil (mean of 2 years)

Treatment	Total weed biomass (g/m^2)		Weed control efficiency at 60 DAS (%)	Weed dry matter (kg/ha)		Weed index (%)
	40 DAS	60 DAS		40 DAS	60 DAS	
Quizalofop-ethyl at 50 g/ha at 30 DAS	44.0	55.0	41.8	440	547	37.5
Imazethapyr at 37.5 g/ha at 30 DAS	36.3	44.7	52.7	363	447	31.2
Chlorimuron-ethyl at 4 g/ha as pre plant incorporation	60.5	66.1	30.0	605	661	44.6
Pendimethalin 1.0 kg/ha as pre-emergence	40.1	49.0	49.2	401	490	34.3
Pendimethalin + imazethapyr 0.75 kg/ha as pre-emergence	32.8	40.3	57.4	328	403	24.9
Pendimethalin + imazethapyr 1.0 kg/ha as pre-emergence	31.2	38.8	58.9	312	388	21.1
Hand weeding at 20 and 40 DAS	19.9	24.0	74.6	199	240	-
Weedy check	78.3	94.4	-	783	944	61.6
LSD (P=0.05)	8.4	9.3		84	93	

Table 2. Influence of different herbicides on growth and yield attributes of lentil (mean of 2 years)

Treatment	Plant height at harvest (cm)	Branches/ plant (no.)	Plant dry matter accumulation (g/m^2)	Pods/ plant (no.)	Seeds/ pod (no.)	1000 - seeds weight (g)
Quizalofop-ethyl at 50 g/ha at 30 DAS	34.8	4.07	21.8	25.8	1.60	22.4
Imazethapyr at 37.5 g/ha at 30 DAS	38.0	4.40	23.4	30.0	1.79	23.3
Chlorimuron-ethyl at 4 g/ha as pre plant incorporation	34.2	3.63	21.7	25.0	1.52	21.3
Pendimethalin 1.0 kg/ha as pre-emergence	36.5	4.20	23.4	27.7	1.71	23.6
Pendimethalin + imazethapyr 0.75 kg/ha as pre-emergence	39.8	4.80	23.7	32.3	1.85	23.7
Pendimethalin + imazethapyr 1.0 kg/ha as pre-emergence	41.6	5.23	24.6	34.2	1.89	24.7
Hand weeding at 20 and 40 DAS	49.2	5.90	26.3	41.0	1.98	24.7
Weedy check	33.3	3.13	18.4	20.3	1.39	18.9
LSD (P=0.05)	7.3	0.66	3.3	5.2	0.27	3.4

Table 3. Influence of different herbicides on seed yield, stover yield, harvest index and economics of lentil (mean of 2 years)

Treatment	Seed yield (t/ha)	Stover yield (t/ha)	Harvest index (%)	*Gross returns (x10^3 `/ha)	*Net returns (x10^3 `/ha)	B:C ratio
Quizalofop-ethyl at 50 g/ha at 30 DAS	0.79	1.39	36.8	32.99	20.51	1.64
Imazethapyr at 37.5 g/ha at 30 DAS	0.87	1.64	34.6	36.41	24.32	2.01
Chlorimuron-ethyl at 4 g/ha as pre plant incorporation	0.70	1.27	35.5	29.27	17.64	1.52
Pendimethalin 1.0 kg/ha as pre-emergence	0.83	1.62	33.8	34.83	21.63	1.64
Pendimethalin + imazethapyr 0.75 kg/ha as pre-emergence	0.95	1.78	34.8	39.74	26.98	2.11
Pendimethalin + imazethapyr 1.0 kg/ha as pre-emergence	1.00	1.84	35.1	41.73	28.47	2.15
Hand weeding at 20 & 40 DAS	1.26	2.17	36.8	52.71	36.94	2.34
Weedy check	0.48	0.84	36.6	20.22	9.25	0.84
LSD (P=0.05)	0.15	0.28	NS	6.02	6.02	0.47

*The price of quizalofop-ethyl ₹ 1200/-lit, imazethapyr ₹ 1600/-lit, pendimethalin ₹ 580/- lit, chlorimuron-ethyl ₹ 350/-, pendimethalin 30 EC+ imazethapyr 2 EC)- ₹ 630/-lit, the cost of two hand weeding (20 and 40 DAS) were ₹ 4800/- for 30 man days, sale price Lentil grain ₹ 50/kg and stover ₹1/kg.

Effect on crop

All the pre- and post-emergence herbicide treatments had significantly higher values of crop growth and yield contributing characters over the weedy check. Among the herbicide treatments, tallest plants (41.63 cm), highest branches/plant (5.23), plant dry matter accumulation (24.57 g/m^2), pods/ plant (34.17), seeds/pod (1.89) and test weight (24.68 g) were recorded with application of pendimethalin + imazethapyr at 1.0 kg/ha as pre-emergence and was closely followed by pendimethalin + imazethapyr at 0.75 kg/ha as pre-emergence. Because of poor weed control efficiency and higher weed competition index among weeds, chlorimuron-ethyl at 4 g/ha as pre-plant incorporation was least effective for raising crop growth and yield contributing characters of lentil (Table 2). On the contrary, hand weeding twice at 20 and 40 DAS recorded significantly tallest plants (49.23 cm), highest branches/plant (5.90), plant dry matter accumulation (26.30 g/m^2), pods/plant (40.97), seeds/pod (1.98) and test weight (24.68 g) over weedy check and most of the treatments.

Seed and stover yield of lentil varied significantly due to weed control treatments. Significantly maximum seed and stover yield 1.26 and 2.17 t/ha was obtained with hand weeding twice at 20 and 40 DAS, respectively over rest of the treatments. Among the herbicides, application of pendimethalin + imazethapyr 1.0 kg/ha as pre-emergence recorded maximum seed (1.0 t/ha) and stover yield (1.84 t/ha), which was obvious due to its higher values of yield attributes, weed control efficiency (58.86%) and lower weed index (21.06%) compared to the rest of the herbicide treatments. However, this treatment was at par with pendimethalin + imazethapyr 0.75 kg/ ha as pre-emergence. Effectiveness of these treatments could be attributed to better control of weeds during critical period of crop–weed competition and thus, provided a weed free environment for a better growth and development of rajmash. These findings were in close proximity with that of Billore *et al*. (1999) and Ram *et al*. (2011) with imazethapyr on field pea. Lower seed yield under chlorimuron ethyl could be attributed to its poor weed control efficiency and higher weed index against grassy weeds.

Economics

The highest net returns (₹ 36,937/ha) and benefit: cost ratio (2.34) were fetched with hand weeding twice at 20 and 40 DAS owing to effective control of broad-leaved as well as grassy weeds (Table 3) over rest of treatments. Among the herbicide treatments, highest net return (₹ 28471/ha) and benefit: cost ratio (2.15) was recorded with pendimethalin + imazethapyr 1.0 kg/ha as pre-mergence (PE) and was followed by pendimethalin + imazethapyr 0.75 kg/ha as PE and imazethapyr at 75 g/ha at 30 DAS. Excellent control of dominant broad-leaved as well as grassy weeds without any adverse effect on crop growth resulting in higher seed yield might have caused superior economic indices in these treatments. Least net return (₹ 9249/ha) and B:C ratio (0.84) was recorded with weedy check due to both poor weed control and low crop yield.

Thus, it may inferred from the above that hand weeding twice at 20 and 40 DAS could be recommended for effective control of mixed weed flora in lentil for getting higher productivity and profitability. However, in case of unavailability of agricultural labour at appropriate time for manual weeding in lentil, pre-emergence application of pre-mix pendimethalin + imazethapyr 1.0 kg/ha (Vellor) could be a good alternative to control the weeds effectively and economically.

REFERENCES

Billore SD, Joshi OP and Ramesh A. 1999. Herbicidal effect on nodulation, yield and weed control in soybean (*Glycine max* L.) *Indian Journal of Agriculture Science* **69**: 329-331.

Chandrakar UK. 2011. *Chemical weed control in lentil* (*Lens culinaris medikus subsp.culinaris*). M.Sc. (Ag) Thesis, IGKV, Raipur (CG).

Mishra JS. 2006. Efficacy of post emergence herbicides against wild oat in field pea. *Indian Journal of Weed Science* **38**: 140-142.

Mohamed ES, Noural AH, Mohamed MI and Saxena MC. 1997. Weed and weed management in irrigated lentil in Northern Sudan. *Weed Research Oxford* **37**(4): 211-218.

Godara SP and Deshmukh SC. 2002. Weed biomass, weed control efficiency and yield of soybean as influenced by various weed control measures, pp. 1198-1200. In: *Balancing Food and Environment Security–A Continuing Challenge*, Proceedings of 2nd International Agronomy Congress, 26-30 November 2002, IARI, New Delhi.

Ram Baldev, Punia SS, Meena DS and Tetarwal JP. 2012. Efficacy of post-emergence herbicides on weed control and seed yield of rajmash (*Phaseolus vulgaris* L.). *Journal of Food Legumes* **25**(4): 306-309.

Ram Baldev, Punia, SS, Meena DS and Tetarwal JP. 2011. Bio-efficacy of post-emergence herbicides to manage weeds in field pea. *Journal of Food Legumes* **24**: 254-257.

Singh Guriqbal, Kaur Harpreet and Khanna Veena. 2014. Weed management in lentil with post-emergence herbicides. *Indian Journal of Weed Science* **46**(2): 187–189.

Yadav RB, Vivek, Singh RV and Yadav KG. 2013. Weed management in lentil. *Indian Journal of Weed Science* **45**(2): 113–115.

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Tillage and nitrogen management effects on weed seedbank and yield of fingermillet

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ABSTRACT

Field and pot culture studies were conducted at Bengaluru to study the influence of three tillage practices, *viz*. conventional tillage (3 ploughings + 3 inter cultivations), reduced tillage (2 ploughings + 2 inter cultivations) and minimum tillage (1 ploughing + 1 inter cultivation) and three nitrogen management practices, *viz*. 100% N through Urea, 100% N through integrated supply (50% N through urea+ 25% N through FYM+ 25% N through *Glyricidia*) and 100% N through organic source (50% N through FYM+ 50% N through *Glyricidia*) on live weed seedbank and yield of fingermillet (*Eleusine coracana* L.) under rainfed pigeonpea-fingermillet system in Alfisols. The results showed that conventional tillage reduced the infestation of *Borreria articularis, Cynodon dactylon* and *Cyperus rotundus* compared to other tillage practices. However nitrogen management practices didn't influence live weed seed bank significantly. Among tillage practices, conventional tillage recorded significantly higher fingermillet yield (3.03 t/ha) compared to other tillage practices and among nutrient management practices integrated supply of N recorded higher yield of 2.67 t/ha compared to other nutrient management practices. More live weed seeds were distributed in upper 10 cm soil depth in minimum tillage whereas in conventional tillage live weed seed distribution was more or less uniform in the soil profile studied.

Key words: Glyricidia, Grain yield, Finger millet**,** Nitrogen effect, Weed seed bank, Tillage effect

Pigeonpea (*Cajanus cajan* L.) - fingermillet (*Eleusine coracana* L.) system is an important cropping system in Southern India particularly in Karnataka state. Both crops are largely grown under rainfed conditions, experiencing moisture deficiency at different growth stages of growth. Deficiency of moisture for both the crops affects normal growth and development resulting in lesser yield under rainfed conditions. Further nutrient deficiency particularly N and unchecked weed growth inflict considerable reduction in fingermillet yield.

Role of tillage in conserving soil moisture and its subsequent beneficial effect on crop productivity has long been recognized. Adequate tillage operations controlled weeds and resulted in higher crop productivity, but caused more soil loss and were more capital intensive (Dogra *et al*. 2002). Tillage influences the vertical distribution of weed seeds in soil layer and weed diversity. No till cropping systems leave most seeds in top 1.0 cm layer of soil profile (Yenish *et al*. 1992). Differential distribution of seeds in the soil profile subsequently leads to change in weed population dynamics (Buhler 1991). Use of organic manure is inevitable for sustained agricultural production by reducing dependence on inorganic fertilizers and to build the soil fertility and improve the soil biological activity. Keeping this in view, a study was under taken to find out the combined influence of tillage and nitrogen management practices on live weed seedbank and yield of fingermillet under pigeonpea-fingermillet system in *Alfisols* of Southern India.

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MATERIALS AND METHODS

Field experiments were conducted during *Kharif* seasons of 2010 and 2011 at the University of Agricultural Sciences, G.K.V.K, Bengaluru. The soil of the experimental field was red sandy clay loam having a pH 5.5, with 0.36% organic carbon, available N 175 kg/ha, P 68.4 kg/ha and K 160 kg/ha. The treatments consisting of three tillage practices, *viz. c*onventional tillage (3 ploughings + 3 inter cultivations), reduced tillage (2 ploughings + 2 inter cultivations) and minimum tillage (1 ploughing + 1 inter cultivation) in main plots combined with three nitrogen management practices, *viz.* 100% N through Urea, 100% N through integrated supply (50% N through urea + 25% N through FYM+ 25% N through *Glyricidia*) and 100% N through organic sources (50% N through FYM+ 50% N through *Glyricidia*) in sub-plots were replicated thrice in split-plot design. Tillage practices were done as per treatment details *viz.*, in conventional tillage, three ploughings (15-20 cm deep) and three inter cultivations during the crop period was done first after 30 days after sowing and remaining two at an interval of fifteen days. In reduced tillage,two ploughings (15-20 cm deep) and two inter cultivations during the crop period was done, first inter cultivation after 30 days after sowing and remaining one after an interval of fifteen days. In minimum tillage, one ploughing (15-20 cm deep) and one inter cultivations during the crop period was done after 30 days after sowing.

Nitrogen management practices were followed as per the treatment details, *viz.* in 100% N through urea treatment, entire dose of nitrogen was applied through urea as basal in pigeonpea where as in finger millet 50% N as basal and remaining 50% after 30 days after sowing; in 100% N through organic sources, 50% of N through FYM and 50% of N through *Glyricidia* was supplied to the crop by incorporating to the field 20 days before sowing of crop; in 100% N through integrated supply, 50% N through urea, remaining nitrogen was supplied through farm yard manure and *Glyricidia* in equal proportion to meet the remaining nitrogen based on their nitrogen equivalent before 20 days of sowing. Recommended phosphorus and potassium was supplied through single super phosphate and muraite of potash, respectively to all the treatements as basal.

In each treatment, a quadrat of 0.5 x 0.5 m was selected at random for recording weed count. Accordingly, the number of monocots, dicots and sedges present within quadrant were counted and expressed as no./m^2. Later the original values were subjected to suitable transformations (square root or logarithmic) depending on the variation in the data and subjected to statistical analysis.

For live weed seedbank analysis, soil samples were collected two times, before sowing of pigeonpea in May 2010 and after harvest of fingermillet in November 2011 to determine the live weed seedbank composition. Samples were taken from three soil depths (0-10, 10-20 and 20-30 cm) in the field. From each plot, five samples of soils with a core auger were taken at randomly. Soil samples from each plot were pooled within the same depth. Soil samples from each plot were thoroughly mixed air dried under shade and ground gently with hands in to the small pieces. Thereafter, 1 kg each of soil, devoid of large rocks and root fragments, was transferred into 20 x 35 cm plastic trays and with 2 cm soil thickness, placed in light screen house. These were watered as and when needed to maintain adequate moisture. Weed seedlings emerged were identified, counted and removed. Seedlings of unidentified weeds were transplanted in to other pots and grown until their identities could be verified. After this, the soil was thoroughly mixed watering was continued for next flush of weed seed germination. The cycle of operation was repeated after every flush of germination, identification and removal of seedlings. Watering was continued for three weeks after weed seed germination ceased.

The data were subjected to statistical analysis to determine differences among tillage, nutrient management practices and different soil depths.

RESULTS AND DISCUSSION

The dominant weed species observed both in experimental field and weed seedbank studies were *Borreria articularis*, *Cynodon dactylon* and *Cyperus rotundus.*

Effect of tillage on weeds and weed seedbank

Different tillage practices significantly influenced weed population. Irrespective of the weed species, conventional tillage significantly reduced the population of weeds compared to reduced tillage and minimum tillage. The inversion of soil by following conventional tillage resulted in deeper placement of weed seeds which could not emerge out, causing a significant reduction in the population of weeds. Similar result was observed by Chahal *et al.* (2003). In minimum tillage during both the years, dominance of perennial grass and sedge started to increase. In minimum tillage due to less disturbance and falling of weed seeds on to the surface of soil both weed population and weed dry weight was significantly higher compared to reduced and conventional tillage treatments (Table 2). Satisfactory weed control in conventional tillage treatment may be attributed to better weed control in this tillage practice and to the stimulatory effect of tillage in inducing weed seed germination and it might be due to the greater deposition of weed seed at soil surface and ploughing each time might kill the germinated weeds. This had a general agreement with previous studies of Ball and Miller (1990), Amanuel and Tanner (1991) and Mohler (1993).

In conventional tillage, weed seeds were distributed uniformly among different soil depths compared to minimum tillage and reduced tillage (Table 3). In minimum tillage all three types of weed species, *viz*. broad-leaved, grass and sedges were significantly higher than other two tillage practices and most of the weed seeds were concentrated in top layers of soil.

Table 1. Effect of tillage and nitrogen management practices on growth and yield of fingermillet

Treatment	Plant height at harvest (cm)	Number of tillers/plant	Grain weight/ plant (g)	Grain yield (t/ha)	B:C ratio
Tillage					
T_1: 3 ploughings + 3 inter cultivations	79.2	6.16	12.0	3.03	3.57
T_2: 2 ploughings + 2 inter cultivations	70.3	5.37	10.7	2.26	2.83
T_3: 1 ploughing + 1 inter cultivation	61.2	4.47	8.3	1.11	1.56
LSD (P=0.05)	2.81	0.61	1.2	0.49	
Nitrogen management					
N_1: 50% N through FYM+ 50 % N through *Glyricidia*	66.2	4.91	9.9	1.66	1.71
N_2: 25% N through FYM+ 25 % N through *Glyricidia* + 50% N through Urea	74.4	5.77	10.7	2.67	3.23
N_3: 100% N through Urea	70.0	5.33	10.4	2.07	3.02
LSD (P=0.05)	3.60	0.40	0.31	0.25	

Table 2. Effect of tillage and nitrogen management practices on weed density (no./m²) and weed dry weight (g/0.25 m²) in fingermillet at harvest

Treatment	Monocots (+)	Dicots (+)	Sedges (+)	Total weed density (#)	Total weed dry weight (#)
Tillage					
T_1: 3 ploughings + 3 inter cultivations	3.52 (11)	2.76 (6.7)	2.81 (7.0)	1.43 (25)	1.26 (17)
T_2: 2 ploughings + 2 inter cultivations	4.94 (23)	3.83 (13.7)	4.22 (16.9)	1.75 (54)	1.69 (47)
T_3: 1 ploughing + 1 inter cultivation	5.78 (33)	4.70 (21.1)	4.96 (23.8)	1.89 (77)	1.80 (62)
SEm±	0.15	0.10	0.12	0.01	0.03
LSD (P=0.05)	0.59	0.41	0.37	0.08	0.10
Nitrogen management					
N_1: 50% N through FYM+ 50 % N through glyricidia	4.84 (23)	3.81 (14.3)	4.10 (16.6)	1.71 (54)	1.61 (44)
N_2: 25% N through FYM+ 25 % N through glyricidia + 50% N through Urea	4.76 (23)	3.77 (13.9)	4.0 (15.9)	1.69 (52)	1.59 (42)
N_3: 100% N through Urea	4.64 (22)	3.71 (13.3)	3.90 (15.1)	1.67 (50)	1.56 (39)
SEm±	0.10	0.04	0.09	0.01	0.02
LSD (P=0.05)	NS	NS	NS	NS	NS

*Figures in parentheses indicate original values, NS- Non significant, Data subjected to, + - square root $(\sqrt{x+1})$, # - log $(\sqrt{x+2})$ transformations

Effect on yield

Plant height was significantly higher under conventional tillage (79.2 cm) than reduced tillage (70.3 cm) and minimum tillage (61.2 cm). Similarly conventional tillage produced significantly higher tiller number (6.16/plant), grain weight (12 g/plant) and grain yield (3.03 t/ha) compared to other tillage practices (Table 1). This may be due to creation of favourable physical condition for seed germination, seedling emergence, stand establishment and subsequent growth which contributed for better growth, yield attributes and yield.

Soil depth and tillage interactions

The interaction between soil depth and tillage was significant. All the dominant weed species observed, *viz. Borreria articularis*, *Cyperus rotundus* and *Cynodon dactylon* were significantly reduced by conventional tillage (Table 2 and 3). The live weed seedbank distribution differed between tillage practices. In minimum tillage practices, large number of live weed seeds was found at the depth of 0-10 cm followed by reduced tillage and conventional tillage. This may be attributed to greater deposition of weed seed at the soil surface due to less disturbance to weeds in minimum tillage which resulted in more addition of weed seeds at the end of their life cycle. In conventional tillage, live weed seeds were distributed more or less uniform compared to reduced and minimum tillage. The total live weed seedbank was higher in minimum tillage and lowest live weed seed bank was observed in conventional tillage (Table 3). This may be attributed satisfactory control of weeds by intensive tillage practices. Similar findings were reported by Ball and Miller (1990).

Table 3. Total live weed seedbank (number per kg of soil) as influenced by tillage, Soil depth and nitrogen management practices

Treatment	At 15 days	At 30 days	At 45 days	At 60 days
Tillage (T)				
T_1	1.16 (13.0)	1.27 (18.3)	0.99 (8.9)	0.69 (3.9)
T_2	1.56 (36.2)	1.66 (49.9)	1.48 (34.7)	1.06 (11.7)
T_3	1.63 (44.8)	1.81 (66.8)	1.64 (46.2)	1.26 (19.7)
SEm±	0.02	0.02	0.02	0.03
LSD (P=0.05)	0.07	0.06	0.07	0.08
Nitrogen (N)				
N_1	1.48 (34.7)	1.60 (45.1)	1.41 (30.2)	1.04 (10.5)
N_2	1.45 (33.0)	1.58 (43.3)	1.37 (28.3)	1.01 (11.3)
N_3	1.42 (31.4)	1.55 (41.5)	1.35 (26.6)	0.97 (9.9)
SEm±	0.02	0.02	0.02	0.03
LSD (P=0.05)	NS	NS	NS	NS
Soil depth (D)				
D_1-10 cm	1.65 (53.2)	1.74 (60.5)	1.56 (40.8)	1.26 (20.3)
D_2- 20 cm	1.44 (28.1)	1.59 (41.7)	1.38 (27.9)	1.01 (10.0)
D_3- 30 cm	1.26 (17.9)	1.40 (27.3)	1.19 (16.5)	0.75 (5.0)
SEm±	0.02	0.02	0.02	0.03
LSD (P=0.05)	0.07	0.06	0.07	0.08

T_1- 3 ploughings + 3 Inter cultivations, T_2- 2 ploughings + 2 Inter cultivations, T_3- 1 ploughing + 1 Inter cultivation, N_1- 50% N through FYM and 50% N through Glyricidia, N_2-25% N through FYM, 25% N through Glyricidia and 50% N through Urea, N_3-100 % N through Urea, NS - Non significant, *Figures in parentheses indicate original values, Data subjected to log $(\sqrt{x+2})$ transformation

Effect of nitrogen management on weed seed-bank and yield

Nitrogen management practices didn't influence weeds and live weed seed bank significantly. However, nitrogen management practices significantly influenced on growth and yield of fingermillet. Grain yield of fingermillet in 100% N supplied through urea was 2.07 t/ha, which increased to 2.67 t/ha due to 50% substitution of N with farm yard manure and Glyricidia leaf manure (Table 1). This has accounted for 28.97% increase in grain yield over 100% N supply through urea. Further, increasing the level of substitution of N by 100% with organics (FYM and *Glyricidia*) did not influence the grain yield rather resulted in significant reduction in yield. Combined application of both the source of nitrogen has resulted in better availability of nitrogen throughout the crop growth period. Fertilizer source of N has met the nutrient requirement of the plant in the early growth stages and the mineralized nitrogen from FYM and *Glyricidia* could supply the nutrient in the later growth stages of the crop. Hence, there was continuous supply of nutrients throughout the crop growth period. Whereas, in 100% N substitution by farm yard manure and *Glyricidia*, mineralization occurs slowly and the supply of nitrogen in the early stages of crop growth was delayed and thus the crop was starved of nitrogen, which has affected crop growth and yield. Similar results were obtained by Aruna and Mohammad (2006), Dass and Patnaik (2007) and Kumar *et al.* (2007).

Tillage and soil depth had significant effects on weeds and live weed seedbank. Live weed seedbank size was greater in minimum tillage than conventional tillage or reduced tillage. This resulted in better performance of fingermillet crop in Southern India.

Table 4. Total live weed seed bank (number per kg of soil) as influenced by tillage at different soil depths

Treatment	At 15 days	At 30 days	At 45 days	At 60 days
T_1D_1	1.26 (17)	1.46(28)	1.21(15)	0.95(7.3)
T_1D_2	1.19 (12)	1.29(18)	0.97(7.3)	0.74(4.0)
T_1D_3	1.03(9.0)	1.04(9.2)	0.81(4.6)	0.38(0.5)
T_2D_1	1.71 (50)	1.77(58)	1.63(41)	1.25(18)
T_2D_2	1.55 (34)	1.67(45)	1.46(27)	1.11(13)
T_2D_3	1.43 (25)	1.53(32)	1.36(22)	0.82(4.9)
T_3D_1	1.98 (93)	1.99(96)	1.83(66)	1.57(36)
T_3D_2	1.57 (37)	1.80(62)	1.70(49)	1.17(14)
T_3D_3	1.33 (19)	1.64(42)	1.39(23)	1.05(9.6)
LSD (P=0.05)	0.09	0.07	0.09	0.14

T_1-3ploughings + 3 Inter cultivations, T_2-2 ploughings + 2 Inter cultivations, T_3- 1 ploughing +1 Inter cultivation, D_1- 10 cm depth, D_2- 20 cm depth, D_3- 30 cm depth, *Figures in parenthesis indicate original values, Data subjected to log $(\sqrt{x+2})$ transformation

Among nitrogen management practices, integrated supply of N found promising in getting better yield of fingermillet however there was no effect of nutrient management practices on weeds and live weed seed bank.

I was concluded that tillage is the limiting factor for live weed seed bank size in the soil. This suggested that intensive tillage practices could make considerable reduction in live weed seedbank in the soil. However, further research will be required to confirm these initial findings and to determine whether dynamics of individual species follows the same pattern as total weed density and which can be made use for more accurate future predictions related to the population dynamics of the weed seed in the soil.

REFERENCES

Amanuel G and Tanner DG. 1991. The effect of crop rotation in two wheat crop production zones of southern Ethiopia. *Weed Science* **39**: 205-209.

Aruna E and mohammad S. 2006. Nutrient management options in rice-sunflower cropping system to sustain productivity and conserve the soil fertility. *International Journal of Agricultural Sciences* **2**(1): 122-129.

Ball DA and Miller SD. 1990. Weed seed population response to tillage and herbicide use in three irrigated cropping sequences. *Weed Science* **38**: 511-517.

Buhler DD. 1991. Influence of tillage systems on weed population dynamics and control in the Northern corn belt of the United States. *Advances in Agronomy* **1**: 51-60.

Chahal PS, Brar HS and Walia US. 2003. Management of *Phalaris minor* in wheat through integrated approach. *Indian Journal of Agronomy* **35**(1&2): 1-5.

Dass A and Patnaik US. 2007. On-farm evaluation of integrated nutrient management in ragi (*Eleusine coracana*). *Indian Journal of Soil Conservation* **35**(1): 79-81.

Dogra P, Joshi BP and Sharma NK. 2002. Economic analysis of tillage practices for maize cultivation in the Himalayan humid subtropics. *Indian Journal of Soil Conservation* **30**(2): 172-178.

Kumar O, Basavarajnaik T and Palaiah P. 2007. Effect of weed management practices and fertility levels on growth and yield parameters in fingermillet. *Karnataka Journal of Agricultural Sciences* **20**(2): 230-233.

Mohler CL. 1993. A model of the effect of tillage on emergence of weed seedlings. *Ecological Applications* **3**: 53-73.

Yenish JP, Doll JD and Buhler DD. 1992. Effect of tillage on vertical distribution and viability of weed seeds in soil. *Weed Science* **40**: 429-433.

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Post-emergence herbicides for weed management in French bean

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ABSTRACT

Experiment was conducted to investigate the effects of imazthapyr and quizalofop-ethyl in different doses (50, 75 and 100 g/ha) with two interval (20-25 and 30-35 DAS), hand weeding twice (20 and 40 DAS) in comparison to unweeded control on yield and yield components of French bean during *Rabi* season of 2009 to 2011 under irrigated condition on Inceptisols. Among herbicides, application of imazethapyr at 100 g/ha at 20 DAS produced lowest weed index and highest weed efficiency and seed yield (1.24 t/ha). Imazethapyr at 100 g/ha at 20-25 DAS gave more economic profit (₹28869/ha) followed by imazethapyr at 100 g/ha at 30-35 DAS (₹27780/ha). None of the herbicides showed phytotoxicity to crop and was compatible with French bean. Imazethapyr and quizalofop-ethyl at lower concentration did not provide satisfactory weed control in rajmash field.

Key words: Economics, French bean, Imazethapyr, Post-emergence, Quizalofop-ethyl

In Maharashtra, French bean locally called 'rajmash' (*Phaseolus vulgaris*) is grown as a minor pulse crop and cultivated during *Kharif* (rainy season). However, with the development of new genotypes, the crop has been introduced during *Rabi* season particularly in the Vidarbha region. It is a short duration crop, which can be included in crop rotations after harvest of mungbean/urdbean as it has been found economically advantageous over wheat. Though, it is a legume crop, it does not nodulate in roots either with native rhizobia or commercially produced cultures. Thus, it requires higher dose of nitrogen. Plant has fibrous roots which draw moisture and nutrients mostly from upper layer of soil surface. Due to high moisture and nutrients in rajmash field, weeds become a problem, thus their timely control is necessary to exploit the yield potential (Srivastava *et al*.2013).

During its early growth stage, weed competes with it leading to severe competition. Since, initial growth of rajmash is very slow, the initial period of growth (30-45 DAS) is most crucial for crop-weed competition. In addition to slow initial crop growth, wider crop spacing also facilit crop-weed competition which poses a serious limitation in rajmash production and thus, estimated seed yield loss may likely to go to the extent of 45-65% under unweeded condition. During winter season, dominance of broad-leaved weeds in the early stages of crop growth period is mainly due to their fast growth and deep root system, which enables them to easily tap soil moisture and nutrients.

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Manual and mechanical methods of weed control are quite effective, but they are costly and time consuming. Thus, chemical weed control becomes a promising option to control the weeds during crop growth period. Herbicides like fluchloralin as pre-plant-incorporation (PPI) and pendimethalin as pre-emergence (PE) have been recommended for weed control, however these are effective only during initial period (up to 30 DAS). Thus, for the effective control of weeds throughout the crop season, use of post-emergence herbicides is necessary. There is also a possibility that use of single post-emergence herbicides may replace the above and raise the income of farmers. Recently some herbicides, particularly imazethapyr and quizalofop-ethyl have been used for selective control of post-emergent weeds in pulses. Therefore, the present investigation was undertaken for development of proper weed control schedule in rajmash.

MATERIALS AND METHODS

Field experiment was conducted at Pulses Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, during *Rab*i season 2009-10 and 2010-11 and during 2011-12 at Regional Research Center, Amravati under AICRP on MULLaRP. The soil of experimental site was clayey with pH 7.8, having available N 235 kg/ha, P 20.9 kg/ha, K 323 kg/ha and organic carbon 4.1 g/kg. The experiment was laid out in randomized complete block design having three replications. The treatment comprised of weedy check (without removal of weeds) and hand weeding twice at 25 and 35 DAS and two post-emergence herbicides, *viz.* imazethapyr (50, 75 and 100 g/ha) and quizalofop-ethyl (50, 75 and 100 g/ha). All the herbicides were applied at 20 and 30 days after sowing (DAS) with knapsack sprayer fitted with flat-fan nozzle using 500 liter water/ha.

Seeds were sown in furrows at 45 x 10 cm apart using 90 kg seed/ha. Uniform dose of 90 kg N + 60 kg P/ha through urea, and SSP, respectively were applied. Half of N and full dose of P were applied at sowing while remaining half N was top dressed after 30 DAS at optimum soil moisture.

Data on weed density and dry weight of weeds were recorded at 45 DAS and at harvest using quadrates 1 x 1 m. The weed samples were first dried under sun and then in hot air oven at 70 °C for three days for recording the dry matter.

Yield attributes and seed yield of French bean were recorded at the time of harvest. The economic analysis of each treatment was done on the basis of prevailing market rates of the inputs used and out-puts obtained under each treatment. The required plant population (45 cm row to row and 10 cm plant to plant) was maintained by thinning plants after three weeks of sowing. The economics of treatments were computed on the basis of prevailing market prices of the inputs used and outputs obtained under each treatment. The market price of imazethapyr and quizalofop-ethyl was ₹1500 and ₹1475/liter, respectively, whereas, cost of two hand weeding 20 and 40 DAS) amounted to ₹ 4800. The sale price of French bean seed was taken at 28/kg.

RESULTS AND DISCUSSION

Weed flora

Weed flora in experimental field consisted of grasses like, *Brachiaria* sp., *Cynodon dactylon;* sedges like *Cyperus rotundus* and broad-leaved weeds like *Parthenium hysterophorous, Physalis minima, Convolvulus arvensis, Euphorbia geniculata* and *Digeria arvensis.* However, grassy weed like *Cyperus rotundus* and broad-leaved weed like *Parthenium hysterophorous, Physalis minima, Convolvulus arvensis* and *Digeria arvensis* dominated over other weeds in the rajmash field and *Cynodon dactylon* were not effectively controlled by any of the herbicides.

Among herbicides and cultural methods of weed control, application of imazethapyr 100 g/ha at 20-25 and 30-35 DAS, respectively followed by quizalofop-ethyl 100 g/ha at 30-35 DAS recorded the lowest dry weight of weeds at all the growth stages followed by application of their respective lower doses. However, higher dose of quizalofop-ethyl *i.e.* 100 g/ha at 20-25 DAS recorded higher dry weight of weed over application of same dose at 30-35 DAS (Table 1). This might be due to grassy weeds generally arises late in the season. However, imazethapyr was effective against annual broad-leaf weeds like *P. hysterophorus, P. minima, D. arvensis, C. arvensis, E. geniculata* and grassy weeds like *Bracharia* sp. and perennial sedges like *C. rotundus.*

Table 1. Growth, yield attributes, seed yield and economics of rajmash as influenced by different treatments

Treatment	Plant height (cm)	Pods/ plant	Seed index (g)	Yield (t/ha)				Net returns (x10^3 ` /ha)	B:C ratio
				2009	2010	2011	Pooled		
Quizalofop-ethyl 50 g/ha at 20-25 DAS	32.2	14.2	41.8	1.05	1.02	0.90	0.99	20.87	1.50
Quizalofop-ethyl 50 g/ha at 30-35 DAS	37.7	15.5	40.6	1.04	0.98	0.86	0.96	19.88	1.44
Quizalofop-ethyl 75 g/ha at 20-25 DAS	33.0	16.9	42.5	1.10	1.13	1.01	1.08	23.64	1.65
Quizalofop-ethyl 75 g/ha at 30-35 DAS	35.2	17.2	40.7	1.08	1.09	0.97	1.05	22.49	1.58
Quizalofop-ethyl 100 g/ha at 20-25 DAS	35.9	18.0	41.9	1.12	1.17	1.05	1.12	24.52	1.67
Quizalofop-ethyl 100 g/ha at 30-35 DAS	37.8	15.8	41.3	1.17	1.13	1.02	1.10	24.03	1.64
Imazethapyr 50 g/ha at 20-25 DAS	34.7	16.5	42.3	1.11	1.10	0.99	1.07	23.49	1.69
Imazethapyr 50 g/ha at 30-35 DAS	37.2	18.4	41.0	1.17	1.07	0.96	1.07	23.59	1.71
Imazethapyr 75 g/ha at 20-25 DAS	36.6	18.8	43.3	1.16	1.12	1.03	1.11	24.44	1.71
Imazethapyr 75 g/ha at 30-35 DAS	37.0	17.4	43.2	1.19	1.21	1.10	1.17	26.59	1.86
Imazethapyr 100 g/ha at 20-25 DAS	36.7	19.4	42.4	1.24	1.32	1.17	1.24	28.87	1.97
Imazethapyr 100 g/ha at 30-35 DAS	35.6	17.4	41.7	1.26	1.26	1.11	1.21	27.78	1.89
Weedy check	38.1	14.7	40.3	0.98	0.85	0.84	0.89	18.79	1.50
HW twice at 20 DAS and 40 DAS	36.8	17.6	41.1	1.38	1.33	1.17	1.30	27.85	1.59
LSD (P=0.05)	1.68	2.63	1.36	0.08	0.11	0.13	0.08	2.05	-

Table 2. Dry weight of weed at harvest, weed control efficiency and weed index at harvest as influenced by different treatments

Treatment	Weed dry weight (g/m^2)			Weed control efficiency (%)			Weed index (%)		
	2009	2010	2011	2009	2010	2011	2009	2010	2011
Quizalofop-ethyl at 50 g/ha at 20-25 DAS	18.0	7.58	4.10	75.3	85.9	89.1	23.7	22.5	19.2
Quizalofop-ethyl at 50 g/ha at 30-35 DAS	16.0	5.12	4.27	78.1	90.5	88.7	24.8	25.2	22.1
Quizalofop-ethyl at 75 g/ha at 20-25 DAS	14.3	2.82	3.77	80.4	94.8	90.0	20.5	14.3	11.1
Quizalofop-ethyl at 75 g/ha at 30-35 DAS	13.7	2.25	4.10	81.2	95.8	89.1	21.8	17.0	14.3
Quizalofop-ethyl at 100 g/ha at 20-25 DAS	12.2	1.45	4.13	83.3	97.3	89.1	18.6	11.2	8.2
Quizalofop-ethyl at 100 g/ha at 30-35 DAS	9.7	1.22	4.90	86.7	97.7	87.0	15.6	14.5	11.1
Imazethapyr at 50 g/ha at 20-25 DAS	13.3	6.5	3.10	81.8	87.9	91.8	19.9	16.4	12.9
Imazethapyr at 50 g/ha at 30-35 DAS	11.1	4.7	3.17	84.8	91.3	91.6	15.1	18.8	15.1
Imazethapyr at 75 g/ha at 20-25 DAS	8.8	2.39	2.87	87.9	95.6	92.4	16.0	14.7	10.3
Imazethapyr at 75 g/ha at 30-35 DAS	6.8	2.16	2.67	90.7	96.0	92.9	14.0	8.6	4.6
Imazethapyr at 100 g/ha at 20-25 DAS	4.4	0.72	2.49	93.9	98.6	93.4	10.6	2.0	3.5
Imazethapyr at 100 g/ha at 30-35 DAS	2.3	0.63	2.40	96.8	98.8	93.6	8.8	4.9	4.1
Weedy control	73.0	54.0	37.7	0.0	0.0	0.0	29.2	34.2	23.4
HW twice at 20 and 40 DAS	11.0	1.1	3.23	84.9	97.9	91.4	0.0	0.0	0.0
LSD (P=0.05)	4.23	4.25	1.27	-	-	-	-	-	-

Yield

The highest yield attributes, *viz*. plant height, pods/plant and grain weight/plant were recorded in HW (Table 1). Among the herbicides applied treatments, highest yield attributes were recorded with imazethapyr 100 g/ha at 20-25 DAS followed by its application at 30-35 DAS. Amongst post-emergence herbicides, lower doses *i.e.* 50 g/ha at early stage (20-25 DAS) and late stage (30-35 DAS) were less effective compared to higher doses *i.e.* 75 and 100 g/ha.

Application of imazethapyr at 75 g/ha at 20-25 and 30-35 DAS was found effective in weed control, however, their lower levels *i.e.* 50 g/ha was observed ineffective in weed control during *Rabi* season. Imazethapyr being freely translocated in plants through roots and shoots could effectively controlled broad-leaved as well as grassy weeds. Meena *et al.* (2011) reported efficient control of weeds by imazethpyr at 100 g/ha over lower doses in soybean. In current investigation also, application of imazethapyr at 100 g/ha at 20-25 DAS effectively controlled emerged grassy, sedges and broad-leaved weeds. Thus, these findings corroborate with the result obtained by Ali (2011) in mungbean.

Spray of quizalofop-ethyl was adequate in plots where grassy weeds were dominated and it failed to control broad-leaved weeds in comparison to imazethapyr. On the contrary, lower seed yield under quizalofop-ethyl could be attributed to its poor weed control efficiency and higher weed index against broad-leaved weeds. Nevertheless, hand weeding at twice recorded significantly lower weed biomass (5.11 g/m^2) and higher weed control efficiency (91.4%) over all other treatments (Table 2). Amongst herbicidal treatments, higher weed control efficiency was observed with imazethapyr 100 g/ha at 30-35 DAS closely followed by the same dose at 20-25 DAS. Similarly, minimum weed index was recorded with imazethapyr 100 g/ha at 30-35 and 20-25 DAS, respectively over rest of the herbicide treatments and weedy check as the treatment effectively controlled both broad-leaved and grassy weeds. Severe crop-weed competition and harsh environment in weedy check condition might have led to reduced yield in weedy check. Similar results were recorded by Nanadan *et al.* (2011) in blackgram. Kumar *et al.* (2014) recorded maximum seed yield in French bean with fluchloralin 1.00 kg/ha and pendimethalin 1.0 kg/ha with a corresponding value 1.11 and 1.10 t/ha. These also increased the nutrient uptake by French bean crop at various crop growth stages over weedy check and other treatments during both the years.

Economics

Higher net return amongst the herbicides treatments in French bean was realized with the application of imazethapyr 100 g/ha at 20-25 DAS (₹ 28869/ha) closely followed by hand weeding twice (₹ 27855) and application of imazthapyr 100 g/ha at 30-35 DAS (₹ 27780). This higher yield was due to effective control of broad-leaved weeds coupled with low cost of application of herbicides (Table 1). Similar economics was also reported by Ram *et al.* (2012). Kumar *et al.* (2014) reported significantly increased in net return over weedy check, with B:C ratio of 1.18 and 1.12 during two years with application of fluchloralin 1.00 kg/ha and pendimethalin 1.00 kg/ha in French bean. However, the minimum values of cultivation cost (₹12554/ha), net return (₹18788/ha) and BCR (1.50) were recorded under weedy check treatment where cost of cultivation could hardly be met up by returns because of loss in yield due to weeds. These results confirm the findings of Srivastava *et al*. (2013) also. It was concluded that that application of imazethapyr 100 g/ha at 20 DAS can be useful for effective and economical weed control in French bean (*Phaseolus vulgaris*).

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REFERENCES

Kumar Amit, Saxena A and Singh PK. 2014. Chemical and mechanical weed management for increased yield of French bean. *Indian Journal of Weed Science* **46**(4): 350–352.

Meena DS, Baldev Ram, Chaman Jadon and Tetarwal JP. 2011. Efficacy of imazethapyr on weed management in soybean. *Indian Journal of Weed Science* **43**: 169-171.

Nandan B, Sharma BC, Anil Kumar and Vikas Sharma. 2011. Efficacy of pre and post- emergence herbicides on weed flora of urdbean under rainfed subtropical Shiwalik foothills of Jammu & Kashmir. *Indian Journal of Weed Science* **43**: 172-174.

Prajapati MP, Patel HA, Prajapati BH and Patel LR. 2004. Studies on nutrient uptake and yield of French bean (*Phaseolus vulgaris* L.) as affected by weed control methods and nitrogen levels. *Legume Research* **27**: 99-102.

Ram Baldev, Punia SS, Meena DS and Tetarwal JP. 2012. Efficacy of post-emergence herbicides on weed control and seed yield of rajmash (*Phaseolous vulgaris* L.). *Journal of Food Legumes* **25**: 306-309.

Sharma GD, Sharma JJ and Sonia Sood. 2004. Evaluation of alachlor, metolachlor and pendimethalin for weed control in rajmash (*Phaseolus vulgaris* L.) in cold desert of North Western Himalayas. *Indian Journal of Weed Science* **36**: 287-289.

Shaukat Ali, Patel JC, Desai LJ and Jitendra Singh. 2011. Effect of herbicides on weeds and yield of rainy season greengram (*Vigna radiata* L. WILCZEK). *Legume Research* **34**: 300-303.

Srivastava AK, Anuj Kumar, Yadav DD and Vishram Singh. 2013. Influence of weed management practices on weed, crop yield and economics of rajmash (*Phaseolus vulgaris* L.) L. *Plant Archives* **13**: 235-238.

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Management of complex weeds in sugarcane by ametryn + trifloxysulfuron

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ABSTRACT

Field experiment was conducted to evaluate the bio-efficacy of ametryn 73.15% + trifloxysulfuron 1.85% W.G for the management of grasses, sedge and broad-leaf weeds in sugarcane. The experiment consisted of nine treatments laid out in randomized block design with three replications. *Cyperus rotundus, Ipomoea* spp, *Brachiaria reptans, Echinochloa colona, Digitaria sanguinalis* and *Dactyloctenium aegyptium* were observed as major weeds. Among herbicide treatments, the lowest density of total weeds was observed with ametryn + trifloxysulfuron at 1500 g/ha though the differences were non-significant when compared with its lower dose *i.e.* 1250 g/ha at 15 and 45 days after application (DAA). Application of ametryn + trifloxysulfuron 1250 and 1500 g/ha recorded significantly lower weed dry weight over any other herbicidal treatment at 15 and 45 days. Highest weed control efficiency of total weeds at both 15 and 45 DAA were recorded with the application of ametryn + trifloxysulfuron 1500 g/ha which was closely followed by 1250 g/ha. The highest cane yields (9.04 t/ha and 10.51 t/ha) were recorded from weed free plot being at par with hand weeding thrice at 30, 60 and 90 DAP.

Key words: Millable cane, Sugarcane, Weed control efficiency, Weed density, Yield

Sugarcane is one of the most important cash crop grown throughout the country. It is tall and relatively strong class of perennial grasses that are known to have a high sugar content. In sugarcane weeds have been estimated to cause 12 to 72% reduction in cane yield depending upon the severity of infestation (Anonymous 2013). Various workers have estimated loss in cane yield due to weeds form 12 to 83% (Kanwar *et al.* 1992 and Sathyavelu *et al.* 2002). Delayed germination, slow initial growth and lateral spread, wide row space and adequate supply of nutrients and moisture in sugarcane provide favorable environment for weed infestation. Sugarcane suffers from weed competitions, which reduces its yield upto 15-75% and even more. It is well known that cultural methods of weed management is most effective to control weeds but timely availability of labours is a problem besides increase in wages. Therefore, chemical control of weeds is considered economical in sugarcane (Kumar *et al.* 2014). Several herbicides have been tried in sugarcane with varying degree of success, but information on combined use of chemical or pre-mix combination of herbicide is scarce. Keeping this in view, the present investigation was undertaken to study the combined use of two chemical in spring planted sugarcane.

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MATERIALS AND METHODS

Field Experiment was conducted during 2012-13 and 2013-14 at N.E. Borlaug Crop Research Centre, GBPUA&T, Pantnagar to evaluate the bio-efficacy of ametryn 73.15% + trifloxysulfuron 1.85% WG for the control of grasses, sedge and broad-leaf weeds in sugarcane. Experiment with nine treatments comprised with three doses of ametryn + trifloxysulfuron 731.5 + 18.5, 914.4 + 23.1 and 1097.2 + 27.7 g/ha and trifloxysulfuron 10 30 g/ha, atrazine 50 WP 1000 g/ha, 2,4-D di-ethyl amine salt 58% SL 3500 g/ha as commercial standards as well as hand weeding thrice at 30, 60 and 90 days after planting (DAP) of sugarcane crop, weed free and weedy check (Table 1) with three replication was laid out in randomized block design.

Three budded sets of sugarcane variety '*Co. Pant 90223*' was planted on March 03, 2012 and March 06, 2013 with recommended package of practices at a row spacing of 75 cm. Herbicides as pre-emergence were applied as spray using 600 liters of water per hectare. Recommended package of practices were followed to raise the crop. Observations on population and dry weight of weeds were taken at 15 and 45 DAA. The data on density (no./m^2) and dry weight (g/m^2) of total grasses, sedges and broad-leaved weeds were taken at 15 and

45 days after application (DAA) of treatments and subjected to log transformation prior to statistical analysis. Yield attributes and yield (t/ha) of sugarcane was recorded at the time of harvesting.

To study the phytotoxic effect of this herbicides on crop, visual rating on the scale of 0 -10 for two treatments of ametryn + trifloxysulfuron *i.e.* 1500 and 3000 g/ha was made and compared with untreated check. The residual effect on succeeding crop (Lentil) was also observed.

RESULTS AND DISCUSSION

Weed flora

The major weeds of experimental field in weedy plots were *Cyperus rotundus*, *Ipomoea* spp., *Brachiaria reptans, Echinochloa colona, Digitaria sanguinalis* and *Dactyloctenium aegyptium*. The other weeds with very low density were *Trianthema monogyna, Digera arvensis, Cloeme viscosa* and *Echinochloa crusgalli.*

Efficacy on density and dry weight of weeds

All the weed control treatments caused significant reduction in the density of total weeds over weedy check during both the years. The highest reduction in the density of total weeds occurred with the execution of three hand weeding at 30, 60 and 90 days after planting (DAP). Among the herbicidal treatments, the lowest density of total weeds were observed with ametryn + trifloxysulfuron 1500 g/ha though the differences were non-significant when compared with its lower dose at 1250 g/ha at 15 and 45 DAA during both the years. Application of ametryn + trifloxysulfuron at all the rates effectively controlled the *C. rotundus* (sedge), *Ipomea* spp., *T. monogyna, D. arvensis* and *C. viscose* (broad-leaf weed) and *Echinochloa* spp., *D. sanguinalis*, *D. aegyptium*, and *B. reptans* (grassy weeds) (Table 1 and 2).

The dry weight of total weeds varied significantly due to weed control measures. All the weed control treatments recorded significantly lower dry weight of total weeds in comparison to weedy check (Table 3). The lowest dry weight of all the weeds were recorded with three hand weeding at 30, 60 and 90 DAP at both the stages. Application of ametryn + trifloxysulfuron1250 and 1500 g/ha recorded significantly lower weed dry weight over any other herbicidal treatment at 15 and 45 days. Mahadevaswamy and Martin (2001) also reported lowest weed population and weed dry matter with pre-emergence weedicides (atrazine /metribuzin/ pendimethalin) followed by hand weeding and hoeing at 45 days after ratoon initiation.

Weed control efficiency

Highest weed control efficiency of total weeds at both 15 and 45 DAA were recorded with the application of ametryn + trifloxysulfuron 1500 g/ha which was closely followed by ametryn + trifloxysulfuron 1250 g/ha. However, the minimum weed control efficiency was recorded with the

Table 1. Density of weeds as influenced by different treatments at 15 DAA

Treatment	*C. rotundus*		*Ipomoea* spp.		*B. reptans*		*E. colona*		*D. sanguinalis*		*D. aegyptium*		Others		Total	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Ametryn + trifloxysulfuron	2.3 (9.3)	2.4 (10.7)	1.0 (2.7)	1.3 (2.7)	2.4 (13.3)	2.7 (13.3)	2.4 (10.7)	1.7 (12.0)	2.5 (12.0)	1.9 (10.7)	1.2 (4.0)	1.8 (5.3)	1.3 (4.0)	1.9 (6.7)	4.0 (56)	4.1 (61.3)
Ametryn + trifloxysulfuron	1.8 (5.3)	1.9 (6.7)	0.0 (0.0)	0.5 (1.3)	1.6 (6.7)	1.8 (5.3)	1.9 (6.7)	1.9 (6.7)	2.1 (8.0)	1.8 (5.3)	0.5 (1.3)	0.5 (1.3)	0.5 (1.3)	1.0 (2.7)	3.0 (29)	3.0 (28.0)
Ametryn + trifloxysulfuron	1.2 (4.0)	1.3 (4.0)	0.0 (0.0)	0.0 (0.0)	1.2 (4.0)	1.0 (2.7)	1.2 (4.0)	1.8 (5.3)	1.2 (4.0)	1.3 (4.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.7 (16)	2.7 (16.0)
Trifloxysulfuron	1.0 (2.7)	0.5 (1.3)	0.0 (0.0)	0.0 (0.0)	2.5 (13.3)	1.7 (12.0)	3.5 (34.7)	3.4 (33.3)	3.1 (24.0)	3.3 (28.0)	0.5 (1.3)	0.0 (0.0)	2.1 (8.0)	1.9 (6.7)	4.4 (84)	4.4 (81.3)
Atrazine	2.4 (25.3)	2.4 (25.3)	1.0 (2.7)	0.5 (1.3)	2.3 (9.3)	1.7 (8.0)	2.3 (9.3)	1.7 (8.0)	1.9 (6.7)	1.9 (6.7)	1.0 (2.7)	0.5 (1.3)	1.8 (5.3)	1.8 (5.3)	4.1 (61)	3.9 (56.0)
2,4-D dimethyl amine salt	1.9 (6.7)	1.7 (8.0)	0.0 (0.0)	0.0 (0.0)	2.4 (10.7)	2.3 (9.3)	3.5 (37.3)	3.6 (34.7)	2.9 (17.3)	2.2 (18.7)	0.5 (1.3)	0.0 (0.0)	1.3 (4.0)	1.0 (2.7)	4.3 (77)	4.3 (73.3)
Hand weeding thrice	1.0 (2.7)	1.8 (5.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.5 (1.3)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	1.3 (4)	1.8 (5.3)
Weed free	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0)	0.0 (0.0)
Untreated check	2.9 (22.7)	2.4 (24.0)	1.9 (6.7)	1.8 (5.3)	1.7 (12.0)	1.9 (10.7)	3.4 (33.3)	3.4 (32.0)	2.9 (22.7)	3.2 (24.0)	2.7 (24.0)	2.9 (22.7)	2.7 (18.7)	3.0 (21)	4.9 (140)	4.9 (140.0)
LSD (P=0.05)	NS	NS	0.9	1.0	1.6	1.5	1.4	1.8	0.8	NS	1.2	1.0	1.2	0.9	0.40	0.4

Figures in parentheses indicate original values which were transformed to $\log_e\ (\sqrt{x+1})$, Doses of treatments are mentioned in Table 3

Table 2. Density of weeds as influenced by different treatments at 45 DAA

Treatment	*C. rotundus*		*Ipomoea* spp.		*B. reptans*		*E. colona*		*D. sanguinalis*		*D. aegyptium*		Others		Total	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Ametryn +	3.6	3.6	0.0	0.0	2.3	2.4	2.1	2.3	2.3	2.4	0.7	1.0	1.8	1.9	4.2	4.4
trifloxysulfuron	(38.7)	(37.3)	(0.0)	(0.0)	(9.3)	(10.7)	(8.0)	(9.3)	(9.3)	(10.7)	(2.7)	(2.7)	(5.3)	(6.7)	(73)	(77)
Ametryn +	2.6	2.3	0.0	0.0	1.9	1.8	1.8	1.2	1.9	1.9	0.5	0.5	1.0	0.0	3.6	3.3
trifloxysulfuron	(21.3)	(25.3)	(0.0)	(0.0)	(6.7)	(5.3)	(5.3)	(4.0)	(6.7)	(6.7)	(1.3)	(1.3)	(2.7)	(0.0)	(44)	(43)
Ametryn +	2.4	2.4	0.0	0.0	1.0	0.0	1.0	0.5	1.2	1.0	0.5	0.0	0.5	0.0	3.2	2.9
Trifloxysulfuron	(13.3)	(14.7)	(0.0)	(0.0)	(2.7)	(0.0)	(2.7)	(1.3)	(4.0)	(2.7)	(1.3)	(0.0)	(1.3)	(0.0)	(24)	(19)
Trifloxysulfuron	2.3	2.4	0.0	0.5	2.3	3.4	3.7	3.6	3.3	3.3	2.1	2.1	1.7	1.8	4.8	4.8
	(9.3)	(10.7)	(0.0)	(1.3)	(24.0)	(33.3)	(41.3)	(38.7)	(33.3)	(28.0)	(8.0)	(8.0)	(5.3)	(5.3)	(117)	(125)
Atrazine	4.2	4.2	0.0	0.0	2.1	2.3	1.9	1.8	1.8	1.9	1.0	1.3	1.2	1.0	4.6	4.6
	(69.3)	(70.7)	(0.0)	(0.0)	(8.0)	(9.3)	(6.7)	(5.3)	(5.3)	(6.7)	(2.7)	(4.0)	(4.0)	(2.7)	(93)	(99)
2,4- D Dimethyl	2.4	3.4	0.0	0.0	2.8	3.4	3.7	3.8	3.5	2.4	1.8	2.0	1.8	1.3	4.9	5.0
amine salt	(25.3)	(33.3)	(0.0)	(0.0)	(22.7)	(30.7)	(42.0)	(44.0)	(32.0)	(25.3)	(5.3)	(6.7)	(5.3)	(4.0)	(131)	(144)
Hand weeding	2.9	2.8	0.0	0.0	0.5	1.0	0.0	0.0	1.0	0.0	0.5	0.0	0.9	2.0	3.2	3.3
thrice	(17.3)	(22.7)	(0.0)	(0.0)	(1.3)	(2.7)	(0.0)	(0.0)	(2.7)	(0.0)	(1.3)	(0.0)	(2.7)	(6.7)	(25)	(32)
Weed free	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0)	(0)
Untreated check	4.0	4.2	2.4	2.7	3.1	3.4	3.7	3.8	3.4	2.9	1.9	2.3	3.3	4.2	5.5	5.6
	(61.3)	(66.7)	(10.7)	(13.3)	(24.0)	(29.3)	(44.0)	(42.7)	(30.7)	(26.7)	(6.7)	(9.3)	(26.7)	(70.7)	(240)	(259)
LSD (P=0.05)	1.9	1.4	0.9	0.5	1.6	0.7	1.36	0.9	0.8	1.5	1.3	1.1	1.3	0.95	0.5	0.5

Figures in parentheses indicate original values which were transformed to $\log_e(\sqrt{x+1})$, Doses of treatments are mentioned in Table 3

Table 3. Dry weight and weed control efficiency as influenced by different treatments

Treatment	Dose		Dry weight (g) 2012				Dry weight (g) 2013			
	g/ha (a.i.)	Product (g or ml/ha)	15 DAA	WCE (%)	45 DAA	WCE (%)	15 DAA	WCE (%)	45 DAA	WCE (%)
Ametryn + trifloxysulfuron	731.5 +18.5	1000 g	4.0 (52.1)	71.6	3.7 (40.1)	79.6	3.9 (51.3)	68.4	3.7 (41.9)	78.4
Ametryn + trifloxysulfuron	914.37+23.12	1250 g	3.4 (29.9)	83.7	2.9 (18.4)	90.6	3.3 (26.7)	83.6	2.9 (18.2)	90.1
Ametryn + trifloxysulfuron	1097.25+27.75	1500 g	2.5 (11.4)	93.8	2.2 (8.2)	95.8	2.2 (8.7)	94.6	2.0 (6.5)	96.6
Trifloxysulfuron	30	300 ml	4.4 (80.7)	56.0	5.0 (144.9)	26.4	4.4 (82.0)	49.6	5.0 (147.2)	24.2
Atrazine	1000	2000 g	4.2 (63.9)	65.2	3.7 (41.2)	79.1	4.2 (65.5)	59.7	3.7 (39.0)	79.9
2,4- D dimethyl amine salt	3500	6034 ml	4.5 (91.7)	50.0	4.9 (139.8)	29.0	4.6 (95.2)	41.4	4.9 (137.8)	29.0
Hand weeding thrice	-	-	1.4 (4.2)	97.7	0.5 (0.7)	99.6	1.3 (3.1)	98.1	0.5 (0.8)	99.6
Weed free	-	-	0.0 (0.0)	100.0	0.0 (0.0)	100.0	0.0 (0.0)	100.0	0.0 (0.0)	100.0
Untreated check	-	-	5.2 (183.6)	00.0	5.3 (196.8)	00.0	5.1 (162.6)	00.0	5.3 (194.2)	00.0

Figures in parentheses indicate original values which were transformed to $\log_e(\sqrt{x+1})$

application of 2,4-D dimethyl amine salt 58% SL 3500 g/ha at both the stages of observations Table 3.

Effect on cane yield

Weeds in untreated weedy plot on an average reduced the cane yield up to 61.8 and 60.5% during 2012 and 2013, respectively, when compared with weed free plot (Table 4). The highest cane yields (9.04 t/ha and 10.51 t/ha) were recorded from weed free plot being at par with hand weeding thrice at 30, 60 and 90 DAP. Singh *et al*. (2011) and Suganthi *et al*. (2013) observed higher cane length number of internodes and cane weight with weed free situations Application of ametryn + trifloxysulfuron 1250 and 1500 g/ha being at par recorded higher cane yield as compared to its lower dose and any other herbicidal treatment. The higher cane yield under these treatments might be due to more cane length and millable cane. The results corroborated with the findings of Chauhan and Srivastava (2002) whorecorded increase in cane yield up to 52% in weed free conditions due to better crop environment. This might be due to effective control of weeds, which provide congenial environment for the crop.

Phytotoxicity and effect on succeeding crop

There were no phytotoxicity symptoms *viz*. stunting, chlorosis, necrosis, epinasty and hyponasty after the application of ametryn + trifloxysulfuron either at 1500 g/ha and 3000 g/ha during the entire crop season.

Table 4. Yield attributing characters and cane yield as influenced by ametryn + trifloxysulfuron

Treatment	Dose		No of millable cane (2 m row length)		Cane length (cm)		Weight/cane (kg)		Cane yield (t/ha)	
	g/ha (a.i.)	Product (g or ml/ha)	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Ametryn + trifloxysulfuron	731.5 +18.5	1000 g	81.1	97.5	180.7	241.1	0.6	1.3	68.3	79.5
Ametryn + trifloxysulfuron	914.37+23.12	1250 g	85.5	99.7	182.9	250.3	0.7	1.4	75.1	87.0
Ametryn + trifloxysulfuron	1097.25+27.75	1500 g	90.0	101.8	186.5	253.7	0.8	1.5	82.3	95.5
Trifloxysulfuron	30	300 ml	89.0	88.8	170.3	235.9	0.4	1.1	51.7	64.5
Atrazine	1000	2000 g	73.3	91.0	171.5	238.9	0.5	1.2	65.9	74.0
2,4- D dimethyl amine salt	3500	6034 ml	66.3	86.2	159.4	234.7	0.3	0.9	50.9	63.5
Hand weeding thrice	-	-	108.7	145.2	187.1	254.3	0.9	1.6	89.8	10.3
Weed free	-	-	111.3	153.8	188.5	255.2	1.0	1.8	90.4	10.5
Untreated check	-	-	55.7	84.5	128.4	233.5	0.2	0.8	34.5	41.5
LSD (P=0.05)			21.8	26.6	30.1	14.0	0.3	0.3	8.0	8.7

The study revealed that none of the doses of ametryn + trifloxysulfuron sprayed on sugarcane crop showed any phytotoxicity symptoms on succeeding (lentil) crop. Per cent germination recorded at 15 days after sowing, plant height and grain yield of lentil crop were also recorded almost similar in all the treatments including untreated check plot during both the years. There was no residual effect of ametryn + trifloxysulfuron found on lentil crop. It was concluded that + trifloxysulfuron 1500 g/ha provide excellent control of weeds and it produced higher yield attributes and cane yield under north Indian conditions.

REFERENCES

Anonymous. 2013. *Status Paper on Sugarcane.* Directorate of Sugarcane Development Govt. of India, Ministry of Agriculture. 8 p.

Chauhan RS and Srivastava SN 2002. Influence of weed management practices on weed growth and yield of sugarcane. *Indian Journal of Weed Science* **34**(3&4): 318-319.

Kanwar RS, Singh S, Sodhi RS and Garcha AIS. 1992. Comparative performance of different herbicide combination for weed control in sugarcane. *Indian Sugar* **42**(8): 621-625.

Mahadevaswamy M and Martin GJ. 2001. Chemical and cultural weed control in ratoon sugarcane. *Madras Agricultural Journal* **88**(10/12): 713-714.

Singh R, Shyam R, Bhatnagar A, Singh VK and Kumar J. 2011. Bio-efficacy of herbicides applied at 2 to 4 leaf stage of weeds in sugarcane after second intercultural. *Indian Journal of Weed Science* **43**(3&4): 145-148.

Sathyavelu A, Somasundaram E, Poonguzhalan R and Rangaraj T. 2002. Integrated weed management in sugarcane. *Indian Sugar* **51**(12): 871-873.

Suganthi M, Muthukrishnan P and Chinnusamy C. 2013. Influence of early post-emergence sulfonylurea herbicides on growth, yield parameters, yield and weed control efficiency in sugarcane. *Journal of Agronomy* **12**(1): 59-63.

Kumar V, Kumar S, Kumar S, Singh O and Kumar V. 2014. Effect of fertility levels and weed management practices on yield potential, nutrient uptake and economics of spring planted sugarcane (*Saccharum officinarum*). *Indian Journal of Agronomy* **59**(1): 139-144.

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Weed management in onion

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ABSTRACT

The experiment involved nine treatments replicated thrice in randomized block design. Significantly lower density and dry matter of weeds were recorded with weed free followed by oxyflurofen 0.30 kg/ha before planting *fb* one hand weeding of 40-60 DATS after transplanting and combined application of oxyflurofen at 0.30 kg/ha before planting + quizalofop-p-ethyl 0.05 kg/ha at 30 days after transplanting. The average bulb weight, plant height, marketable bulb and total bulb yield were also highest in weed free while it was at par to oxyflurofen at 0.30 kg/ha before planting *fb* one hand weeding of 40-60 days after transplanting and oxyflurofen at 0.30 kg/ha + quizalofop-p-ethyl 0.05 kg/ha at before planting and 30 days after transplanting. The maximum B: C ratio of 2.31 was obtained in combined spray of oxyflorfen and quizalofop-p-ethyl at before planting and 30 days after transplanting of crop.

Key words: *Allium cepa*, Onion, Oxyflurofen, Pendimethalin, Quizalofop-p-ethyl

Onion (*Allium cepa* L.) belonging to the family Alliaceae is one of the important bulbous vegetable crop of economic importance and widely cultivated all over the world, with particular distribution in the Asian continent and in Europe. It is mainly used for cuisine and culinary purpose and also preventing coronary heart diseases and other aliments (Sangha and Bariag 2003). Due to its poor competitive ability with its slow initial growth and lack of adequate foliage makes onion weak against weeds. In addition, their cylindrical upright leaves do not shade the soil to block weed growth. Un-controlled weed growth reduces the bulb yield up to 40-80% depending upon the nature of intensity and duration of weed competition in onion field. Hand weeding is a common method of weed control adopted by farmers but comparatively this method is costly and time consuming. Thus use of herbicides is one of the options left with the farmers to eliminate crop weed competition at early growth stage of crop. Therefore, this study was conducted to compare the effectiveness of different control methods of weeds in onion crop.

MATERIALS AND METHODS

Field experiment was conducted to compare various weed management practices in onion at Tirhut College of Agriculture, Dholi, Muzafferpur during consecutive three *Rabi* season from year 2009 to 2012. The soil of experimental site was sandy loam in texture, alkaline in reaction (pH:8.51), low in available N (219 kg/ha), available P (14.63 kg/ha), available K (109 kg/ha) and low in organic carbon content (0.43).The experiment with nine treatments was laid out in randomized block design in three replications (Table 1). Onion var. '*Agrifound light red*' (52 days old seedling) was transplanted at a spacing of 20 x 10 cm apart on December 14, 17 and 19 during 2009, 2010 and 2011, respectively. Well decomposed FYM 10 t/ha was applied uniformly at the time of field preparation and crop was fertilized with 100:80:80 kg NPK/ha. All the herbicides were applied at standard time of their application by using a Maruti foot sprayer fitted with flat fan nozzle with spray volume of 700 liter water/ha. Observations on density of weeds and their dry weight were taken at 90 DAT stage of onion crop. The crop was harvested on April 28, May 01 and May 02 in the year 2010, 2011 and 2012, respectively. The bulbs were harvested from net plot and yield was recorded after grading. The data on density and dry weight of grassy weeds were subjected to square root transformation *i.e.* $\sqrt{x + 0.5}$ prior to statistical analysis.

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RESULTS AND DISCUSSION

Effect on weeds

The field were infested with *Phalaris minor* among grasses, *Chenopodium album, Melilotus alba, M. indica, Parthenium hysterophorus, Anagallis arvensis, Physalis minima* among broad-leaved weeds and *Cyperus rotundus* in sedges during all the years.

All the weed control treatments resulted significant reduction in total weed density and dry matter accumulation in comparison to weedy check (Table 1). Oxyfluorfen 0.30 kg/ha *fb* one hand weeding, oxyfluorfen 0.30 kg + quizalofop-p-ethyl 0.05 kg/ha, pendimethalin + quizalofop-p-ethyl (1.0 + 0.05 kg/ha) and oxyfluorfen 0.30 kg/ha *fb* quizalofop-p-ethyl 0.05 kg/ha were statistically at par with each other in reducing weed density at 90 DAT. The similar trends were also found in total weed dry matter except oxyfluorfen at 0.30 kg/ha *fb* quizalofop-p-ethyl 0.05 kg/ha, which recorded significantly higher weed biomass than others. These findings were in confirmation with Kumar and Mourya (2006) and Kumar *et al.* (2014). The result on weed control efficiency (WCE) showed variability among different weed management schedules in onion. The WCE of different herbicide treatment varied from 39% (pendimethalin alone) to 57.4% (oxyflorfen *fb* one hand weeding). Maximum WCE was recorded in weed free followed by oxyflorfen *fb* one hand weeding at 40-60 DAT (57.5%) and oxyfluorfen + quizalofop-p-ethyl (56.1%). Low weed index in oxyflorfen *fb* one hand weeding at 40-60 DAT and oxyfluorfen + quizalofop-p-ethyl indicated that competition due to weeds was lowest in these treatments as compared to others. Similar results were also reported by Sinare *et al.* (2014).

Effect on crop

The vegetative growth and yield contributing character were varied significantly owing to different weed control treatments (Table 2). The significantly highest plant height (60.27 cm) and average weight of bulb (70.54 g) was obtained with weed free and it was non-comparable to oxyflorfen *fb* one hand weeding at 40-60 DAT but statistically superior to all other treatments. The average bulb weight in onion varied from 49.99 g (weedy check) to 70.54 g (weed free) with a mean value of 60.89 g. Among the herbicide, heaviest bulb weight (68.76 g) was recorded in oxyflorfen *fb* one HW at 45 DAT, which was also at par to oxyflurofen + quizalofop-p-ethyl. The highest no. of leaves was also recorded in oxyflorfen + quizalofop-p-ethyl, which was similar to other weed control treatments except alone treatments of oxyflorfen and pendimethalin. The variability in growth and yield parameter are due to effectiveness of weed control methods which ultimately increased the nutrient availability for the crop (Marwat *et al.* 2003).

Weeds in weedy check reduced the onion total bulb yield by 32.7% over weed free (Table 2). Among the weed control treatments, weed free recorded the highest marketable bulb yield (35.65 t/ha), which was statistically similar to oxyflourfen + one hand weeding (36.20 t/ha) and oxyfluorfen + quizalofop -p-ethyl, but significantly differed from all other treatment. The trend was also same with total bulb yield of onion. The findings was in close proximation to Dudi *et al.* (2011) and Chattopadhyay *et al.* (2011). Follow up application of oxyfluorfen and pendimethalin with quizalofop-p-ethyl resulted increase in marketable and total bulb yield of onion than its alone application at before planting and 30 DAT but all these were at par to each other. Weed dry matter also showed negatively correlated with marketable and total bulb yield (r = -0.88 and r= -0.90) and accounted for 77 and 80% variation, respectively due to different weed control

Table1. Effect of different weed control treatments on weed density, weed dry matter, weed control efficiency and weed index in onion (pool data of three year)

Treatment	Total weed density (no./m^2)	Total weed dry matter (g/m^2)	Weed control efficiency (%)	Weed index (%)
Oxyflurofen 0.30 kg/ha before planting and 30 DAT	5.75 (32.6)	9.08 (82.3)	41.2	28.1
Oxyflurofen *fb* quizalofop-p-ethyl 0.30 *fb* 0.05 kg/ha before planting and 30 DAT	5.54 (30.3)	8.93 (79.3)	43.3	18.2
Oxyflurofen + quizalofop-p-ethyl 0.30+0.05 kg/ha at planting and 30 DAT	4.95 (24.0)	7.85 (61.4)	56.1	9.4
Pendimethalin 1.0 kg/ha before planting and 30 DAT	5.73 (32.3)	9.24 (85.3)	39.0	28.0
Pendimethalin *fb* quizalofop-p-ethyl 1.0 *fb* 0.05 kg/ha before planting and 30 DAT	5.60 (30.8)	8.99 (80.4)	42.6	18.8
Pendimethalin + quizalofop-p-ethyl 1.0 + 0.05 kg/ha at planting and 30 DAT	5.45 (28.9)	8.64 (74.2)	47.0	14.4
Recommended practices (oxyflurofen *fb* one hand weeding) 0.30 kg/ha before planting and 40-60 DAT	4.87 (23.3)	7.70 (59.5)	57.5	6.6
Weed free	0.0 (0.0)	0.0 (0.0)	100.0	0.0
Weedy check	7.79 (60.6)	11.84(139.9)	0.0	32.7
LSD (P=0.05)	0.69	0.98	-	-

Figure given in parentheses indicate actual values, *fb*= followed by

Table 2. Effect of weed management practices on vegetative growth, average weight and bulb yield of onion (pool data of three year)

Treatment	Plant height (cm)	Number of leaves	Average weight of bulb (g)	Marketable bulb yield (t/ha)	Total bulb yield (t/ha)	B:C ratio
Oxyflurofen 0.30 kg/ha before planting and 30 DAT	54.4	6.2	54.2	25.97	26.02	2.03
Oxyflurofen *fb* quizalofop-p-ethyl 0.30 *fb* 0.05 kg/ha before planting and 30 DAT	54.5	7.0	60.0	28.34	29.60	2.20
Oxyflurofen + quizalofop-p-ethyl (0.30 + 0.05) kg/ha at planting and 30 DAT	56.7	8.7	65.7	32.12	32.80	2.31
Pendimethalin 1.0 kg/ha before planting and 30 DAT	51.3	6.9	55.5	25.04	26.05	1.99
Pendimethalin *fb* quizalofop-p-ethyl (1.0 *fb* 0.05) kg/ha before planting and 30 DAT	53.5	8.3	59.4	28.51	29.38	2.10
Pendimethalin + quizalofop-p-ethyl 1.0 + 0.05 kg/ha at planting and 30 DAT	55.2	7.2	64.9	30.19	30.98	2.24
DOGR Recommended practices (oxyflurofen *fb* one hand weeding) 0.30 kg/ha before planting and 40-60 DAT	58.5	7.3	68.8	32.83	33.80	2.30
Weed free	60.3	7.8	70.5	35.65	36.20	2.29
Weedy check	47.4	5.1	50.0	23.48	24.35	1.27
LSD (P=0.05)	3.4	1.6	3.1	3.97	3.68	-

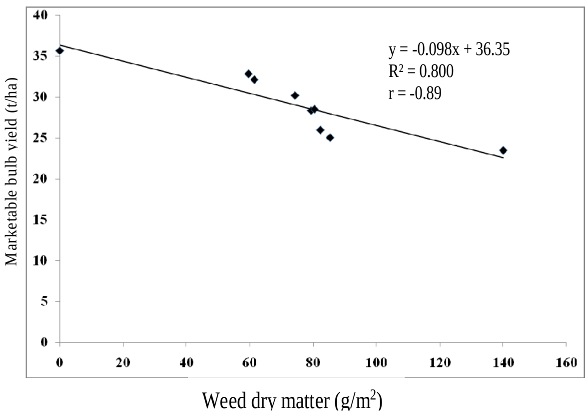

Fig. 1. Correlation between marketable bulb yield and weed dry matter

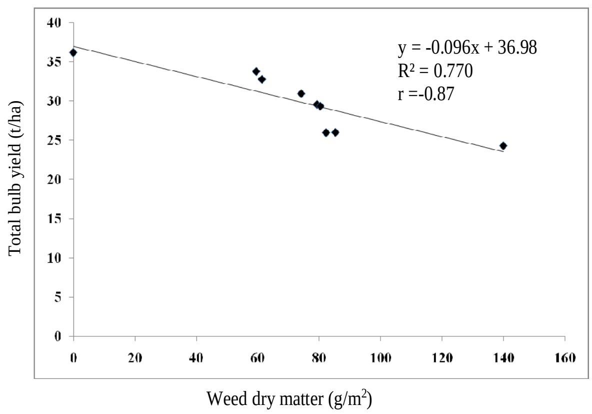

Fig. 2. Correlation between total bulb yield and weed dry matter

treatments (Fig. 1 and 2). The B:C ratio estimated in different weed management practices indicated that maximum B:C ratio of 2.31 in oxyflorfen + quizalofop-p-ethyl which was very close to oxyflorfen *fb* one hand weeding at 40-60 DAT (2.30) and weed free (2.29).

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REFERENCES

Chattopadhyay S, Mahalanabish S, Bhuina P, Santra P and Maity TK. 2011. Bio-efficacy of herbicides in onion. pp. 256-257. In: *Alliums: Current Scenario and Emerging trends*, National symposium, 12-14th March, 2011, Pune.

Dudi BS, Dhankar SK and Singh J. 2011. Effect of weed management practices on yield and its component in onion, pp. 254-255. In: *Alliums: Current Scenario and Emerging trends*, National symposium 12-14th March, 2011, Pune.

Kumar U, Prasad B and Chandra G. 2014. Effect of different herbicides on growth, yield and weed flora of onion (*Allium cepa* L.). *Journal of Hill Agriculture* **5**(2): 207-210.

Kumar Naresh and Mourya IB. 2006. Effect of different herbicides on growth and efficacy for weed control in onion (*Allium cepa* L.) seed crop. *Annals of Agricultural Research* **27**: 245-49.

Sangha JK and Bariag P. 2003. Efficacy of multiple dietary therapies in reducing risk factor for coroner heart disease. *Journal of Human Ecology* **14**: 33-36.

Sinare RT, Andhale RP and Gautam M. 2014. Weed control in onion with herbicides. *Indian Journal of Weed Science* **46**(2): 192-194.

Tripathy P, Sahoo BB, Patel D and Dash DK. 2013. Weed management studies in onion (*Allium cepa* L.) *Journal of Crop and Weed* **9**(2): 210-212.

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Weed control in clusterbean through post-emergence herbicides

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ABSTRACT

Field experiment was conducted at Bikaner for two consecutive years during *Kharif* seasons of 2012 and 2013 to test the efficacy of different weed control measures against weeds in clusterbean *Cyamopsis tetragonoloba* (L.) Taub. The experiment consisting of seven treatments, *viz*. imazethapyr 40 g/ha, quizalofop-ethyl 37.5 g/ha, fenoxaprop-p-ethyl 50 g/ha, imazethapyr + imazamox 40 g/ha, pendimethalin 0.75 kg/ha as pre-emergence (PE), hand weeding twice at 20 and 40 DAS and weedy check. Among herbicids, post-emergence application of imazethapyr + imazamox (ready mix) 40 g/ha applied at 3-4 leaf stage (around 20 DAS) recorded lowest weed density and dry weight of both grassy and broad-leaved weeds with maximum weed control efficiency (88.1%). Application of imazethapyr alone at 40 g/ha applied at 3-4 leaf stage (around 20 DAS) significantly reduced the density and dry weight of broad-leaved weeds but not effective significantly against grassy weeds. Yield attributes *i.e* pods/plant, seed and straw yields, net return and B: C ratio were also superior with imazethapyr + imazamox 40 g/ha applied at 3-4 leaf stage (around 20DAS).

Key words: Clusterbean, imazethapyr, imazethapyr + imazamox, post-emergence herbicidal control, Weed control efficiency

Clusterbean *Cyamopsis tetragonoloba* (L.) Taub. locally known as guar, is an important drought hardy leguminous crop. Guar is basically a crop that is cultivated mostly in the arid and semiarid areas. Its seeds contain 28-33% gum. Clusterbean is mainly cultivated in marginal and rain fed areas where inadequate weed management is a major constraint in harnessing its production potential. Being a rainy season crop, it suffers badly due to severe competition by mixed weed flora. Yield reduction due to weed infestation is of the tune of 53.7% (Saxena *et al.* 2004).

Hand weeding is a traditional and effective method of weed control, but untimely rains, unavailability of labour at peak time and increasing labour cost are the main limitations of manual weeding. Under such situations, the only alternative that needs to be explored is the use of suitable herbicide, which may be effective and economically viable. Application of fluchloralin and pendimethalin at 0.75-1.0 kg/ha as pre-emergence were effective against weeds in clusterbean (Dhaker *et al.* 2009) but inadequate moisture and westerly winds blowing at time of sowing in this region left little moister for soil applied herbicide to act effectively, which resulted poor efficiency of these herbicides in most of the time in arid zone soils (Punia *et al.* 2011). To overcome the problem, post-emergence herbicides for pulses and leguminous crops were tried at the critical period of crop weed competition at 20-30 DAS (Yadav 1998) of clusterbean. With these points in view, the present investigation aims to test the efficacy of early post-emergence herbicides in cluster bean.

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MATERIALS AND METHODS

Field experiment was carried out for two consecutive years during *Kharif* seasons of 2012 and 2013 at SK Rajasthan Agricultural University Farm, Bikaner to test the efficacy of different weed control measures against weeds. There were seven treatments consisting of imazethapyr 40 g/ha, quizalofop ethyl 37.5 g/ha, fenoxaprop-p-ethyl 50 g/ ha, imazethapyr + imazamox 40 g/ha, pendimethalin 0.75 kg/ha as pre-emergence (PE), hand weeding twice at 20 and 40 DAS and weedy check. The treatments were arranged in randomized block design (RBD) with three replications.

The soil of the experimental field was loamy sand with low in organic carbon (0.08%) and available N (78 kg/ha), medium in available P (22 kg/ ha) and available K (210 kg/ha) with pH 8.2. Cluster bean variety '*RGC-1066*' was sown on 18 July 2012 and 20 July 2013 with crop geometry of 30 x 10 cm with recommended package of practices. The pre-sowing irrigation was given for sowing the crop during both the years. The total rainfall during the season was 174.8 mm in 2012 and 202.6 mm in 2013. There was a stress period of about 28 days during 2012 and 25 days in 2013 season. Fertilizers were applied uniformly through urea and DAP at 20 kg N and 40 kg P_2O_5/ha. Above ground weed biomass was sampled at 60 DAS using a quadrant of 0.5 x 0.5 m. Plant material was dried at 65°C for 48 h before determining dry weight. Standard methods were followed for weed, crop and economics analysis.

RESULTS AND DISCUSSION

Effect on weed

The major weed flora in experimental field consisted of *Amaranthus viridis, Gisekia poiedious, Digera arvensis, Portulaca olerecea, Trianthema portulacastrum* among broad-leaved weeds and *Cenchrus biflorus, Eragrostis pilosa* and *Eragrostis tanella* among grassy weeds.

Imazethapyr + imazamox (ready mix) 40 g/ha, imazethapyr alone at 40 g/ha applied at 3-4 leaf stage (around 20 DAS) and pendimethalin at 0.75 kg/ha as pre-emergence significantly reduced the density and dry weight of broad-leaved weeds in clusterbean as compared to weedy check and other herbicidal treatments during both the years (Table 1 and 2). Punia *et al.* (2011) also reported better control of weeds in clusterbean by imazethapyr. Further, imazethapyr + imazamox (ready mix) at 40 g/ha and imazethapyr alone at 40 g/ha applied at 3-4 leaf stage (around 20 DAS) significantly lower down the density and dry weight of broad- leaved weeds as compared to pendimethalin at 0.75 kg/ha during 2012. However, during 2013 pendimethalin at 0.75 kg/ha reduced broad-leaved weeds significantly as compared to imazethapyr at 40 g/ha but statistically at par with imazethapyr + imazamox at 40 g/ha. The pooled data of two years revealed that imazethapyr + imazamox at 40 g/ha recorded significantly lower density and dry weight of total weeds as compare to all other herbicidal treatments except pendimethalin at 0.75 kg/ha as pre-emergence. Quizalofop-ethyl 37.5 g/ha and fenoxaprop-p-ethyl 50 g/ha at 3-4 leaf stage failed to control density and dry weight of broad-leaved weeds. As far as grassy weeds were concerned, imazethapyr + imazamox 40 g/ha, quizalofop-ethyl 37.5 g/ha and fenoxaprop-ethyl 50 g/ha significantly controlled the grassy weeds as compared to weedy check, imazethapyr alone at 40 g/ha but statistically at par with pendimethalin at 0.75 kg/ha as pre-emergence during both the years and pooled basis. Mundra and Maliwal (2012) and Nandan *et al.* (2011) also revealed that quazalfop-ethyl 37.5 g/ha and fenoxaprop-ethyl 50 g/ha effectively controlled grassy weeds but poorly managed the broad leaved weeds in blackgram and greengram, respectively. Density of grassy weeds was lower than broad-leaved weeds in the experiment.

Poor performance of pendimethalin at 0.75 kg/ha during 2012 in controlling weeds was due to hot Westerly winds blowing just after sowing of crop which reduced the upper layer moisture of the soil thus reduced the efficacy of the pendimethalin, however, in 2013 continuous rains for 3 days after sowing of clusterbean was recorded with commencement of monsoon in the region and therefore, moisture remained in the upper layer of the soil during germination phase which increased the

Table 1. Effect of weed control measures on weed density in clusterbean

Treatment	Weed density (no./m^2)								
	2012			2013			Pooled		
	Broad-leaved	Grassy	Total	Broad-leaved	Grassy	Total	Broad-leaved	Grassy	Total
Imazethapyr 40 g/ha (at 3-4 leaf stage)	1.90 (*2.7)	2.73 (6.50)	3.20 (9.25)	3.42 (10.4)	5.38 (27.9)	6.27 (38.30)	3.75 (13.11)	5.95 (34.4)	6.97 (47.5)
Quizalofop-ethyl 37.5 g/ha (at 3-4 leaf stage)	4.36 (18.2)	1.49 (1.25)	4.53 (19.5)	5.50 (29.2)	1.71 (1.9)	5.66 (31.10)	6.95 (47.4)	2.02 (3.1)	7.17 (50.5)
Fenoxaprop-p-ethyl 50 g/ha (at 3-4 leaf stage)	4.15 (16.2)	1.47 (1.25)	4.30 (17.5)	5.89 (33.7)	1.75 (2.1)	6.06 (35.80)	7.13 (49.9)	2.07 (3.3)	7.36 (53.2)
Imazethapyr + imazamox 40 g/ha (at 3-4 leaf stage)	2.16 (4.2)	2.28 (4.25)	3.10 (8.5)	2.34 (4.5)	2.95 (7.7)	3.63 (12.20)	3.11 (8.7)	3.59 (11.9)	4.65 (20.6)
Pendimethalin 0.75 kg/ha as pre-emergence	3.54 (12.0)	1.96 (3.00)	4.0 (15)	2.63 (5.9)	2.27 (4.1)	3.31 (10.00)	4.35 (17.9)	2.84 (7.1)	5.10 (25.0)
Hand weeding at 25 and 40 DAS	2.08 (3.7)	1.31 (0.75)	2.34 (4.5)	1.65 (1.72)	2.03 (3.1)	2.41 (4.82)	2.55 (5.55)	2.19 (3.8)	3.21 (9.3)
Weedy check	4.55 (19.7)	3.15 (9.00)	5.43 (28.7)	8.59 (72.8)	5.76 (32.2)	10.5 (105.00)	9.67 (92.5)	6.50 (41.2)	11.61 (133.7)
LSD (P=0.05)	0.96	0.39	0.66	0.75	0.65	0.61	0.71	0.44	0.97

*Original values are in parentheses, PE- Pre-emergence, DAS- Day after sowing

Table 2. Effect of weed control measures on weed dry weight in clusterbean

Treatment	Weed dry weight (g/m^2)									Weed control efficiency (%)		
	2012			2013			Pooled					
	Broad-leaved	Grassy	Total	Broad-leaved	Grassy	Total	Broad-leaved	Grassy	Total	Broad-leaved	Grassy	Total
Imazethapyr 40 g/ha at 3-4 leaf stage	1.68	4.42	6.12	13.4	9.98	23.4	15.1	14.4	29.5	85.2	14.4	75.2
Quizalofop-ethyl 37.5 g/ha at 3-4 leaf stage	20.55	0.22	20.75	77.5	1.10	78.7	98.1	1.3	99.4	4.22	92.3	16.6
Fenoxaprop-p-ethyl 50 g/ha at 3-4 leaf stage	18.82	0.25	19.14	69.5	1.60	71.1	88.3	1.83	90.1	13.7	89.0	24.4
Imazethapyr + imazamox 40 g/ha at 3-4 leaf stage	0.62	1.80	2.45	9.32	2.55	11.8	9.9	4.35	14.2	90.3	74.1	88.1
Pendimethalin 0.75 kg/ha as PE	5.380	2.08	7.45	7.4	1.75	9.1	12.8	3.83	16.6	87.4	77.2	86.4
Hand weeding at 25 and 40 DAS	0.92	0.38	1.36	2.3	1.20	3.50	3.25	1.53	4.82	96.8	90.9	95.9
Weedy check	18.08	6.20	24.3	84.3	10.6	94.9	102.4	16.83	119.2	0.00	0.00	0.00
LSD at (0.05)	0.49	0.16	O.61	15.9	1.31	78.6	20.2	2.46	23.8	-	-	-

Table 3. Effect of weed control measures on yield attributes and yield of clusterbean

Treatment	Plant height (cm)			Pods/plant			Seed index (g)			Seed yield (t/ha)			Straw yield (t/ha)		
	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean	2012	2013	Mean
Imazethapyr 40 g/ha at 3-4 leaf stage	99.5	108.2	103.8	64.2	57.0	60.6	3.4	3.6	3.5	0.93	1.19	1.06	3.43	1.85	2.64
Quizalofop-ethyl 37.5 g/ha at 3-4 leaf stage	85.5	103.5	94.5	48.7	37.2	42.9	3.4	3.4	3.3	0.41	0.74	0.57	1.96	1.15	1.56
Fenoxaprop-p-ethyl 50 g/ha(at 3-4 leaf stage	76.5	103.5	90.0	45.2	43.2	44.2	3.4	3.4	3.3	0.48	0.86	0.67	2.11	1.33	1.72
Imazethapyr + imazamox 40 g/ha at 3-4 leaf stage	98.5	108.2	103.3	67.7	59.0	63.3	3.5	3.8	3.6	1.12	1.37	1.24	3.40	2.12	2.76
Pendimethalin 0.75 kg/ha PE	85.7	95.8	90.7	53.0	54.0	53.5	3.4	3.4	3.3	0.72	1.47	1.10	2.92	2.28	2.60
Hand weeding at 25 and 40 DAS	107.0	107.0	107	66.7	61.0	63.8	3.5	3.5	3.5	0.83	1.44	1.13	3.39	2.24	2.81
Weedy check	73.7	88.7	81.2	47.7	33.5	40.6	3.4	3.6	3.5	0.41	0.80	0.60	1.65	1.23	1.44
LSD a(P=0.05)	8.8	11.5	7.4	5.4	13.0	2.8	NS	NS	NS	0.16	0.34	0.14	0.76	0.53	0.46

efficacy of pendimethalin. Sireesha *et al.* (2011) reported that performance of pendimethalin depends upon the moister in the soil.

Effect on crop

Application of imazethapyr + imazamox at 40 g/ha and imazethapyr alone at 40 g/ha at 20 DAS (3-4 leaf stage) and pendimathalin 0.75 kg/ha as PE significantly increased the plant height and pods/plant and consequently seed and straw yield of cluster bean compared to weedy check and quizalofop-ethyl 37.5 g/ha and fenoxaprop-p-ethyl 50 g/ha at 3-4 leaf stage (around 20 DAS) but statistically at par with two hand weeding during both the years and pooled basis (Table 3). The results were in closed conformity with the finding of Yadav *et al.* (2011). Imazethapyr + imazamox 40 g/ha produced maximum and significantly higher yield attributes (pods/plant) and seed and straw yield of clusterbean as compared to imazethapyr 40 g/ha and pendimathalin 0.75 kg/ha during 2012, while it was statistically at par with pendimathalin 0.75 kg/ha in 2013, however, on pooled basis, imazethapyr + imazamox 40 g/ha at 20 DAS significantly increased the seed yield of cluster bean compared to other herbicides but it was statistically at par with two hand weeding. This might be due to the fact that imazethapyr + imazamox 40 g/ha significantly controlled both broad-leaved and grassy weeds while imazethapyr alone at 40 g/ha controlled only broad-leaved and not of grassy weeds and consequently produced significantly lower yield attributes particularly of pods/plant (Table 1,2 and 3). The performance of pendimathalin 0.75 kg/ha was not consistent as it was not able to control weeds during 2012 (Table 1 and 2). Mundra and Maliwal (2012) also reported poor control of weeds in black gram by pendimethalin in rainfed areas. Significantly lower seed and straw yields were also obtained in the plots applied with quizalofop-ethyl at 37.5 g/ha and fenoxaprop-p-ethyl 50 g/ha at 3-4 leaf stage as these herbicides were able to reduce density and dry weight of grassy weeds only but as earlier state broad-leaved weeds dominated the experimental fields during both the years. Nandan *et al.* (2011) also reported similar results in blackgram.

Table 4. Effect of weed control measures on economics of cluster bean

Treatment	Net returns (x10^3 `/ha)			B:C ratio		
	2012	2013	Mean	2012	2013	Mean
Imazethapyr 40 g/ha at 3-4 leaf stage	30.99	39.87	35.43	2.81	3.33	3.07
Quizalofop-ethyl 37.5 g/ha at 3-4 leaf stage	4.15	17.85	11.00	1.24	2.01	1.62
Fenoxaprop-p-ethyl 50 g/ha at 3-4 leaf stage	7.64	23.38	15.51	1.43	2.32	1.87
Imazethapyr + imazamox 40 g/ha at 3-4 leaf stage	39.05	48.07	43.56	3.26	3.78	3.52
Pendimethalin 0.75 kg/ha as pre-mergence	19.58	52.21	35.89	2.09	3.90	2.99
Hand weeding at 25 and 40 DAS	23.60	49.35	36.47	2.21	3.53	2.87
Weedy check	4.70	21.48	13.09	1.28	2.30	1.79

Economics

The net returns and benefit: cost ratio were maximum for imazethapyr + imazamox at 40 g/ha during both the years and on pooled basis (Table 4). It was followed by imazethapyr 40 g/ha applied at 20 DAS with B:C ratio of 3.07 and pendimethalin with B:C ratio of 2.99 on pooled basis.

It was concluded that application of imazethapyr + imazamox (ready mix) 40 g/ha at 20 DAS (3-4 leaf stage) was more effective in controlling both broad-leaved and grassy weeds, increasing seed yield and economically feasible in cluster bean in arid regions. Other herbicide imazethapyr 40 g/ha applied at 20 DAS was also effective where broad-leaved were more dominated.

REFERENCES

Dhaker H, SL Mundra and NK Jain. 2009. Weed management in cluster bean [*Cyamopsis tetragonoloba* (L.)]. *Indian Journal of Weed Science* **41**: 224-227.

Mundra SL and PL Maliwal. 2012. Influence of quizalofop-ethyl on narrow-leaved weeds in black gram and its residual effect on succeeding crops. *Indian Journal of Weed Science* **44**: 231-234.

Nandan B, Sharma BC, Kumar Anil and Vikas Sharma. 2011. Efficacy of pre- and post-emergence herbicides on weed flora of urd bean under rainfed subtropical Shiwalik foothills of Jammu and Kashmir. *Indian Journal of Weed Science* **43**: 172-174.

Punia SS, Singh Samunder and Yadav Dharambir. 2011. Bioefficacy of imazethapyr and chlorimuron-ethyl in cluster bean and their residual effect on succeeding rabi crops. *Indian Journal of Weed Science* **43**(1&2):48-53.

Saxena A, Singh YV and Singh RC. 2004. Crop weed competition in cluster bean in arid region. *Journal of Arid Legume* **1**: 41-43.

Sireesha A, Rao PC, Swapna G and Ramalakshmi S. 2011. Persistence of pendimethalin and oxyyflourfen at different temperature and moisture levels in an alfisol and vertisol. *Indian Journal of Weed Science* **43**: 181-187.

Yadav RS. 1998. Effect of weed removal in cluster bean (*Cyamopsis tetragonoloba*) under different rain fall situations in an arid region. *Journal of Agronomy and Crop Science* **181**: 209-214.

Yadav SL, Kaushik MK and Mundra SL. 2011. Effect of weed control practices on weed dry weight, nutrient uptake and yield of cluster bean [*Cyamopsis tetragonoloba* (L.)] under rainfed condition. *Indian Journal of Weed Science* **43**: 81-84.

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Exotic rust fungus to manage the invasive mile-a-minute weed in India: Pre-release evaluation and status of establishment in the field

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ABSTRACT

The mile-a-minute weed, *Mikania micrantha*, is a highly problematic and widespread invasive weed in the moist forests of the Western Ghats and in the north-eastern states in India causing significant damage to natural forests as well as to plantation crops, including tea, coffee, bamboo, coconut and teak. The microcyclic rust fungus, *Puccinia spegazzinii*, was identified as a potential classical biological control agent to replace the unsustainable or even hazardous conventional control methods. Following a successful risk analysis under quarantine at CABI (UK), a pathotype of the fungus (IMI 393067) from Trinidad and Tobago was imported into India. Prior to its release in the open field, the rust was further evaluated under strict quarantine conditions to ascertain the susceptibility of *M. micrantha* populations from three regions in India where the weed is invasive, and to confirm the safety of economically important plant species and indigenous flora. Results of host-specificity screening of 90 plant species belonging to 32 families ensured that the Trinidadian pathotype of *P. spegazzinii* was highly host-specific and could not infect any of the test plant species, though it was highly pathogenic to most of the target weed populations from Assam, Kerala and the Andaman and Nicobar Islands. The rust was released in Assam and Kerala but failed to establish at the time. However, due to the apparent success of this rust at controlling *M. micrantha* in the Pacific region, further releases in India are recommended.

Key words: Classical biological control, host-specificity, *Mikania micrantha*, *Puccinia spegazzinii*

The mile-a-minute weed, *Mikania micrantha* H.B.K. (Asteraceae), is a Neotropical invasive plant that smothers native vegetation in the tropical moist agroforests and natural forests of India, especially in Kerala and in the north-eastern states. The weed has also become a destructive factor in plantation crops causing significant damages to tea, coffee, banana, bamboo, coconut and teak in the areas with high soil moisture. It is also of major concern in the Andaman and Nicobar Islands, and in the eastern states of Odisha and West Bengal. Contemporary control methods which involve weeding and use of herbicides are laborious, expensive, unsustainable and hazardous to the environment. Also, in moist deciduous forests, the infestation by *M. micrantha* is on the increase, which makes harvesting by tribals of reeds, bamboo and other non-wood forest products difficult, affecting their livelihood (Sankaran *et al.* 2001). In north-eastern India, the main impact is on tea production, where unusually this crop is grown at low altitudes, within the invasive range of the weed.

Socio-economic studies conducted on home-garden farming systems in the Western Ghats region showed that *M. micrantha* has an impact on production costs and income of all sizes of holdings (Sankaran *et al.* 2001). In general, weeds form the greatest constraint to cultivation, and *M. micrantha* accounted for 10-20% of the total weeding costs.

M. micrantha is also a serious issue in several other countries, especially in the Asia-Pacific region (Waterhouse 1994). The first classical biological control (CBC) attempt for this weed was through the release of *Liothrips mikaniae* (Priesner) (Thysanoptera: Phlaeothripidae) in the Solomon Islands in 1988 and later in Malaysia in 1990. Unfortunately, neither release led to establishment most likely because of predation by ants of the nymphal stage of the agent (Cock *et al.* 2000).

During 1996-2000, an international collaborative project was funded by the UK Department for International Development (DFID) to investigate the

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CBC potential of fungal pathogens against *M. micrantha* in India and a microcyclic rust fungus *Puccinia spegazzinii* de Toni (Evans and Ellison 2005) was identified as a potential CBC agent (Murphy *et al.* 2000). CABI screened 11 pathotypes of *P. spegazzinii* from different origins and IMI 393067 from Trinidad was found to be promising against the Indian populations of *M. micrantha* (Ellison *et al.* 2004). After initial screening of 60 plant species, including 11 *Mikania* spp. from Brazil, Colombia, Costa Rica, Peru, Ghana, South Africa and the one Asian native species from Taiwan (not present in India), the Trinidadian pathotype was found to be specific to a very limited number of species within the genus *Mikania* (Ellison *et al.* 2008). A dossier (Ellison and Murphy 2001) on this risk assessment was submitted to the Government of India to obtain permission for introduction of the rust into India.

P. spegazzinii (pathotype IMI 393067) was imported into India in the implementation phase of the project, which was a collaborative venture between CABI (UK) and four institutes in India: Project Directorate of Biological Control (now NBAIR) and National Bureau of Plant Genetic Resources (NBPGR, New Delhi); Kerala Forest Research Institute (KFRI, Peechi); and Assam Agricultural University (AAU, Jorhat). Since *P. spegazzinii* was not known to occur in India (CABI 2006), before the rust inoculum was released in the open field, it was further evaluated under strict quarantine conditions to ensure the safety of indigenous flora against the introduced fungus (Ellison *et al.* 2008).

MATERIALS AND METHODS

Importation, establishment and maintenance of rust in quarantine

M. micrantha plants (Peechi, Kerala population) inoculated at CABI with the Trinidadian pathotype (IMI 393067) of *P. spegazzinii* were imported into India (vide Permit No. 33/2004 in PQ Form 13; date of issue: 3 August 2004) on 2 September 2004 and established under strict quarantine conditions in the CL-4 level National Containment-cum-Quarantine Facility (NCQF) for Transgenic Planting Material of NBPGR in New Delhi. The pathogen was passed several times through *M. micrantha* (Thrissur, Kerala, population), established, and maintained without hyperparasites by re-inoculation, approximately every six weeks, onto fresh plants which were given a standard 24-hour dew period. All the used-up inoculum, as well as the inoculated test plants, was autoclaved and incinerated after the mandatory experimental period. Other used materials such as protective clothing, etc. were also destroyed in a similar manner. Used soil was autoclaved before discarding.

Target weed

Populations of *M. micrantha* in the form of young seedlings or cuttings were obtained from three different regions in India (Table 1). These comprised five populations collected from Chimmoni, Peechi, Shoranur, Thrissur and Vazhachal representing two districts of Kerala; populations collected from 15 locations of 13 districts of Assam; and 10 populations collected from Andaman and Nicobar Islands, representing North and Middle Andaman, and South Andaman districts. These planting materials were potted and regularly propagated through cuttings in NCQF. The plants were maintained at 18±1 °C for multiplying the rust inoculum. Imidacloprid (0.004%) (Confidor 200SL, Bayer) was used occasionally to eliminate sucking pests (mostly red spider mites).

Test plant species

Selection of plants for the host-specificity screening of the rust was based on the taxonomic classification of the target weed in relation to the centrifugal phylogenetic testing sequence proposed by Wapshere (1974) and also included plants of economic importance in the potential areas of release of the rust, in accordance with the International Plant Protection Convention guidelines (FAO 1996), so as to allay concerns of decision-makers and the general public.

Based on the mode of propagation, seeds, seedlings, cuttings or other vegetative propagules of 90 plant species belonging to 32 families (Tables 2, 3 and 4) were collected or procured from different parts of India and other sources like National Gene Bank, NBPGR, National Seeds Corporation Limited, and some seed companies. The list included 35 plant species representing 13 out of the 17 tribes existing in Asteraceae (Katinas 2005). Details of the 28 cultivars/ accessions of sunflower tested for host-specificity of the rust are given in Table 3. All the plants were potted in autoclavable plastic pots, containing garden soil mixed with both organic manure and inorganic fertilizers, and seedlings were maintained for rust inoculations. Some of the important plant species screened earlier at CABI (UK) were also included for screening. All the plant collections were maintained under available natural light conditions inside designated bays at 18±1 ºC till inoculations. Plants were watered at least once a day. Adequate care was taken to ensure that the plants did not harbour any insect or mite pests.

Rust inoculation and assessment of pathogenicity

The inoculation procedure prescribed by Ellison *et al.* (2004) with due modification (Sreerama Kumar and Rabindra 2005) was adopted. Young, healthy seedlings of test plants were sprayed with distilled water and kept in the dew chamber (Fig. 1). *P. spegazzinii* produces basidiospores under high humidity conditions from cushions of teliospores that are embedded in the plant tissue. The teliospores are not released, and hence, the inoculum used in the experimental work was composed of infected leaf, petiole and/or stem. The inoculum was spread over the grill-like tray just above the plants to be inoculated in such a manner that the pustules (for example, on the lower surface of the leaves) faced the healthy plants kept on the lower rack. A 48-hour dew period at 20 °C and 100% RH was used to ensure every opportunity for test plant to pick up the infection. *M. micrantha* plants from Peechi were used as control. The teliospores at high humidity produced basidiospores (Fig. 2) which were ejected from the teliospores and fell on the young seedlings below. Four seedlings/saplings of each test plant were inoculated and each experiment was repeated twice. For some plant species, populations from more than one location were tested. Symptoms were recorded as described by Ellison *et al.* (2004) on the pathogenicity score (PS) from 0-4 (0 = no macroscopic symptoms; 1 = necrotic or chlorotic spots on inoculated vegetative parts - no sporulation; 2 = abnormal infection site: chlorotic patches on vegetative parts with very low teliospore production around edges of chlorosis; 3 = abnormal infection site: pustules reduced in size with low teliospore production in relation to compatible host-pathogen interaction; 4 = normal pustule formation, in relation to compatible host-pathogen interaction). All the inoculated test plants were kept under observation for six weeks (double the time taken by the weed to express full symptoms) and thereafter, autoclaved and incinerated. The rust inoculum was maintained on *M. micrantha* plants by regular inoculations.

RESULTS AND DISCUSSION

First visible symptoms of rust appeared 5-7 days after inoculations as chlorotic spots on leaves, petiole and stem (Fig. 3). These spots further enlarged and within 12-15 days developed into cinnamon-coloured telia with teliospores embedded in sori (Figs 4a and 4b).

M. micrantha plants from Assam inoculated with the rust fungus showed a remarkable variability in the susceptibility towards the pathogen (Table 1). Weed populations from districts Barpeta, Cachar, Darrang, Kokrajhar, Lakhimpur and Nalbari were found to be highly susceptible (PS 4), while those from Sivasagar and Sonitpur exhibited medium susceptibility (PS 3-4). Weed populations from Dhemaji and Nagaon showed medium susceptibility (PS 3). *M. micrantha* populations from Karbi Anglong and Tinsukia showed resistance to the fungus with slight infection (PS 2). Three populations from Jorhat district showed mixed susceptibility with

Table 1. Susceptibility of *Mikania micrantha* populations from different regions in India to *Puccinia spegazzinii* (Trinidadian pathotype)

State/ union territory	Place of collection/ population (district)	Total no. of plants inoculated	Mean pathogenicity score
Assam	Diphu (Karbi Anglong)	9	2
	Gelapukhuri (Tinsukia)	8	2
	Jorhat (Jorhat)	20	3-4
	Kokrajhar (Kokrajhar)	17	4
	Nagajanka (Jorhat)	8	2
	North Lakhimpur (Lakhimpur)	8	4
	Orang (Darrang)	8	4
	Pathsala (Barpeta)	12	4
	Sepon (Sivasagar)	8	3-4
	Silapathar (Dhemaji)	12	3
	Silchar (Cachar)	8	4
	Silongoni (Nagaon)	12	3
	Tezpur (Sonitpur)	8	3-4
	Titabar (Jorhat)	28	4
	Tihu (Nalbari)	9	4
Kerala	Chimmoni (Thrissur)	25	4
	Peechi (Thrissur)	> 100	4
	Shoranur (Palakkad)	> 100	4
	Thrissur (Thrissur)	> 100	4
	Vazhachal (Thrissur)	25	4
Andaman and Nicobar Islands	Central Agricultural Research Institute (CARI), Garacharma, Port Blair (South Andaman)	31	4
	Garacharma village, Port Blair (South Andaman)	14	3-4
	Hut Bay, Little Andaman (South Andaman)	8	4
	Kalpong Hydroelectric Project (KHEP) Junction (North and Middle Andaman)	23	3-4
	Kalpong (North and Middle Andaman)	9	3-4
	Keralapuram (North and Middle Andaman)	8	4
	Mount Harriet National Park (South Andaman)	9	4
	Nayashahar (South Andaman)	10	4
	Radhanagar, Havelock Island (South Andaman)	24	3-4
	Not labelled by the collector	10	4

the collection from Titabar showing PS 4 and that from Nagajanka showing rust symptoms with PS 2. The third one from Jorhat had a score of 3-4. The results of screening of *M. micrantha* populations from 13 districts of Assam suggest that most of the weed populations in the North, South and West

Table 2. Asteraceae inoculated with *Puccinia spegazzinii* (Trinidadian pathotype) for host-specificity screening

Tribe	Scientific name	Common name	Cultivar	Source/ place of collection[@]
Anthemideae	*Artemisia annua* L.	Sweet sagewort/ sweet wormwort	EC-202429	NBPGR Regional Station, Bhowali, Uttarakhand
	Chrysanthemum carinatum Schousboe*	Tricolor chrysanthemum	-	NBPGR
	Matricaria aurea Boiss.	Golden cotula	-	SN
Arctotideae	*Gazania rigens* (L.) Gaertn.**	Treasure flower	-	SN
Astereae	*Solidago canadensis* L.	Canada goldenrod	-	Bengaluru, Karnataka
	Aster chinensis L.**	China aster		SN
	Bellis perennis L.	Daisy		SN
	Brachyscome iberidifolia Benth.	Swan river daisy	-	SN
Calenduleae	*Calendula officinalis* L.*	Calendula	-	NBPGR
	Dimorphotheca sinuata DC.	Cape-marigold	-	SN
Cichorieae	*Lactuca sativa* L.*	Lettuce	-	New Delhi
(= Lactuceae)	*Sonchus arvensis* L.	Field sowthistle	-	NBPGR
Cynareae	*Carthamus tinctorius* L.*	Safflower	-	Bengaluru, Karnataka
	Centaurea cyanus L.	Cornflower/ bachelor's button	Frosty Mix	Namdhari Seeds Pvt. Ltd., Bidadi, Karnataka
Eupatorieae	*Ageratum conyzoides* L.**	Goat weed	-	AAU; Andaman and Nicobar Islands
	Ageratum houstonianum Mill.	Floss flower/ mist flower	-	SN
	Chromolaena odorata (L.) R.M. King & H. Robinson*	Siam weed	-	Bengaluru, Karnataka; Nicobar Islands, Andaman and Nicobar Islands
	Eupatorium adenophorum Spreng. (Banmara)**	Crofton weed	-	Ootacamund, Tamil Nadu
	Stevia rebaudiana (Bertoni) Bertoni*	Sweet leaf	-	Assam
Helenieae	*Tagetes erecta* L.	Big marigold/ Aztec marigold	African Marigold (Tall)	NBPGR
	Tagetes tenuifolia Cav.	Striped marigold	Single Signet	NBPGR
Heliantheae	*Cosmos bipinnatus* Cav.	Cosmos	-	Bengaluru, Karnataka
	Dahlia sp.	Dahlia	Unwins Mix	Karnataka
	Eclipta alba (L.) Hassk.	False daisy	-	Nancowry, Nicobar Islands, Andaman and Nicobar Islands
	Guizotia abyssinica Cass.	Niger-seed	-	Bengaluru, Karnataka
	Helianthus annuus L.*#	Sunflower	Morden	Tamil Nadu
	Parthenium hysterophorus L.*	Congress grass	-	NBPGR
	Tithonia diversifolia (Hemsl.) Gray	Mexican sunflower/ tree marigold	-	Bengaluru, Karnataka
	Wedelia biflora (L.) DC.	Sea daisy	-	Nicobar Islands, Andaman and Nicobar Islands
	Zinnia elegans Jacq.	Elegant zinnia	Giant Dahlia Fld. Double Mixed	Karnataka
Inuleae	*Blumea junghuhniana* (Miq.) Boerl.	Blumea	-	Nicobar Islands, Andaman and Nicobar Islands
Mutisieae	*Gerbera jamesonii* Bolus ex Hook. f.*	Transvaal daisy/ Barberton daisy	-	SN
Senecioneae	*Cineraria lyrata* DC.	Wild parsley	Jubilee Mix	New Delhi
	Erechtites valerianifolia (Link ex Wolf) Less. ex DC.	Tropical burnweed	-	Assam
Vernonieae	*Vernonia anthelmintica* (L.) Willd.**	Purple fleabane	-	Andaman and Nicobar Islands; NBPGR

*Plant species (or **same genus) tested at CABI (UK) earlier and found non-susceptible to *P. spegazzinii* (Trinidadian pathotype). #Showed mild chlorotic flecks (PS 1). [@]Abbreviations: AAU: Assam Agricultural University, Jorhat, Assam; NBPGR: National Bureau of Plant Genetic Resources, New Delhi; SN: Sunder Nursery, New Delhi.

Assam are susceptible to the pathotype of *P. spegazzinii* (PS 4) while those in the East and Central Assam show some resistance (PS 2/3). On the other hand, all the five populations of *M. micrantha* from Kerala were found to be highly susceptible with PS 4 (Table 1).

All the 10 populations of *M. micrantha* from Andaman showed rust symptoms with PS not less than 3 (Table 1), thus indicating the susceptibility of the weed populations from the Islands. Two populations each from South Andaman (Garacharma village and Radhanagar) and North and Middle Andaman (KHEP Junction and Kalpong) showed medium susceptibility with PS 3-4, but the rest all were highly susceptible.

Out of the 35 plant species in Asteraceae, 34 did not show any reaction to rust inoculation (Table 2), suggesting their immunity to *P. spegazzinii*. In sunflower (cv. Morden), however, mild chlorotic flecks (PS 1) were observed on a few top leaves **(**Fig. 5**)** that were directly under the heavy inoculum inside the dew chamber, after 6-8 days of inoculation (Table 2)**.** Ellison *et al*. (2008) also observed similar chlorotic spots on sunflower in the primary host-range screening with the same pathotype in UK. They monitored the leaves showing chlorosis till senescence and found no further development of disease. In the present study, to avoid the risk of the alien rust fungus posing threat to the sunflower biodiversity in India, an additional screening of sunflower cultivars/accessions was undertaken to ascertain the results. A total of 27 more cultivars/ accessions, in addition to Morden, of sunflower collected from various sources were inoculated and the chlorotic flecks were observed in eight samples, including Morden (Table 3). During the microscopic examination no mycelial growth was observed in the leaf tissue of the plants showing chlorotic flecks. All the inoculated sunflower plants showed normal growth and flowering. Ellison *et al*. (2008) also observed such symptoms on the sunflower sample from India and noticed the germination of basidiospores and formation of appressoria on the leaves, but there was no penetration of the tissues. The plants showing chlorotic flecks were observed until flowering and the leaves had senesced. The resistance reaction of sunflower was further confirmed with microscopic and histopathological studies. The flecks did not develop further and there was no spore formation. It was concluded that sunflower is not susceptible to *P. spegazzinii* and the development of chlorotic flecks was only due to hypersensitive reaction of no economic consequence.

Table 3. Additional screening of sunflower cultivars/ accessions for reaction to *Puccinia spegazzinii* (Trinidadian pathotype)#

Cultivar/ accession	Source	Reaction
AHT-16	AAU, Jorhat, Assam	+
AHT-17	AAU, Jorhat, Assam	-
IH-673	AAU, Jorhat, Assam	+
IH-662	AAU, Jorhat, Assam	-
CO-2	Tamil Nadu	-
Morden	Tamil Nadu	+
Swarna Hybrid	Tamil Nadu	-
CO-4 (TNAUSUF-7)	Tamil Nadu	-
TCSH-1 (TNAU)	Tamil Nadu	+
PRO-011	Gene Bank, NBPGR, New Delhi	-
LSFH-35	Gene Bank, NBPGR, New Delhi	-
CMSH-84A	Gene Bank, NBPGR, New Delhi	-
Surya	NBPGR, New Delhi	-
MSFH-17	NBPGR, New Delhi	+
KP-AK-164 (IC-415484)	NBPGR, New Delhi	-
SM-BJ-6 (IC-411604)	NBPGR, New Delhi	-
KP-AK-76 (IC-415396)	NBPGR, New Delhi	-
SM-BJ-22 (IC-411620)	NBPGR, New Delhi	-
JBT-38/228 (IC-424494)	NBPGR, New Delhi	+
SM-BJ-50 (IC-411648)	NBPGR, New Delhi	-
SM-BJ-99 (IC-411697)	NBPGR, New Delhi	-
KP-AK-37 (IC-415357)	NBPGR, New Delhi	-
IC-328856	NBPGR, New Delhi	+
EC-512670 (France)	NBPGR, New Delhi	-
EC-512671 (France)	NBPGR, New Delhi	-
EC-512682 (France)	NBPGR, New Delhi	-
EC-512683 (France)	NBPGR, New Delhi	-
EC-68414	NBPGR, New Delhi	+

+ = chlorotic flecks observed on leaves (pathogenicity score 1); - = no chlorotic flecks observed. #Chlorotic spots were observed on sunflower leaves in CABI (UK), but there was no further disease development and the chlorosis faded and disappeared as the leaves aged. A microscopic analysis also proved that fungal penetration was inhibited (Ellison *et al.* 2008).

Ellison *et al*. (2008) recorded a hypersensitive response to the same rust pathotype on *Calendula officinalis*, *Eupatorium cannabinum* and *Stevia rebaudiana*; however, no such reaction was observed during the present testing, which included *C. officinalis*, *S. rebaudiana* and a different species of *Eupatorium*.

No rust symptoms were observed on any of the other 55 test plant species belonging to 31 families (Table 4) and representing various economically important crop groups, viz. cereals, vegetables, pulses, ornamentals, oilseeds, fibre crops, fruit crops, medicinal crops, spices and condiments, etc. Further, the results of 21 plant species, including nine in Asteraceae and 12 others of high economic importance, tested earlier at CABI (UK) also reconfirmed their immunity to the rust fungus.

Table 4. Other economically important plant species inoculated with *Puccinia spegazzinii* (Trinidadian pathotype) for host-specificity screening

Family	Scientific name	Common name	Cultivar	Place/ source of collection[@]
Anacardiaceae	*Anacardium occidentale* L.	Cashew	Vengurla	Bengaluru, Karnataka
	Mangifera indica L.	Mango	Mallika	New Delhi
Bromeliaceae	*Ananas comosus* (L.) Merr.	Pineapple	Mauritius	KAU
Campanulaceae	*Lobelia erinus* L.	Garden lobelia	Crystal Palace	SN
Caryophyllaceae	*Dianthus caryophyllus* L.	Carnation	-	SN
	Gypsophila muralis L.	Cushion baby's-breath	White Covent Garden	New Delhi
Cruciferae	*Brassica nigra* (L.) Koch**	Black mustard	RK-01-03	NBPGR
	Coronopus didymus (L.) Sm.	Lesser swine-cress	-	NBPGR
	Iberis sp.	Candytuft	-	New Delhi
	Matthiola incana (L.) W.T. Aiton	Hoary stock	-	SN
	Raphanus sativus L.*	Radish	Pusa Desi	NSC
Dioscoreaceae	*Dioscorea bulbifera* L.	Potato yam	Gajendra	AAU
Euphorbiaceae	*Ricinus communis* L.	Castorbean	DCH 519	NBPGR
Fabaceae	*Arachis hypogaea* L.*	Groundnut/ peanut	TG-45	NBPGR
	Vigna unguiculata (L.) Walp.	Cowpea	Pusa Phalguni	NBPGR
Lamiaceae	*Salvia splendens* Sellow ex Schult.	Scarlet sage	Bonfire salvia	New Delhi
Lauraceae	*Cinnamomum zeylanicum* Blume	Cinnamon	IISR Navasree	KAU
Linaceae	*Linum usitatissimum* L.*	Flax/ linseed	RLC-81	NBPGR
Malvaceae	*Gossypium arboreum* L.	Desi cotton	Karbi	AAU
	Gossypium hirsutum L.	Upland cotton	MECH-162 (Non- Bt); MECH-162 (Bt)	MAHYCO
Moraceae	*Artocarpus heterophyllus* Lam.	Jackfruit	-	AAU
Musaceae	*Musa paradisiaca* L.	Banana	-	AAU
Myristicaceae	*Myristica fragrans* Houtt.	Nutmeg	IISR Viswashree	KAU
Myrtaceae	*Syzygium aromaticum* (L.) Merr. & Perry	Clove	-	KAU
Palmae	*Areca catechu* L.	Arecanut/ betel-nut palm	Mangala	KAU
	Cocos nucifera L.*	Coconut	Bengal Selection	AAU
Pedaliaceae	*Sesamum indicum* L.	Gingelly/ sesame	-	AAU
Piperaceae	*Piper betle* L.	Betel vine	-	KAU
	Piper nigrum L.	Black pepper	Panniyur-1	KAU
Poaceae	*Bambusa arundinacea* (Retz.) Willd.	Thorny bamboo	-	KFRI
	Ochlandra travancorica (Bedd.) Benth. ex Gamble.	Elephant grass	-	AAU
	Oryza sativa L.*	Paddy/ rice	NDRK 5026-R -	Genetics Division, IARI NSC
	Pennisetum typhoides (Burm.f.) Stapf. & C.E. Hubb.	Pearl millet	HHB-117	NBPGR
	Saccharum officinarum L.	Sugarcane	CO-1148	AAU
	Sorghum bicolor (L.) Moench*	Sorghum	UP Chari-2	NBPGR
	Triticum aestivum L.	Bread wheat	PBW-343	Genetics Division, IARI
	Zea mays L.*	Corn/ maize	Composite Lakshmi	NBPGR
Polemoniaceae	*Phlox drummondii* Hook.	Annual phlox/ Drummond's phlox	-	SN
Rubiaceae	*Coffea arabica* L.*	Arabian coffee	Kaveri	KAU
Scrophulariaceae	*Antirrhinum majus* L.	Snapdragon	-	SN
	Linaria bipartita (Vent.) Willd.	Clovenlip toadflax	-	SN
Solanaceae	*Capsicum annuum* L.	Chilli/ red pepper	Pusa Hyper-2	NSC
	Nicotiana tabacum L.	Tobacco	-	NBPGR
	Petunia sp.	Garden petunia	Multiflora Double Mix	New Delhi
	Solanum melongena L.*	Brinjal/ eggplant	PK	NSC
Sterculiaceae	*Theobroma cacao* L.*	Cocoa	CCRP-1	KAU
Theaceae	*Camellia sinensis* (L.) O. Kuntze*	Tea	TV-23	AAU
Tiliaceae	*Corchorus capsularis* L.	Jute	J-295; JRC-212; JRO-524	AAU
Tropaeolaceae	*Tropaeolum majus* L.	Garden nasturtium	-	SN
Verbenaceae	*Tectona grandis* L.f.*	Teak	-	KFRI
	Verbena officinalis L.	Common vervain/ pigeon's-grass	Time Mixed	New Delhi
Violaceae	*Viola tricolor* L.	Heart's ease/ pansy	-	SN
Zingiberaceae	*Curcuma domestica* Val.	Turmeric	Prathibha	IISR Experimental Farm, Peruvannamuzhi, Kerala
	Elettaria cardamomum (L.) Maton	Green cardamom	CCS-1	IISR Regional Station, Appangala, Karnataka; Kerala
	Zingiber officinale Rosc.	Ginger	-	New Delhi

*Plant species (or **same genus) tested at CABI (UK) earlier and found non-susceptible to *P. spegazzinii* (Trinidadian pathotype).

[@]Abbreviations: AAU: Assam Agricultural University, Jorhat, Assam; IARI: Indian Agricultural Research Institute, New Delhi; IISR: Indian Institute of Spices Research; KAU: Kerala Agricultural University, Thrissur, Kerala; KFRI: Kerala Forest Research Institute, Peechi, Kerala; MAHYCO: Maharashtra Hybrid Seeds Company; NSC: National Seeds Corporation Limited, New Delhi; NBPGR: National Bureau of Plant Genetic Resources, New Delhi; SN: Sunder Nursery, New Delhi.

Fig. 1. Inoculation in the dew chamber

Fig. 2. Basidiospore production

Fig. 3. Initial chlorotic spots on *Mikania micrantha* leaves

Fig. 4a. Mature telia on *Mikania micrantha* leaves

Fig. 4b. Mature telia on *Mikania micrantha* stem

Fig. 5. Mild chlorotic flecks on sunflower leaf

Host-specificity testing is an essential part of risk analysis and is the key tool to assess whether the biological agent is safe to release into a new environment. Based on the results from screening a wide range of plant species for host-specificity, the Plant Protection Advisor to Government of India granted permission for limited field release of the Trinidadian pathotype of *P. spegazzinii*. The rust inoculum was released at identified sites in Assam and Kerala (Sankaran *et al.* 2008). In Kerala, the rust was released in agricultural systems and forest areas in during August-October 2006. The releases were successful in the sense that the rust had spread to the native population of the weed at all release sites. The maximum distance of spread was 1.5 m away from the source plant. However, the rust persisted on the field population of the weed only till December until the temperature and humidity at the sites were suitable for survival of the pathogen and disease spread. Low inoculum load and inappropriate time of release are considered to be the main reasons for the failure in survival of the rust in the field beyond December. The ideal time for release was June-August, during the southwest monsoon in Kerala (which provided the optimum conditions for rust infection), which would have promoted wider spread of the rust and its survival during the summer. On the other hand, in Assam, the rust failed to establish probably because of plant biotypic variation in susceptibility. With this release of *P. spegazzinii,* India had become the eighth country in the world and the first on mainland Asia to deliberately and scientifically introduce an exotic fungal pathogen for CBC of a weed. Once established in the fields this CBC agent can provide a cheaper, safer and sustainable solution for the management of *M. micrantha*. The host-susceptibility results presented here indicate the potential of the rust not only on the Indian mainland but also in the Andaman archipelago, where *M. micrantha* is a perennial problem to the local flora.

In 2008, *P. spegazzinii* was imported and released (but in this case, a different isolate was used) at nearly 560 sites in 15 provinces in Papua New Guinea (PNG) and over 80 sites on four islands in Fiji (Day *et al*. 2011 and 2013). In PNG, the rust had established in 11 provinces, spreading up to 40 km from some sites, and in Fiji, it had established on two islands. Further field monitoring indicated the potential of *P. spegazzinii* to control this weed in many parts of both countries, by way of reducing the weed density (Day *et al*. 2011). Results of the release from PNG, Fiji (Day *et al*. 2011 and 2013) and also in Taiwan (S.S. Tzean, personal communication, 2013) indicate strong possibility of survival of the rust in the field in Kerala exerting an impact on the population of *M. micrantha*. It is evident from results elsewhere that once there is a critical concentration of the rust in the area, the infection will enter into an epidemic phase. It can be concluded that fresh releases of the rust, probably using the isolate released in PNG and Taiwan (Ellison *et al.* 2014), during the southwest monsoon (June/July) may help survival of the pathogen in the field in Kerala and subsequent control of the weed population.

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REFERENCES

CABI. 2006. *Crop Protection Compendium*. CAB International, Wallingford, UK.

Cock MJW, Ellison CA, Evans HC and Ooi PAC. 2000. Can failure be turned into success for biological control of mile-a-minute weed (*Mikania micrantha*), pp. 155-167. In: *Proceedings of the X International Symposium on Biological Control of Weeds* (Ed. Spencer PM), Montana State University, Bozeman, USA, 4-14 July 1999, Montana State University Press, Bozeman, Montana, USA.

Day MD, Kawi AP, Fidelis J, Tunabuna A, Orapa W, Swamy B, Ratutini J, Saul-Maora J and Dewhurst CF. 2011. Biology, field release and monitoring of the rust fungus *Puccinia spegazzinii* (Pucciniales: Pucciniaceae), a biological control agent of *Mikania micrantha* (Asteraceae) in Papua New Guinea and Fiji, pp. 211-217. In: *Proceedings of the XIII International Symposium on Biological Control of Weeds* (Eds Wu Y, Johnson T, Sing S, Raghu S, Wheeler G, Pratt P, Warner K, Center T, Goolsby J and Reardon R), Waikoloa, Hawaii, USA, 11-16 September 2011, USDA Forest Service-FHTET, Morgantown, USA.

Day MD, Kawi A, Tunabuna A, Fidelis J, Swamy B, Ratutuni J, Saul-Maora J, Dewhurst CF and Orapa W. 2013. Biological control of *Mikania micrantha* in Papua New Guinea and Fiji using the rust fungus *Puccinia spegazzinii*, pp. 150-157. In: *Proceedings of the VIII International Workshop on Biological Control and Management of* Choromolaena odorata *and other Eupatorieae* (Eds Zacharidaes C, Strathie LW, Day MD and Muniappan R), Nairobi, Kenya, 1-2 November 2010, ARC-PPRI, Pretoria, South Africa.

Ellison CA and Murphy ST. 2001. *Dossier on* Puccinia spegazzinii *de Toni (Basidiomycetes: Uredinales) a Potential Biological Control Agent for* Mikania micrantha *Kunth. ex H.B.K. (Asteraceae) in India*. Unpublished document, CABI Bioscience, UK Centre (Ascot), UK, 50 p.

Ellison CA, Day MD and Witt A. 2014. Overcoming barriers to the successful implementation of a classical biological control strategy for the exotic invasive weed *Mikania micrantha* in the Asia-Pacific region, pp. 135-141. In: *Proceedings of the XIV International Symposium on Biological Control of Weeds* (Eds Impson FAC, Kleinjan CA and Hoffmann JH), Kruger National Park, South Africa, 2-7 March 2014, University of Cape Town, Cape Town, South Africa.

Ellison CA, Evans HC and Ineson J. 2004. The significance of intraspecies pathogenicity in the selection of a rust pathotype for the classical biological control of *Mikania micrantha* (mile-a-minute weed) in Southeast Asia, pp. 102-107. In: *Proceedings of the XI International Symposium on Biological Control of Weeds* (Eds Cullen JM, Briese DT, Kriticos DJ, Lonsdale WM, Morin L and Scott JK), Canberra, Australia, 27 April-2 May 2003, CSIRO Entomology, Canberra, Australia.

Ellison CA, Evans HC, Djeddour DH and Thomas SE. 2008. Biology and host range of the rust fungus *Puccinia spegazzinii*: A new classical biological control agent for the invasive, alien weed *Mikania micrantha* in Asia. *Biological Control* **45**: 133-145.

Evans HC and Ellison CA. 2005. The biology and taxonomy of rust fungi associated with the neotropical vine *Mikania micrantha*, a major invasive weed in Asia. *Mycologia* **97**: 935-947.

FAO. 1996. *International Standards for Phytosanitary Measures.* Secretariat of the International Plant Protection Convention, Rome, Italy, 21 p.

Katinas L. 2005. Course on Systematics and Classification of Asteraceae (The Daisy Family). Accessed on 27 October 2015. *www.botany.wisc.edu/katinas.*

Murphy ST, Ellison CA and Sankaran KV. 2000. *The Development of a Biocontrol Strategy for the Management of the Alien Perennial Weed,* Mikania micrantha *H.B.K. (Asteraceae) in Tree Crop Based Farming Systems in India*. Final Technical Report for DFID Project No. R 6735, unpublished document, CABI Bioscience, UK Centre (Ascot), UK, 78 p.

Sankaran KV, Muraleedharan PK and Anitha V. 2001. *Integrated Management of the Alien Invasive Weed* Mikania micrantha *in the Western Ghats*. KFRI Research Report No. 202, Kerala Forest Research Institute, Peechi, India, 51 p.

Sankaran KV, Puzari KC, Ellison CA, Sreerama Kumar P and Usha Dev. 2008. Field release of the rust fungus *Puccinia spegazzinii* to control *Mikania micrantha* in India: protocols and raising awareness, pp. 384-389. In: *Proceedings of the XII International Symposium on Biological Control of Weeds* (Eds Julien MH, Sforza R, Bon MC, Evans HC, Hatcher PE, Hinz HL and Rector BG), La Grande Motte (Montpellier), France, 22-27 April 2007, CAB International, Wallingford, UK.

Sreerama Kumar P and Rabindra RJ. 2005. *Supplementary Dossier on* Puccinia spegazzinii *de Toni (Basidiomycetes: Uredinales) a Potential Biological Control Agent for* Mikania micrantha *Kunth. ex H.B.K. (Asteraceae) in India*. Unpublished document, Project Directorate of Biological Control, Bangalore, India, 23 p.

Wapshere AJ. 1974. A strategy for evaluating the safety of organisms for biological weed control. *Annals of Applied Biology* **77**: 201-211.

Waterhouse DF. 1994. *Biological Control of Weeds: Southeast AsianProspects*. Australian Centre for International Agricultural Research, Canberra, Australia, 302 p.

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Short communication

Penoxsulam as post-emergence herbicide for weed control in transplanted rice

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Among the several factors responsible for low rice productivity, weeds are considered to be one of the major limiting factors due to their manifold harmful effects (Singh *et al.* 2009). Most of the traditional herbicides in use are applied at higher doses *i.e.*, 0.8 to 1.5 kg/ha, hence the continuous use would end in high residual effect in soil and water. Recent trend of herbicide use is to find out an effective weed control by using low dose herbicides, which will not only reduce the total volume of herbicide use but also the application becomes easier and economic (Kathiresan 2001). Penoxsulam is one of the low dose high efficacy broad spectrum herbicide which offers eco-friendly weed control. Therefore, this study was conducted to assess the bio-efficacy of post-emergence application of penoxsulam (24 SC) in transplanted rice.

The field experiment was conducted at a farmer's field in Kanjirathady Padasekharam in Nemom block, Thiruvananthapuram district (Kerala) located at 8.5º N latitude and 76.9º E longitudes at an altitude of 29 m above mean sea level (MSL). The soil of the experimental site was sandy clay loam in texture (coarse sand 47.65%, fine sand 10.90%, silt 9.05% and clay 32.40%) and the soil order was 'Oxisol'. The soil pH was 6.0 and it was high in organic carbon (1.16%), available P (22.4 kg/ha) and medium in availableN (500 kg/ha) and K (170.1 kg/ha). The experiment was laid out in randomized block design (RBD) with eight treatments and replicated thrice. The gross plot size was 20 m^2 (5 x 4 m). Medium duration rice variety '*Uma (MO 16)*' having duration of 120-125 days was used for the study. Twenty days old seedlings were transplanted in the main field at two to three seedlings per hill and the water level was maintained at about 1.5 cm during transplanting with a spacing of 20 x 10 cm. Penoxsulam was applied at 10 to 12 days after transplanting (DAT), whereas bispyribac-sodium and 2,4–D sodium salt were applied at 20 DAT. Hand operated knapsack sprayer fitted with a flat fan type nozzle (WFN 40) was used for spraying the herbicides adopting a spray volume of 500 l/ha. For manually weeded plots two weeding were given at 20 and 40 DAT. To study the weed dynamics, quadrate of size 0.5 m^2 was placed at random in two sites in each plot and the weeds within the frames of the quadrate were identified and recorded at 20 and 40 DAT. Data were statistically analyzed using Analysis of Variance techniques (ANOVA).

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Weed species and density

The dominant broad-leaved species were *Limnocharis flava, Monochoria vaginalis, Ludwigia parviflora, Marsilea quadrifolia* and *Lindernia rotundifolia*. Among sedges, *Cyperus difformis* and *Scirpus grossus* were the dominant ones. *Echinochloa colona* and *Panicum repens* were dominant grassy weeds.

Lower density of sedges, grasses and broad-leaved was recorded (Table 1 and 2) at higher doses of penoxsulam (25.0 and 22.5 g/ha).

Weed control efficiency

Higher doses of penoxsulam 25.0 g/ha and 22.5 g/ha recorded significantly lower total dry matter production compared to its lower doses (Table 2).This result was confirmed by Singh *et al.* (2009). The weed control efficiency of penoxsualam 25 g/ha was 96.2% at 40 DAT, which was comparable with its lower doses and bispyribac-sodium (Table 2).

Effect on crop

Penoxsulam 22.5 g/ha registered the highest value for productive tillers/m^2 and filled grains/panicle (Table 3). However, with regard to number of productive tillers/m^2, penoxsulam 25.0 g/ha and bispyribac-sodium 30.0 g/ha also recorded comparable values. With respect to number of filled grains/panicle, along with these treatments 2,4-D sodium salt 1.0 kg/ha also recorded comparable values.

Table 1. Effect of different weed management practices on absolute density (no./m²) of grasses, broad-leaved weeds and sedges in transplanted rice

Treatment	Grasses		BLWs		Sedges	
	20 DAT	40 DAT	20 DAT	40 DAT	20 DAT	40 DAT
Penoxsualam 17.5 g/ha	1.33 (1.48)	6.00 (2.43)	16.0 (4.12)	7.33 (2.70)	14.7 (3.94)	10.0 (3.20)
Penoxsualam 20 g/ha	2.66 (1.90)	4.66 (2.21)	12.7 (3.69)	6.00 (2.42)	14.0 (3.86)	5.33 (2.34)
Penoxsualam 22.5 g/ha	0.66 (1.24)	2.00 (1.65)	13.3 (3.78)	4.33 (2.42)	8.00 (2.98)	1.33 (1.17)
Penoxsualam 25 g/ha	0.66 (1.24)	0.66 (1.24)	7.33 (2.64)	2.66 (1.60)	4.66 (2.37)	0.00 (1.00)
Bispyribac-sodium 30 g/ha	14.0 (3.85)	6.66 (2.76)	94.7 (9.78)	16.0 (3.98)	94.0 (9.74)	6.66 (2.63)
2,4-D sodium salt 1000 g/ha	16.0 (4.11)	12.0 (3.59)	91.3 (9.60)	19.3 (4.38)	102 (10.1)	14.7 (3.88)
Hand weeding twice	14.7 (3.94)	15.3 (4.04)	94.7 (9.75)	27.3 (5.22)	95.0 (9.79)	15.3 (3.97)
Weedy check	12.0 (3.59)	97.3 (9.91)	94.0 (9.75)	192 (10.2)	104 (10.19)	90.0 (10.4)
LSD (P=0.05)	0.62	1.23	0.98	0.60	0.99	0.73

Values in parentheses are transformed values, DAT- Days after transplanting

Table 2. Effect of different weed management practices on total weed density, dry weight and weed control efficiency in transplanted rice

Treatment	Total weed density (no./m²)		Total weed dry weight (g/m²)		WCE (%)	
	20 DAT	40 DAT	20 DAT	40 DAT	20 DAT	40 DAT
Penoxsualam 17.5 g/ha	27.3 (5.22)	24.2(4.81)	2.04 (1.42)	2.62 (1.62)	86.4	95.5
Penoxsualam 20 g/ha	29.3 (5.40)	18.6 (4.18)	1.23 (1.11)	2.62 (1.62)	91.6	94.2
Penoxsualam 22.5 g/ha	26.3 (5.13)	9.6 (2.93)	0.55 (0.74)	2.43 (1.56)	93.6	94.5
Penoxsualam 25 g/ha	25.2 (5.01)	8.5 (2.75)	0.44 (0.66)	2.28 (1.51)	96.9	96.2
Bispyribac-sodium 30 g/ha	202.5 (14.2)	33.3(5.77)	12.9 (3.60)	2.43 (1.56)	15.7	92.1
2,4-D sodium salt 1000 g/ha	209.1 (14.5)	46.9 (6.88)	12.5 (3.54)	2.40 (1.55)	17.9	76.1
Hand weeding twice	204.2 (14.3)	58.9 (7.61)	13.8 (3.71)	5.48 (2.34)	10.7	75.1
Weedy check	209.4 (14.5)	311.5 (17.6)	15.4 (3.93)	46.1 (6.79)	-	-
SE m (±)	0.27	0.22	0.06	0.04		
LSD (P=0.05)	0.86	0.84	0.19	0.12		

Values in parentheses are transformed values, DAT- Days after transplanting

Table 3. Effect of weed management practices on yield attributes and grain yield

Treatment	Panicles/m²	Filled grains/ panicle	Yield (t/ha)	Net income (x10³ `/ha)	B: C ratio
Penoxsualam 17.5 g/ha	567	106	5.14	45.01	1.61
Penoxsualam 20 g/ha	577	110	5.14	44.35	1.60
Penoxsualam 22.5 g/ha	683	120	5.40	49.06	1.67
Penoxsualam 25 g/ha	656	116	5.27	45.83	1.63
Bispyribac sodium 30 g/ha	610	116	5.26	45.75	1.62
2,4-D sodium salt 1000 g/ha	508	114	5.14	45.98	1.62
Hand weeding twice	458	109	4.91	35.01	1.46
Weedy check	421	101	4.21	29.36	1.31
LSD (P=0.05)	113	8.50	0.52	7.48	0.12

Among the different treatments, penoxsulam 22.5 g/ha recorded the highest yield (5.40 t/ha) and it was statistically at par with all the herbicide treatments and hand weeding. Penoxsulam applied at 22.5 g/ha registered the highest net returns and B:C ratio compared to other treatments.

SUMMARY

Penoxsulam at 22.5 and 25.0 g/ha was found effective to control weeds in transplanted rice on the basis of vegetation analysis. However, based on economic analysis, penoxsulam at 22.5 g/ha could be adjudged as the best treatment for effective and economic weed management.

REFERENCES

Kathiresan RM. 2001. Sustainability of weed management practices in rice-black gram cropping system. p. 79. In: *Eco-friendly Weed Management Options for Sustainable Agriculture.* Proceedings of First Biennial Conference in the New Millennium, University of Agricultural Sciences, Bangalore.

Singh VP, Singh SP, Tripathi N, Singh M and Abnish K. 2009. Bioefficacy of penoxsulam on transplanted rice weeds. *Indian Journal of Weed Science* **41**(1&2): 28-32.

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Short communication

Bispyribac-sodium influence on nutrient uptake by weeds and transplanted rice

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Key words: Bispyribac-sodium, Economics, Nutrient uptake, Transplanted rice

Rice (*Oryza sativa* L.) is the staple food for more than half of the world's population. It provides 27% dietary energy and 20% dietary protein in the developing world. Among the production constraints weed infestation has been recognized as major one and yield reduction due to crop weed competition has been reported to be 28 to 45% (Singh *et al.* 2003). Nutrient depletion by weeds, besides other factors, also depends on soil type and composition of weeds. Keeping these in view, the present investigation was undertaken to know the effect of different levels of bispyribac sodium 10% SC herbicide on nutrient uptake by transplanted rice.

Field experiment was conducted during Summer 2011 at Zonal Agricultural Research Station, V.C. Farm, Mandya, Karnataka to study the bio-efficacy of bispyribac-sodium on growth, yield and yield attributes of transplanted rice. The soil texture of the experimental field was red sandy loamy with low available N (274.6 kg/ha), medium in available P (27.2 kg/ha) and available K (174.3 kg/ha) with slightly acidic in reaction (pH 6.05). There were 11 treatments consisting of bispyribac-sodium 10% SC at 10, 15, 20, 25, 30 and 35 g/ha at 15 DAT, pretilachlor 50% EC at 750 g/ha at 5 DAT, bensulfuron-methyl + pretilachlor (10 kg/ha) at 8 DAT, hand weeding and passing cono-weeder twice at 20 and 40 DAT, respectively and unweeded check. The experiment was laid out in randomized complete block design (RCBD) with three replications. Twenty five days old seedlings (variety '*Jaya*') were transplanted at a spacing of 20 x 10 cm. Crop was raised by as per the recommendation of state university (10 t/ha FYM and 125:62.5:62.5 kg NPK/ha). Bispyribac-sodium was sprayed by knapsack sprayer fitted with flat fan nozzle using 500 l/ha of water as spray solution. The pre-emergence herbicides like pretilachlor and bensulfuron-methyl + pretilachlor were applied at 3 and 8 DAT, respectively. Weed population and weed dry weight of weeds were recorded at 60 DAT and yield and yield components at maturity. The data on weed count and weed dry weight were subjected to square root transformation using the formula $\sqrt{x + 0.5}$ and analysis was done. The composite plant and weed samples were collected at harvest was oven dried and grounded into fine powder using Wiley mill.

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Nitrogen, phosphorus and potassium content of the samples were estimated by microkjeldhal method, vanadomolybdo phosphoric yellow colour method and flame photometer method, respectively and subsequently the nutrient uptake by weeds, grain and straw was computed on hectare basis as computed by Sunil *et al.* (2011). The procedure followed by Sunil *et al*. (2011) was adopted to work out the economics of different weed control treatments information on the existing market price of different herbicides and inputs was used. The data collected were subjected to statistical analyses in the randomized complete block design following the method of Gomez and Gomez (1984).

Effect on weeds

Cyperus difformis, Cyperus iria, Fimbristylis woodrowii (among sedges); *Panicum repens, Echinochloa colona, Echinochloa crusgalli, Cynodon doctylon* (among grasses); *Rotala densiflora, Eclipta alba, Spilanthus calva, Portulaca quadrifida* (among broad-leaved weeds) were the major weeds associated with the transplanted rice.

Application of bispyribac-sodium 35 g/ha at 15 DAT recorded lower weed population and dry weight and this was statistically at par with bispyribac-sodium 30 g/ha at 15 DAT and bispyribac-sodium 25 g/ha at 15 DAT. Whereas, unweeded check recorded significantly higher weed population and weed dry weight. The reduction in the weed population and weed dry weight in these treatments were mainly due to effective control of weeds at all stages of crop growth period. These results confirmed findings of Veeraputhiran and Balasubramanian (2013).

Effect on yield

Application of bispyribac-sodium 25 g/ha at 15 DAT recorded significantly higher grain and straw yield as compared to unweeded check, which was also at par with the application of bensulfuron-methyl + pretilachlor (10 kg/ha) at 8 DAT. The increase in yield was mainly attributed to better control of weeds throughout the crop growth which resulted in better utility of nutrients, moisture and light by the crop which reflected through increased leaf area, number of productive tillers per hill, number of filled grains per panicle, panicle weight and test weight. These results were in conformity with the findings of Sunil *et al.* (2010). The lowest grain and straw yield were recorded in unweeded check owing to severe weed competition which resulted in reduction in the magnitude of growth and yield components (Table 2). Veeraputhiran and Balasubramanian (2013) recorded grain yield of 6.84 and 6.51 t/ha during 2010 and 2011, respectively by post-emergence application of bispyribac-sodium at 25 g/ha, which were at par with higher doses of bispyribac-sodium, twice hand weeding and weed free and significantly higher than butachlor application. However, Kumar *et al.* (2013), recorded bispyribac-sodium at 30 kg/ha dose as the best treatment in terms of net returns due to weed management in transplanted rice at Palampur, Himachal Pradesh

Effect on nutrient uptake by weeds and crop

Lowest uptake of nutrients by weeds was noticed with bispyribac-sodium 35 g/ha at 15 DAT (Table 1). The nutrient uptake by crops was inversely proportional to nutrient uptake by weeds. Similarly increase in nutrient uptake by increase in weed competition also reported by Singh *et al.* (2003).

Table 1. Effect of weed management practices on weed growth, nutrient uptake by weeds and its economics

Treatment	Weed population (no./m^2)	Weed dry weight (g/m^2)	Nutrient uptake by weeds (kg/ha)			Economics	
			N	P	K	Net returns (x10^3 `/ha)	B:C ratio
Bispyribac sodium 10 g/ha at 15 DAT	8.49(71.6)	3.79(13.9)	6.28	1.47	9.25	30.02	1.01
Bispyribac sodium 15 g/ha at 15 DAT	7.68(59.1)	3.41(11.2)	4.15	1.32	8.75	33.60	1.12
Bispyribac-sodium 20 g/ha at 15 DAT	7.06(49.3)	3.17(9.6)	3.52	1.28	6.23	37.45	1.23
Bispyribac-sodium 25g/ha at 15 DAT	5.71(32.1)	2.63(6.4)	1.18	0.25	1.75	45.48	1.48
Bispyribac-sodium 30 g/ha at 15 DAT	5.37(28.3)	2.41(5.3)	1.09	0.23	1.68	33.22	1.07
Bispyribac-sodium 35 g/ha at 15 DAT	5.12(25.7)	2.30(4.8)	1.02	0.21	1.62	32.76	1.04
Pretilachlor 750 g/ha at 5 DAT	7.24(52.0)	3.22(9.9)	5.82	1.45	7.08	30.23	1.01
Bensulfuron-methyl + pretilachlor 10 kg/ha at 8 DAT	7.08(49.7)	3.18(9.6)	3.45	1.25	6.15	39.47	1.29
Two hand weeding at 20 and 40 DAT	6.03(34.6)	2.68(6.7)	1.75	0.34	2.54	41.20	1.27
Conoweeder at 20 and 40 DAT	7.56(56.6)	3.33(10.6)	5.52	1.15	6.52	34.32	1.12
Unweeded check	11.78(132.3)	5.25(27.1)	12.32	2.78	20.28	22.28	0.85
LSD (P=0.05)	0.76	0.23	1.72	0.37	1.68		

DAT: days after transplanting, a.i.: active ingredient

Table 2. Effect of weed management practices on grain yield, straw yield and nutrient uptake by transplanted rice

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Nutrient uptake by transplanted rice (kg/ha)								
			N			P			K		
			Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
Bispyribac-sodium 10g/ha at 15 DAT	5.06	6.07	50.5	45.6	96.1	9.49	2.84	12.3	12.9	117.2	130.2
Bispyribac-sodium 15 g/ha at 15 DAT	5.39	6.47	54.2	48.6	102.7	10.1	3.03	13.1	13.8	124.9	138.8
Bispyribac-sodium 20 g/ha at 15 DAT	5.70	6.84	58.6	51.4	113.0	10.6	3.20	13.8	14.6	132.0	146.7
Bispyribac-sodium 25g/ha at 15 DAT	6.47	7.66	65.0	57.5	122.6	12.1	3.59	15.7	16.6	147.9	164.5
Bispyribac-sodium 30 g/ha at 15 DAT	5.45	6.54	54.7	49.1	103.9	10.2	3.06	13.2	13.9	126.3	140.3
Bispyribac-sodium 35 g/ha at 15 DAT	5.44	6.53	54.7	49.1	103.8	10.2	3.05	13.2	13.9	126.1	140.0
Pretilachlor 750 g/ha at 5 DAT	5.11	6.11	51.3	45.9	97.3	9.58	2.86	12.4	13.1	118.1	131.2
Bensulfuron-methyl + pretilachlor (10 kg/ha) at 8 DAT	5.99	7.23	60.2	54.3	111.6	11.2	3.39	14.6	15.3	139.6	155.0
Two hand weeding at 20 and 40 DAT	6.24	7.49	62.7	56.3	119.0	11.7	3.51	15.2	16.0	144.7	160.7
Cono weeder at 20 and 40 DAT	5.50	6.60	55.2	49.6	104.9	10.3	3.09	13.4	14.1	127.4	141.5
Unweeded check	4.10	4.92	41.2	37.0	78.2	7.69	2.30	9.99	10.5	95.0	105.5
LSD (P=0.05)	0.38	0.42	4.09	3.48	0.38	1.98	0.58	1.82	2.34	13.4	15.1

DAT: days after transplanting, a.i.: active ingredient

Application of bispyribac-sodium 35 g/ha at 15 DAT recorded significantly higher NPK uptake by transplanted rice as compared to unweeded check. However, it was at par with bensulfuron-methyl + pretilachlor (10 kg/ha) at 8 DAT. Higher nutrient uptake of crop in these treatments was mainly attributed to lower weed population and weed dry weight and this has helped the crop to grow well and absorb more nutrients from the soil. These results are in line with Sunil *et al*. (2011).

Economics

The lowest cost of cultivation was recorded with unweeded check. Whereas, highest cost of cultivation was recorded with two hand weeding at 20 and 40 DAT followed by application of bispyribac-sodium 35 g/ha at 15 DAT. Application of bispyribac-sodium at 25 g/ha at 15 DAT has recorded highest net returns and B:C ratio which was followed by bensulfuron-methyl + pretilachlor (10 g/ha) at 8 DAT. Whereas, the lowest net returns and B:C ratio was obtained in unweeded check (Table 2).

Correlation studies

The grain yield had significant and positive correlation with growth parameters like plant height at maturity, No. of leaves per hill, number of tillers per hill at maturity, leaf area at 90 DAS and total dry matter at maturity. The yield parameters such as number of productive tillers per hill, panicle length, weight of panicle, 1000-grain weight, number of filled grains per panicle showed significant and positive correlation with grain yield. There was a significant and positive correlation with total nitrogen uptake, phosphorus uptake and potassium uptake. The grain yield was significant and negatively correlated with weed parameters like total weed density at maturity and weed biomass at maturity. There was a significant and negative correlation between grain yield and weed uptake, v*iz*. N uptake, P uptake and K uptake (Table 3).

Table 3. Correlation between growth, yield, nutrient uptake parameters

Growth and yield attributes, nutrient uptake and weed parameters	Correlation coefficient (r)
Growth parameter	
Plant height at maturity	0.803*
No. of tillers at maturity	0.930*
No. of leaves per hill at maturity	0.847*
Leaf area at 90 DAS	0.911*
Total Dry Matter at maturity	0.913*
Yield parameter	
No. of productive tillers per hill	0.981*
Panicle length	0.958*
Weight of panicle	0.980*
1000 - grain weight	0.828*
No. of filled grains per panicle	0.951*
Nutrient uptake by transplanted rice at maturity	
Nitrogen uptake	0.996*
Phosphorus uptake	0.998*
Potassium uptake	0.997*
Weed parameter	
Weed density at maturity	-0.817*
Weeds biomass at maturity	-0.779*
Nutrient uptake by weeds at maturity	
Nitrogen uptake	-0.837*
Phosphorus uptake	-0.777*
Potassium uptake	-0.821*

*Correlation significant at P = 0.01

SUMMARY

Application of bispyribac-sodium 25 g/ha at 15 DAT recorded significantly lower total weed population and higher grain (6.47 t/ha) and straw yield (7.66 t/ha) as compared to pretilachlort 750 g/ha at 5 DAT. The nutrient uptake by weeds for N,P and K was significantly higher with unweeded check (12.32, 2.78 and 20.28 kg/ha, respectively). Whereas the lowest uptake was noticed with bispyribac-sodium 35 g/ha at 15 DAT (1.02, 0.21 and 1.62 kg/ha, respectively). The nutrient uptake by rice for N, P, and K was significantly higher with bispyribac-sodium 25 g/ha at 15 DAT (122.66, 15.74 and 164.51 kg/ha, respectively) as compared to unweeded check (78.24, 9.99 and 105.58 kg/ha, respectively). Similar trend was observed with net returns and B:C ratio.

REFERENCES

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

Kumar S, Rana SS, Chander Navell and Ramesh. 2013. Mixed weed flora management by bispyribac-sodium in transplanted rice. *Indian Journal of Weed Science* **45**(3): 151–155.

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.

Sunil CM, Shekara BG, Ashoka P, Kalyana murthy KN and Madhukumar V. 2011. Effect of integrated weed management practices on nutrient uptake in aerobic rice (*Oryza sativa* L.), *Research on Crops* **12**(3): 629-632.

Sunil CM, Shekara BG, Kalyanamurthy KN, Shankaralingappa BC. 2010. Growth and yield of aerobic rice as influenced by integrated weed management practices. *Indian Journal of Weed Sciences* **42**(3&4): 180-183.

Veeraputhiran R and Balasubramanian R. 2013. Evaluation of bispyribac-sodium in transplanted rice *Indian Journal of Weed Science* **45**(1): 12–15.

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Short communication

Effect of tillage and herbicides on rhizospheric soil health in wheat

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Key words: Free-living nitrogen fixing bacteria, Phosphate solubilising bacteria, Soil biomass carbon, Soil respiration, Percent root colonization, Phosphate solubilising bacteria

Adoption of intensive cropping systems has resulted in a long-scale use of agro chemicals. Weeds as one of the groups of pest are the major biological constraint, and lack of suitable eco-friendly weed control alternatives has led to increase in reliance on herbicides in many crops. Generally herbicides are not harmful when applied at recommended rates (Selvamani and Sankaran 1993) but some herbicides may affect non-target organisms including microorganisms (Shukla 1997). These effects on non target organisms may reduce the performance of important and critical soil functions such as organic matter decomposition, nitrogen fixation and phosphate solubilisation which support the soil health, plant growth and in turn crop productivity. Therefore, knowledge about effects of long-term application of herbicide on soil microbes is highly essential. Hence, present investigation to study the long-term effect of different tillage systems and application of herbicides for rice-wheat cropping systems in wheat crop was carried out to find effect on physic-chemical and microbial properties in the rhizosphere soil.

Field experiment was conducted during 2012-13 in rice-wheat cropping system at Narendra Dev University of Agriculture and Technology, Kumarganj, Faizabad, Uttar Pradesh. The main plot treatments included tillage system, *viz*. Zero- zero tillage (Z-Z tillage), zero-conventional tillage (Z-C tillage), conventional-zero tillage (C-Z tillage), conventional-conventional tillage (C-C tillage) while the sub-plot treatments included weed management measures such as hand weeding at 35 and 55 DAS, isoproturon 1.0 kg/ha + 2,4-D + 1 HW (45 DAS) and weedy check. Rhizospheric soils were collected randomly from the top layers of the soil depth (0-15 cm) from each plot at 50 DAS and at harvest for rhizospheric soil health studies from experimental field during *Rabi* season 2012 using standard methods.

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Effect of tillage system

Establishment methods had no significant effect on physico-chemical and microbial properties at 50 DAS, and at harvest stages. Among various tillage systems, slight improvement in physico-chemical and microbial properties was observed under zero tillage as compared to conventional tillage. This was mainly due to slight improvement in organic carbon percentage.

At 50 DAS, maximum free-living 'N' fixing bacteria (FLNFB), phosphate solubilizing bacteria (PSB), soil biomass carbon (SBC), soil respiration and enzyme activities (acid –P, alkaline-P and dehydrogenase) was recorded in Z-Z tillage (11.72 c.f.u. x 10^4/g, 11.50 c.f.u. x 10^4/g, 112.75 µg, 93.21 µgp- NP/h/g and 15.12 µg TPF/h/g). Similar trend were also recorded at harvest (Table 1). Maximum beneficial micro organisms were recorded at harvest stage. It may be due to improvement in physico-chemical and biological properties of soil.

Effect of weed control measures

Weed control measures did not affect soil properties. However, significant variations were observed in microbial properties between two hand weeding and herbicides (isoproturon 1.0 kg/ha + 2, 4-D + 1 HW). This was mainly due to herbicide effect. Maximum microbial properties *i.e.* FLNFB (12.50 cfu × 10^4), PSM (11.55 cfu × 10^4), SBC (113.11 µg), SR (60 mg per 100 soil/d), PRC (14), Acid-P (94.11 µgp-NP/h/g), alkaline-P (164.20 µgp-NP/h/g) and DHA (18.52 µg) was observed in two hand weeding. Among various weed control measures, maximum microbial population was recorded in hand weeding and minimum in herbicide treated plots. Hand weeding always promotes aeration in soil, it involves a bit of rhizosphere soil mixing and this can contributes to enhanced microbial activities. While Bhale *et al.*(2012) reported that hand weeding allows pulverization of soil and better soil aeration which ultimately increase the microbial population in the soil.

Table 1. Effect of establishment methods and weed management practices on soil microbial properties of rhizospheric soil of wheat

Treatment	50 DAS								At harvest						
	FLNFB	PSM	SBC	SR	PRC	Acid P	Alkaline P	DHA	FLNFB	PSM	SBC	SR	Acid P	Alkaline P	DHA
Tillage system															
Z-Z	11.7	11.5	112	0.55	13.0	93.2	158	15.1	17.5	13.9	104	0.48	90.0	153	15.5
Z-C	11.5	10.9	112	0.54	11.5	92.7	157	15.1	15.8	13.7	102	0.45	80.5	154	14.9
C-Z	10.4	10.0	111	0.52	11.3	92.2	162	15.0	15.7	12.2	100	0.45	85.7	155	14.0
C-C	10.5	10.5	111	0.54	12.0	91.0	161	14.5	15.1	13.5	100	0.48	88.0	157	14.7
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weed control															
HW at 35 and 55 DAS	12.5	11.5	113	0.60	14.0	94.1	164	18.5	15.1	14.0	110	0.62	92.2	160	16.0
Isoproturon 1.0kg/ha + 2,4-D + 1 HW (45 DAS)	10.1	9.2	103	0.57	10.5	87.2	152	12.1	13.0	12.2	107	0.58	90.1	157	12.5
Weedy check	10.2	10.0	105	0.53	10.1	89.5	155	13.0	13.2	12.3	106	0.51	90.3	152	10.1
LSD (P=0.05)	1.20	1.25	6.50	0.14	2.20	3.50	6.50	1.27	NS	NS	NS	0.15	NS	5.90	1.37

PSM- P-solubilizing microorganism (c.f.u. x 10^4/g); Acid P -Acid -phosphate activity (µgp-NP/h/g); Alkaline P -Alkaline -phosphate activity (µgp-NP/h/g); SBC –Soilbiomasscarbon (µg); DHA - De-hydrogenase activity (µg TPF/h/g); SR - Soil respiration (mg CO_2 per 100 soil/d); PRC - Percent root colonization

Further results revealed that isoproturon + 2,4-D applied in wheat under rice-wheat cropping system did not leave any residual harmful effect on physico-chemical and microbial properties of the soil.

It was concluded that various tillage system and weed control measures in wheat crop did not leave any harmful residual effect on physico-chemical and microbial properties of the soil.

SUMMARY

Four tillage systems *viz.* (i) zero–zero tillage (ii) zero-conventional tillage (iii) conventional-zero tillage (iv) conventional–conventional tillage systems were evaluated on the survival and growth of free living nitrogen fixing bacteria, total phosphate solubilising bacteria, soil biomass carbon, soil respiration, per cent root colonization and enzymic activities in rhizospheric soil. Among weed control measures, comparative effects of hand weeding and recommended herbicides (isoproturon at 1.0 kg/ha + 2,4-D + 1 HW (45 DAS) were tested along with weedy check. The results revealed that tillage systems did not influence microbial soil health. The maximum growth of different micro organisms was observed in zero tillage system, whereas minimum was in conventional tillage system. There were no adverse effects of recommended herbicide use on soil microbial health. Application of isoproturon + 2,4-D had no adverse effect on rhizosphreric soil health of wheat crop.

REFERENCES

Bhale VM, Karmore JV and Patil YR. 2012. Integrated weed management in groundnut. *Pakistan Journal of Weed Science Research* **18**: 733-739.

Selvamani S and Sankaran S. 1993. Soil microbial population as affected by herbicides. *Madras Journal of Agriculture* **80**: 397-399.

Shukla AK. 1997. Effect of herbicide butachlor, fluchloralin, 2,4-D and oxyfluorfen on microbial population and enzyme activities of rice field soil. *Indian Journal of Ecology* **24**: 189-192

Singh JP and Tarafdar JC. 2002. Rhizospheric micro-flora as influenced by sulphur application, herbicides and rhizobium inoculation in summer mungbean. *Journal of Indian Society of Soil Science* **50**(1): 127-129.

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Short communication

Integrated weed management in blackgram

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Blackgram (*Vigna mungo* L.) is one of the important pulse crops grown in India, which belong to the family "Leguminoseae". It is consumed in various forms as whole or split, husked and unhusked. It is rich in protein (24%), carbohydrate (60%), fat (1-5 %), amino acids, vitamins and minerals and much richer than most of grains used as concentrate. In India, blackgram producing states are Andhra Pradesh, Bihar, Madhya Pradesh, Maharashtra, Uttar Pradesh, West Bengal, Punjab, Haryana, Tamil Nadu, Karnataka, Odisha and Gujarat. It is grown in an area of about 3.06 million ha with a total production of 1.70 million tones with average productivity of 555 kg/ha (AICRP on MULLaRp, 2014-15). The area under summer blackgram is increasing by leaps and bounds in South Gujarat, where perennial irrigation facilities are available from Ukai-Kakarapar irrigation project. The area and production of this crop is about 1.09 lakh hectares and 0.73 lakh million tones, respectively with productivity of 672 kg/ha in the state (Anon. 2014).

Amongst the various factors known to augment the crop production, weeds form a single negative factor, which play key role against achieving full yield potential of the crop. The critical period of crop weed competition in blackgram crop is from 15 to 45 DAS (Vats and Sawhney 1980). Use of herbicides has become imperative due to costly labour and their unavailability. The use of herbicides can be reduced if used in integrated manner. This work was done to find out suitable integrated method for the weed control in blackgram besides other suitable method.

The experiment was carried out during summer season of 2014 at Navsari Agricultural University, Navsari (Gujarat) with 10 treatments in three replication. The soil popularly known as "Deep Black" soil with pH 7.98, EC 0.36 dS/m, available N 230 kg/ha, P 38 kg/ha, K 379 kg/ha. Summer blackgram variety *"T-9"* was sown at 20 kg/ha at 30 cm row spacing on February 15, 2014. Crop was grown with recommended package of practices except weed management. Inter-culturing operation was carried out in inter row space through bullock drawn implement and simultaneous removal of weeds manually in intra row space. All the herbicide were applied with manually operated knapsack sprayer fitted with flat fan nozzle at a spray volume of 500 l/ ha. Weed count was recorded at 30, 60 DAS and at harvest. Dry weight of weeds was recorded at harvest. Data were subjected to square root ($\sqrt{x + 0.5}$) to transformation.

Experimental field was infested with *Cyperus rotundus*, *Echinochloa crusgalli*, *Digitaria sanguinalist, Sorghum halepense, Cynodon dactylon, Amaranthus viridis, Alternanthera sessillis, Digera arvensiss* and *Convolvulvulus arvensis.*

All herbicidal and integrated treatments significantly reduced the weed density and their biomass over weedy check. The lowest dry weight of weeds was found in pendimethalin 1.0 kg/ha as PE + hand weeding at 30 DAS and highest dry weight of weeds was recorded in plot treated with oxyfluorfen 0.18 kg/ha PE + imazethapyre 1.0 kg/ha at 30 DAS as post-emergence (POE). The lowest weed index of 2.07% and the highest weed control efficiency (80.96%) was registered under pendimethalin 1.0 kg/ ha PE + HW at 30 DAS, which was closely followed by oxyfluorfen 0.18 kg/ha as pre-emergence + HW at 30 DAS (79.2%) and pendimethalin 1 kg/ha as pre-emergence + IC at 30 DAS (77.3%). The finding matched with the results of Vivek *et al.* (2008) and Kaur *et al.* (2009).

The results indicated that different weed control treatments exerted their significant influence on plant growth characters. Among all weed control treatments, plant height and branches/plant were significantly higher in weed free, which was followed by pendimethalin 1.0 kg/ha as PE + hand weeding at 30 DAS, oxyfluorfen 0.18 kg/ha PE + hand weeding

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Table 1. Effect of weed-control treatments on weed index, weed control efficiency, dry weight of weeds growth and yield attributes of blackgram

Treatment	Weed index (%)	Weed control efficiency (%)	Dry weight of weeds (kg/ha)	Plant height (cm)	Pods/ plant	Test weight (g)	Grain yield (t/ha)	Stover yield (t/ha)	Net returns (x10^3 `/ha)	B:C ratio
Weedy check	26.4	0	143.7	17.7	15.6	29.2	0.55	1.22	17.3	2.35
Weed free	0.0	100.0	0.0	28.2	23.1	36.8	1.25	2.67	52.5	4.43
Pendimethalin 1 kg /ha as PE + IC at 30 DAS	3.7	77.3	32.6	26.7	20.5	35.3	1.10	2.34	45.0	3.96
Pendimethalin 1 kg /ha as PE + hand weeding at 30 DAS	2.1	81.0	27.3	27.9	22.2	36.0	1.22	2.61	50.4	4.18
Pendimethalin 1 kg /ha as PE + imazethapyre 0.1 kg/ha at 30 DAS (PoE)	17.2	70.0	43.1	19.8	18.2	32.1	0.74	1.62	23.7	2.43
Pendimethalin 1kg /ha asPE+ quizalofop-p-ethyl at 0.05 kg/ha at 30 DAS (PoE)	13.6	73.7	37.8	23.1	18.9	33.5	0.77	1.70	25.9	2.60
Oxyfluorfen 0.18 kg/ha PE + IC at 30 DAS	11.7	75.5	35.2	26.3	19.9	34.7	0.86	1.90	32.4	3.23
Oxyfluorfen 0.18 kg/ha PE+ hand weeding at 30 DAS	3.6	79.2	29.9	27.6	21.7	35.8	1.19	2.44	49.1	4.24
Oxyfluorfen 0.18 kg/ha PE + imazethapyre 0.1 kg /ha at 30 DAS (PoE)	18.1	68.2	45.8	18.5	17.1	30.3	0.64	1.40	19.0	2.19
Oxyfluorfen 0.18 kg/ha PE + quizalofop-p-ethyl 0.05 kg/ha at 30 DAS (PoE)	15.5	71.8	40.5	21.6	18.8	32.6	0.75	1.66	25.2	2.62
LSD (P=0.05)	9.6	3.9	5.8	2.6	2.5	4.8	0.17	0.39	-	-

at 30 DAS, pendimethalin1.0 kg/ha as PE + IC at 30 DAS and oxyfluorfen 0.18 kg/ha PE + IC at 30 DAS (Table 1).Test weight (g), increased significantly with pendimethalin 1.0 kg/ha as PE + hand weeding at 30 DAS (35.97 g). Significantly maximum number of pods/plant (23.09) was recorded in weed free, but it was found at par with pendimethalin 1.0 kg/ha as PE + hand weeding at 30 DAS and oxyfluorfen 0.18 kg/ ha PE + hand weeding at 30 DAS. The increase in growth attributes under these treatments might be attributed due to the reduction in weed competitiveness with the crop, which ultimately favored better environment for growth and development of crop. Similar findings were reported by Kaur *et al.* (2009).

Effect of integrated weed management was found on seed yield significantly (Table 1). Pendimethalin 1.0 kg/ha as PE + hand weeding at 30 DAS produced highest grain and stover yield of 1.22 and 2.61 t/ha, respectively, and closely followed by oxyfluorfen 0.18 kg/ha PE + hand weeding at 30 DAS with seed and stover yield of 1.19 t/ha and 2.44 t/ha; pendimethalin 1.0 kg/ha as PE + IC at 30 DAS seed and stover yield of 1.11 t/ha and 2.34 t/ha. However, all these treatments were at par with weed free treatment. Higher grain yield under integrated weed control treatments (herbicide + hand weeding) may be attributed mainly to the better control of weeds during different stages, manual removal of emerging weedsby hand by herbicides and thereby providing better yield attributes. (Chhodavadia *et al.* 2013).

Weed-free treatment recorded significantly higher uptake of N, P and K by crop and remained at par with pendimethalin 1.0 kg/ha as pre-emergence + HW at 30 DAS, oxyfluorfen 0.18 kg/ha as pre-emergence + HW at 30 DAS and pendimethalin 1.0 kg/ha as pre-emergence + IC at 30 DAS. It can be explained in the light of the facts that these treatments controlled the weeds effectively, might have made more nutrients available to crop and consequently encouraged higher concentration of nutrients and more yield and thereby higher uptake of nutrients by the crop.

Significant increase in protein content in weed free (25.70%) was followed by pendimethalin 1.0 kg/ ha as PE + hand weeding at 30 DAS, oxyfluorfen0.18 kg/ha PE+ hand weeding at 30 DAS, pendimethalin1.0 kg/ha as PE + IC at 30 DAS, pendimethalin 1.0 kg/ha as PE + quizalofop-p-ethyl 0.05 kg/ha at 30 DAS (POE), oxyfluorfen 0.18 kg/ha PE + IC at 30 DAS and oxyfluorfen at 0.18 kg/ha PE+ hand weeding at 30 DAS (Table 2). This can be ascribed to better control of weeds by manual weeding and integration with herbicidal method as compared to unweeded condition, which might have increased uptake of nutrients and water.

Maximum gross and net return of ₹ 67846 and ₹ 52533/ha, respectively were realized under weed free which was closely followed by pendimethalin 1.0 kg/ha as PE + hand weeding at 30 DAS, oxyfluorfen 0.18 kg/ha PE + hand weeding at 30 DAS and pendimethalin 1.0 kg/ha as PE + IC at 30 DAS.

Table 2. Effect of weed-control treatments on protein content and nutrient uptake by blackgram and weeds

Treatment	Protein content in (%)	Nutrient uptake (kg/ha) Crop			Weed		
		N	P	K	N	P	K
Weedy check	23.4	20.7	5.25	16.8	26.4	2.45	16.8
Weed free	25.7	51.3	7.50	23.7	0.0	0.00	0.0
Pendimethalin 1 kg/ha as PE + IC at 30 DAS	24.9	44.2	6.75	21.4	15.1	1.40	8.4
Pendimethalin 1 kg/ha as PE + hand weeding at 30 DAS	25.4	49.7	7.25	22.9	11.3	1.05	5.6
Pendimethalin 1 kg/ha as PE + imazethapyr 0.1 kg/ha at 30 DAS (PoE)	23.9	28.3	5.75	18.3	22.6	2.10	14.0
Pendimethalin 1 kg/ha asPE+ quizalofop-p-ethyl at 0.05 kg/ha at 30 DAS (PoE)	24.4	30.2	6.25	19.8	18.8	1.75	11.2
Oxyfluorfen 0.18 kg/ha PE + IC at 30 DAS	24.7	34.0	6.50	20.6	17.0	1.57	9.8
Oxyfluorfen 0.18 kg/ha PE+ hand weeding at 30 DAS	25.2	47.8	7.00	22.1	13.2	1.22	7.0
Oxyfluorfen 0.18 kg/ha PE + imazethapyr 0.1 kg /ha at 30 DAS (PoE)	23.6	24.3	5.50	17.5	24.5	2.28	15.4
Oxyfluorfen 0.18 kg/ha PE + quizalofop-p-ethyl 0.05 kg/ha at 30 DAS (PoE)	24.1	28.9	6.00	19.1	20.7	1.93	12.6
LSD (P=0.05)	1.49	7.43	1.19	3.66	3.68	0.32	1.68

SUMMARY

Weed free treatment produced highest seed yield which was at par with pendimethalin 1.0 kg/ha as pre-emergence (PE) + hand weeding at 30 DAS and oxyfluorfen 0.18 kg/ha PE + hand weeding at 30 DAS. However, among the other treatments, pendimethalin 1.0 kg/ha as PE + hand weeding at 30 DAS was found superior in controlling weeds and increasing seed yield.

REFERENCES

AICCIP on MULLaRp 2014-15. *Annual Report*, Publish from IIPR- Kanpur, 26 p.

Anonymous. 2014. *District Wise Area, Production and Yield/ha of Important Food and Non-food Crops in Gujarat State*. Department of Agriculture, Gujarat state, Krushi Bhavan paldi, Ahemadabad.

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

Kaur G, Brar HS, and Singh Guriqbal. 2009. Effect of weed management on weeds, growth and yield of summer mungbean (*Vigna radiata* L.). *Indian Journal of Weed Science* **41**(3&4): 228-231.

Vivek NS, Rana, RS and Tomar SS. 2008. Effect of weed interference on weeds and productivity of blackgram (*Phaseolus mungo* L.). *Indian Journal of Weed Science* **40**(1&2): 65-67.

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Short communication

Weed control in fenugreek with pendimethalin and imazethapyr

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Fenugreek (*Trigonella foenum-graecum* L.) locally known as 'Methi' in Hindi, is an important multiuse spice crop of arid and semi-arid regions of India. Fenugreek is an annual herb with trifoliate leaves and it can grow to be about two feet tall belongs to family Fabaceae. India is the largest producer of fenugreek in the world where Rajasthan, Gujarat, Uttaranchal, Uttar Pradesh, Madhya Pradesh, Haryana and Punjab are the major fenugreek producing states. Rajasthan produces the lion's share of India's production, accounting for over 80% of the total fenugreek output (Anonymous 2012). In Haryana, the crop is sown in an area of 4978 ha with seed production of 13,973 tonnes (Anonymous 2009). Growth of fenugreek is very slow in the initial stage and it does not form a canopy that can suppress weed growth until several weeks after sowing. Therefore, the crop faces severe competition from weeds causing yield reductions from 14.2 to 69.0% depending upon density and duration of competition.

Manual weeding for weed control in fenugreek is generally not accomplished at critical period of crop weed competition due to non-availability of labour. In earlier studies, pendimethalin 0.75 kg/ha and fluchloralin 0.75 kg/ha were reported effective chemicals to control weeds in fenugreek. In the present study imazethapyr and a few other herbicides have been evaluated to control weeds in this important crop.

Field experiment was conducted on sandy loam soil of KVK farm, Jind (Haryana) during *Rabi* season of 2011-12. The soil of the experimental field was sandy loam in texture with low in organic carbon (0.23%) and available N (210 kg/ha), medium in P (13 kg/ha) and high available K (556 kg/ha) with slightly alkaline pH (8.3) and EC 1.13 dS/m. The experiment was laid out in randomized block design with three replications. There were 14 weed control treatments *viz*. weedy check, weed free, two hoeing at 25 and 50 DAS, pendimethalin 1.0 kg/ha, trifluralin 1.0 kg/ha and three doses (35, 45 and 55 g/ha) of imazethapyr each applied as PPI, PRE and at 2-4 trifoliate leaf stage replicated thrice making a total of 42 experimental units, each measuring 6 x 6 m^2. The required quantity of herbicides was worked out and was mixed with water and sprayed uniformly at different stages of crop growth with knapsack sprayer fitted with flat fan nozzle at a spray volume of 500 l/ha. Category-wise weed density (no./m^2) and biomass of weeds (g/m^2) were recorded by putting a quadrate (50 x 50 cm^2) at two random spots in each plot at 25, 50, 75, 100 DAS and at harvest. Fenugreek cultivar '*HM-103*' was sown in lines 30 cm apart during last week of November in each experimental unit. All the recommended package of practices was followed to raise the crop. The crop was harvested during last week of April, 2012. Data on weed density and biomass of weeds were transformed using $\sqrt{X+1}$ before subjected to statistical analysis and weed control efficiency (WCE) was calculated based on the biomass accumulated by the weeds.

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Effect on weeds

The experimental field was infested with broad-leaved weeds comprised of *Chenopodium album, Chenopodium murale, Melilotus indica* and *Rumex dentatus.*

All weed control treatments significantly reduced the total population and dry matter accumulation by weeds than weedy check (Table 1). Trifluralin as PPI, pendimethalin as pre-emergence (PRE) and imazethapyr 55 g/ha either applied as PPI or PRE provided excellent control of weeds up to 25 DAS. At 100 DAS and at harvest, post-emergence application of imazethapyr (55 g/ha) significantly reduced the weed population over other herbicidal treatments. Excellent efficacy of this herbicide against broad-leaved weeds was also reported by Sikkema *et al.* (2005).

Chenopodium album and *C. murale* accumulated more dry weight and were real culprit in crop-weed competition. Pendimethalin and trifluralin at 1.0 kg/ha caused significant reduction in weed dry weight recorded at 25 and 50 DAS. Efficient control

Table 1. Weed flora as influenced by weed management practices at different crop growth stages

Treatment	Weed population (no/m^2)				Biomass of weeds (g/m^2)				WCE (%)
	25 DAS	50 DAS	100 DAS	Harvest	25 DAS	50 DAS	100 DAS	Harvest	
Imazethapyr (35 g/ha) PPI	8.7 (75)	12.0 (122)	12.2 (147)	11.4 (128)	6.6	43.4	108.1	110.4	40
Imazethapyr (45 g/ha) PPI	7.9 (62)	10.4 (107)	11.5 (132)	10.8 (115)	5.0	36.4	99.6	101.6	45
Imazethapyr (55 g/ha) PPI	6.2 (37)	7.5 (56)	9.6 (91)	9.1 (81)	3.0	20.9	72.7	77.2	58
Imazethapyr (35 g/ha) PRE	8.7 (74)	11.0 (120)	11.9 (140)	11.2 (125)	6.9	41.9	104.5	105.9	42
Imazethapyr (45 g/ha) PRE	7.9 (61)	10.2 (103)	11.2 (125)	10.4 (107)	4.8	32.8	97.4	98.0	47
Imazethapyr (55 g/ha) PRE	5.8 (33)	7.4 (53)	9.2 (83)	8.4 (69)	2.6	21.1	70.1	75.7	59
Imazethapyr (35 g/ha) 2-4 trifoliate leaf stage	10.3(105)	8.0 (63)	9.5 (90)	9.1 (81)	8.6	29.4	90.0	82.7	55
Imazethapyr (45 g/ha) 2-4 trifoliate leaf stage	9.8 (95)	7.2 (51)	8.7 (75)	8.3 (67)	6.5	26.1	77.6	73.0	60
Imazethapyr (55 g/ha) 2-4 trifoliate leaf stage	9.1 (81)	5.5 (29)	7.0 (48)	6.2 (37)	5.6	15.0	53.1	58.3	69
Trifluralin (1000 g/ha) PPI	6.2 (38)	8.7 (75)	9.4 (88)	8.7 (75)	2.8	23.9	80.3	92.5	50
Pendimethalin (1000 g/ha) PRE	5.6 (30)	8.3 (68)	8.9 (78)	8.1 (65)	2.7	22.5	77.0	87.6	52
Two hoeing 25 and 50 DAS	11.5(131)	1.0 (0)	4.0 (15)	3.5 (11)	11.0	0.0	11.5	18.3	90
Weed free	1.0 (0)	1.0 (0)	1.0 (0)	0 (0)	0	0	0	0	100
Weedy check	12.0 (142)	14.9 (221)	16.82(282)	16.1(258)	15.7	75.2	181.7	184.2	0
LSD (P=0.05)	0.5	0.3	0.3	0.31	1.3	2.5	4.7	5.3	-

DAS- Days after sowing; PE - Pre-emergence; PPI - Pre plant incorporation

of weeds in fenugreek by pendimethalin applied as pre-emergence at 750-1000 g/ha has been reported earlier (Narender *et al.* 2014). At 100 DAS and at harvest, pendimethalin showed slightly better control of weeds over trifluralin and imazethapyr (55 g/ha) applied as pre-plant incorporation or pre-emergence. Two hand hoeings proved very effective in minimizing density of all weeds at all the stages of crop growth. Maximum weed control efficiency (69%) was achieved with post-emergence use of imazethapyr (55 g/ha) which was higher than trifluralin and pendimethalin.

Effect on crop

Effect of different weed control treatments was also observed on yields attributing character *viz.* pods per plant, seeds per pod, test weight, grain yield per plant and grain yield. Significantly lower values of pods per plant, seeds per pod, test weight and seed yield were recorded under weedy check and highest values of these were recorded in weed free and two hoeing. The yield attributes in plots treated with pendimethalin at 1.0 kg/ha were statistically at par with post-emergence application of imazethapyr at 55 g/ha. Among herbicidal treatments maximum grain yield (kg/ha) was recorded with post-emergence use of imazethapyr at 55 g/ha which was significantly higher than all other herbicidal treatments. Number of seeds per pod and grain yield per plant in trifluralin treated plots was significantly less as compared to post-emergence use of imazethapyr at 55 g/ha.

Test weight, and grain yield were highest in plots kept weed free throughout the crop season. The comparative economics showed that pendimethalin at 1.0 kg/ha was most economical weed control treatment with net returns of ₹ 9712/ha with benefit-cost ratio of 1.99 which was closely followed by post-emergence application of imazethapyr at 55 g/ha (₹ 9609/ha) and benefit-cost ratio of 1.93. Thus for econo-effective weed management in fenugreek, pre-emergence application of pendimethalin at 1.0 kg/ha or post-emergence use of imazethapyr at 55 g/ha may be adopted as an alternative to manual weeding with maximum returns and seed yield. Among herbicidal treatments, the lowest return over weedy check was given by imazethapyr at 35 g/ha applied as pre-plant incorporation.

Economics

The comparative economics of various weed control treatments is presented in table 2. Data of the present investigation revealed that to raise an economical crop of fenugreek, proper weed management is must. Pendimethalin at 1.0 kg/ha gave the highest return (₹ 8542/ha) over weedy check followed by imazethapyr (55 g/ha) applied at 2-4 trifoliate leaf stage and pre-emergence. Among herbicidal treatments, the lowest return over weedy check was given by imazethapyr at 35 g/ha applied as pre-plant incorporation.

Table 2. Yield attributes, yield, net returns and benefit: cost ratio of fenugreek as influenced by herbicdes

Treatment	No. of pods/ plant	No. of seeds/ pod	Test weight (g)	Grain yield/ plant (g)	Grain yield (t/ha)	Net returns (x10^3 `/ha)	B:C
Imazethapyr (35 g/ha) PPI	58.5	15.6	11.3	8.6	1.06	3.98	1.40
Imazethapyr (45 g/ha) PPI	71.2	17.3	11.7	9.9	1.19	5.42	1.53
Imazethapyr (55 g/ha) PPI	92.2	17.9	11.7	11.3	1.44	840	1.81
Imazethapyr (35 g/ha) PRE	62.1	15.3	11.5	8.9	1.11	4.56	1.46
Imazethapyr (45 g/ha) PRE	72.2	16.8	11.8	10.4	1.21	5.66	1.56
Imazethapyr (55 g/ha) PRE	94.2	18.2	12.0	11.8	1.48	8.94	1.86
Imazethapyr (35 g/ha) 2-4 trifoliate leaf stage	62.6	16.2	11.3	8.9	1.11	4.62	1.46
Imazethapyr (45 g/ha) 2-4 trifoliate leaf stage	84.2	17.2	11.8	10.0	1.23	5.97	1.59
Imazethapyr (55 g/ha) 2-4 trifoliate leaf stage	95.5	18.4	12.0	11.9	1.53	9.61	1.93
Trifluralin (1000 g/ha) PPI	92.3	17.8	12.0	11.3	1.44	8.87	1.90
Pendimethalin (1000 g/ha) PRE	92.9	18.4	12.1	11.7	1.48	9.71	1.99
Two hoeing 25 and 50 DAS	99.7	18.2	11.9	11.9	1.55	4.97	1.32
Weed free	101.6	19.0	12.3	13.3	1.63	3.66	1.20
Weedy check	51.7	15.1	10.9	7.04	0.79	1.17	1.12
LSD (P=0.05)	3.41	0.59	0.17	0.41	0.05	-	-

DAS- Days after sowing

SUMMARY

Trifluralin as PPI, pendimethalin as pre-emergence and imazethapyr at 55 g/ha either applied as PPI or PRE provided excellent control of weeds up to 25 DAS. At 100 DAS and at harvest, post-emergence application of imazethapyr (55/ha) significantly reduced the weed population over other herbicidal treatments. Maximum dry matter accumulation by the crop, yield and yield attributes were recorded in weed free plots which was significantly higher over all herbicidal treatments. Maximum weed control efficiency (69%) was observed with post-emergence application of imazethapyr 55 g/ha.

REFERENCES

Anonymous. 2009. *Annual Functional Plan 2009-10*. Directorate of Horticulture, Haryana, India.

Anonymous. 2012. *Spice Board of India*. Ministry of Commerce and Industry, Government of India.

Mandam AR and Maiti RG. 1994. Efficacy of different herbicides for weed control in fenugreek (*Trigonella foenum-graecum* L.). *Trop Pest Management* **35**(3): 138-142.

Sikkema P, Deen W and Vyas S. 2005. Weed control in pea with reduced rates of imazethapyr applied pre-emergence and post-emergence. *Weed Technology* **19**: 14-18.

Narendra Singh, Mundra SL and Kaushik MK. 2014. Production potential of fenugreek as influenced by weed management practices. *Indian Journal of Weed Science* **46**(2): 197-199.

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Short communication

Weed management in zero-till sorghum

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Key words: Sorghum, Weed management, Yield, Zero tillage

Sorghum [*Sorghum bicolor* (L.) Moench] cultivation under zero tillage is practiced under rice-fallow conditions after *Kharif* rice in coastal districts of Andhra Pradesh. Usually, farmers grow pulses (greengram and blackgram) in rice-fallows in the Krishna-Godavari zone of Andhra Pradesh as "utera" crop (broadcasting of seeds in standing crop of rice). However, in recent times, the area under pulses has declined due to late planting of rice and severe attack of viral diseases (YMV) and parasitic weed (dodder). Farmers of this region are now growing maize (in assured irrigated areas) and sorghum (in limited irrigated areas) in rice-fallows as an alternate crop to pulses (Mishra *et al.* 2011). Weed problem in zero-till sown sorghum is severe due to lack of field preparation, left over weeds from previous rice crop and excess moisture during early stages of crop growth. Though information pertaining to weed control in normal sown crop is available but in zero till sown sorghum it is scanty. Keeping this in view, the present investigation was undertaken to study the effect of weed management practices on weed control and yield of zero till sown sorghum.

Field experiment was conducted at Agricultural College Farm, Bapatla during *Rabi* 2011-12 on sandy clay loam soil with pH 7.8, low in organic carbon (0.49 per cent) and available N (227 kg/ha), P (80 kg/ha) and K (440 kg/ha). Experiment comprising of ten treatments (Table 1) was laid out in a randomized block design with three replications. Sorghum variety '*Mahalakshmi'* was sown after the harvest of rice crop with a spacing of 45 x 10 cm. Fertilizers were applied to the plots as N-P_2O_5-K_2O 100-60-60 kg/ha through urea, SSP, MOP respectively. The entire amount of P and half of K was applied as basal dose prior to sowing as band placement. N was top-dressed as 20 kg/ha as basal, 40 kg/ha at 30 DAS and 40 kg/ha at 60 DAS along with 30 kg/ha of K fertilizer.

All the herbicidal treatments were applied with a manually operated knapsack sprayer fitted with flat fan nozzle using a spray volume of 500 l/ha. The data on weed density was subjected to square root transformation using $\sqrt{x + 0.5}$ to reduce large variations.

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Weed flora

The major weed flora of the experimental field were *Cynodon dactylon*, *Digitaria marginata*, *Cyperus rotundus*, *Cleome viscosa*, *Physalis minima* and *Convolvulus arvensis*. Other weeds were *Echinochloa colona*, *Panicum repens*, *Fimbristylis miliaceae*, *Euphorbia hirta*, *Phyllanthus maderaspatensis* and *Xanthium strumarium*.

All the weed control treatments significantly reduced the density and dry weight of weeds compared to weedy check at 60 DAS (Table 1). Among the treatments, the lowest weed density, dry weight and highest weed control efficiency (WCE) of 65% was observed in the sequential treatment with pre-emergence application of pendimethalin 0.75 kg + paraquat 0.5 kg/ha *fb* post-emergence application of 2,4-D amine 0.58 kg/ha and was at par with other sequential treatments and hand weeding at 20 and 40 DAS, but significantly superior to pre-emergence application of herbicides. The lower weed growth in these treatments was mainly due to effective control of weeds in the early stage by pre emergence herbicides and at later stage by post emergence herbicides. Maximum weed growth was observed in unweeded check. In general, sequential treatments were found to be superior to one time application of herbicides. Similar observations reported in normal sown sorghum by Sharma *et al.* (2000).

All the herbicides under study were found to be selective to sorghum crop without any injury. All the weed management treatments exhibited profound influence on grains per panicle, grain and straw yield (Table 2). Among the treatments, highest grain yield (7.13 t/ha) was observed in sequential treatment with the pre-emergence application of pendimethalin 0.75 kg + paraquat 0.5 kg/ha *fb* post-emergence application of 2,4-D amine salt 0.58 kg/ha at 30 DAS and was at par with other sequential treatments and hand weeding at 20 and 40 DAS but significantly

Table1. Effect of different treatments on weed and crop growth parameters

Treatment	Weed density (no./m^2) at 60 DAS	Weed dry weight (g/m^2) at 60 DAS	WCE at 60 DAS (%)	Plant height at 60 DAS (cm)	Crop dry weight at 60 DAS (t/ha)
Hand weeding 20 and 40 DAS	5.8 (33.8)	45.7	68	183	11.9
Atrazine alone (1.0 g/ha) 2 DAS	8.2 (69.0)	84.6	42	159	8.8
Pendimethalin alone (0.75 g/ha) 2 DAS	8.5 (71.8)	86.8	43	160	8.4
Atrazine + paraquat (1.0+0.5 g/ha) 2 DAS	8.2 (68.2)	84.1	42	163	9.8
Pendimethalin + paraquat (0.75+0.5 g/ha) 2 DAS	8.2 (67.2)	83.6	43	160	10.2
Atrazine alone (1.0 g/ha) 2 DAS *fb* 2,4-D amine salt (0.58 g/ha) 30 DAS	7.0 (49.5)	62.9	57	169	11.0
Pendimethalin alone (0.75 g/ha) 2 DAS *fb* 2,4-D amine salt (0.58 g/ha) 30 DAS	6.9 (48.2)	56.7	62	168	11.4
Atrazine + paraquat (1.0+0.5 g/ha) 2 DAS *fb* 2,4-D amine salt (0.58 g/ha) 30 DAS	7.0 (48.5)	53.9	63	181	11.7
Pendimethalin + paraquat (0.75+0.5 g/ha) 2 DAS *fb* 2,4-D amine salt (0.58 g/ha) 30 DAS	6.9 (47.5)	53.0	65	186	12.5
Weedy check	11.0 (122.0)	150.1	-	152	8.1
LSD (P=0.05)	1.8	25.8	13	19	2.8

Figures in parentheses are original values

Table 2. Effect of different treatments on yield attributes, yield and economics in zero till sown sorghum

Treatment	Panicle length (cm)	Grains per panicle (no.)	100-seed weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Net monetary returns (x10^3 `/ha)	Returns per rupee of investment
Hand weeding 20 and 40 DAS	34.9	1896	2.03	6.98	9.94	61.42	4.17
Atrazine alone (1.0 g/ha) 2 DAS	31.4	1739	1.99	5.03	8.64	46.32	4.71
Pendimethalin alone (0.75 g/ha) 2 DAS	31.9	1730	1.93	5.13	8.51	46.79	4.59
Atrazine + paraquat (1.0+0.5 g/ha) 2 DAS	31.5	1765	1.98	5.49	9.18	50.64	4.77
Pendimethalin + paraquat (0.75+0.5 g/ha) 2 DAS	31.0	1797	2.01	5.66	9.51	52.05	4.72
Atrazine alone (1.0 g/ha) 2 DAS *fb* 2,4-D amine salt (0.58 g/ha) 30 DAS	32.3	1865	2.10	6.64	9.74	63.84	5.87
Pendimethalin alone (0.75 g/ha) 2 DAS *fb* 2,4-D amine salt (0.58 g/ha) 30 DAS	32.5	1884	1.96	6.77	9.85	64.77	5.74
Atrazine + paraquat (1.0+0.5 g/ha) 2 DAS *fb* 2,4-D amine salt (0.58 g/ha) 30 DAS	33.9	1876	2.01	6.83	9.86	65.07	5.63
Pendimethalin + paraquat (0.75+0.5 g/ha) 2 DAS *fb* 2,4-D amine salt (0.58 g/ha) 30 DAS	34.6	1930	2.09	7.13	9.93	67.84	5.64
Weedy check	29.2	1507	1.82	4.67	8.80	43.00	4.62
LSD (P=0.05)	NS	233.5	NS	0.93	0.56		

Note: Sorghum grain: ₹ 11.00/- kg. Sorghum straw: ₹ 0.40/-kg.

superior to pre-emergence application of herbicides. The increased grain yield in these treatments might be due to cumulative effect of lower weed density, dry weight, higher WCE and increased number of grains per panicle. The lowest grain yield (4.67 t/ha) was observed in weedy check with an yield loss of 52.8% as compared to the best treatment because of severe weed competition during the crop growth period. Regarding economics, the treatment pendimethalin 0.75 kg + paraquat 0.5 kg/ha *fb* post-emergence application of 2,4-D amine 0.58 kg/ha recorded higher net returns (₹ 67,840/ha) but the highest benefit cost ratio (₹ 5.87) obtained with pre-emergence application of atrazine 1.0 kg/ha *fb* 2,4-D amine 0.58 kg/ha at 30 DAS, which was due to differences in cost of inputs. Thus, it can be summarized that pre-emergence application of atrazine 1.0 kg/ha *fb* 2,4-D amine 0.58 kg/ha at 30 DAS was found to be effective and economical for weed management in zero till sown sorghum as an alternative to hand weeding.

REFERENCES

Mishra JS and Rao SS. 2011. Integrated weed management in sorghum. *Indian Farming* **61**(2): 7-11.

Rao SS, Regar PL, Jaingid BL and Singh YV. 2007. Effect of nutrient and weed management on forage sorghum (*Sorghum bicolor*) under rainfed condition. *Indian Journal of Agronomy* **52**(2): 879-883.

Sharma RP, Dadheech RC and Jat LN. 2000. Effect of atrazine and nitrogen on weed growth and yield of sorghum [*Sorghum bicolor* (L.) Moench]. *Indian Journal of Weed Science* **32**(1&2): 96-97.

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Short communication

Leaching behaviour of metsulfuron–methyl

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Key words: Metsulfuron-methyl, Leaching, Soil, HPLC

A major concern about weed management in the agricultural scenario is persistence, mobility, and bioavailability of pesticide residues in the environment (Sachan *et al.* 2007). Long persistence and high mobility of a herbicides increase the risk of contamination of surface water and ground water. Metsulfuron-methyl [2-(4-methoxy-6-methyl-1, 3,5-triazin-2-yl-carbamoylsulfamoyl) methyl benzoate] is selective pre-emergence and post-emergence sulfonylurea herbicide, used primarily to control various broad-leaf and grassy weeds. It was already established that sulfonylurea group of herbicides are very effective against various broad-leaf weeds and grasses. Metsulfuron-methyl is a systemic compound with foliar and soil activity and it works rapidly after it is taken up by the plants. It is very effective on weeds that include bulbs or tubers and is extensively used in agriculture in India. Work on metsulfuron fate and leaching has been done by some workers (Pons and Barriuso1997 and James *et al.* 2004). Despite its extensive use, very little is known about its percolation potential in Indian soil (Sondhia 2009, Singh *et al.* 2014). Thus, our objective was to evaluate the downward movement/leaching potential of metsulfuron-methyl with representative clay loam soil of Pantnagar, Uttarakhand, India.

Soil samples of different depth, *i.e.* 0-15, 15-30, 30-45, and 45-60 cm from N.E Borlaug Crop Research Center, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India were collected, air dried and passed through a 2 mm sieve. Soil was clay loam (clay 32.0%. silt 44.0% and sand 24.0%.) with 1.30% organic carbon, 7.34 pH and 0.174ms EC. Technical and commercial grade of metsulfuron-methyl (Convo 20 WP) obtained from M/s Atul Ltd, Valsad, India was used in leaching experiments.

Leaching experiment was conducted in 2009 at room temperature and arranged in completely randomized design with three replicates. The leaching studies were performed in columns made from vertically polyvinyl chloride columns (10 cm internal diameter and 60 cm long). The columns were cut longitudinally into two halves and rejoined by using packing tape. The average volume of the column was recorded. One end of PVC column was covered with muslin cloth and a funnel was attached to the bottom of each column for collection of leachates into 1000 ml flasks. Individual columns were packed with 6.5 kg clay loam soil (1.75 kg for 45-60 cm, 1.70 kg for 30-45 cm, 1.55 kg for 15-30 cm and 1.50 kg for 0-15 cm depth respectively). Columns were filled with soil according to the different depth taken. Columns were saturated overnight by flowing water from above and also keeping them dipped in water contained in a bucket. Excess water was drained out by 1 day drainage cycle and columns were covered with aluminum foil to prevent evaporation. For monitoring vertical movement and leaching loss of metsulfuron-methyl, 10 ml of the herbicide was applied to surface of column with pipette at recommended dose *i.e.* 4 g/ha.

The addition of water was done for seven days at the rate of 200 ml for 12 h per day (equivalent to 1730 mm annual rainfall) so that infiltration rate of soil does not exceed. A set of soil columns receiving same amount of water only served as control. Water eluting from the column was collected daily in flask and processed for analysis of herbicide. After seven days, when addition of water was completed, the soil columns were allowed to dry for 24 hours. Columns were cut into two halves and the soil was cut into 5 cm segment each and processed for residue analysis. Detection and quantification of metsulfuron-methyl was done by HPLC.

A 20 gm representative air dried soil sample was extracted with 50 ml of dichloromethane: methanol (1:3 v/v) shaken over an orbital shaker for one hour and filtered. The procedure was repeated twice with 25 ml of solvent mixture. All filtrates were pooled and concentrated to 1 ml under vacuum at 45±1 ^{o}C. The extract was loaded on a pre-washed solid phase C-18

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solid phase extraction (SPE) cartridge and eluted by using methanol. Elute obtained was dried under vacuum and the residue was filtered through 0.22µ millipore PTFE filter and dissolved into HPLC grade acetonitrile for further analysis.

Water sample (50 ml) of leachate was liquid – liquid partitioned with methylene chloride (100 ml and twice with 50 ml), the organic layer was pooled and was dried over anhydrous sodium sulphate and volume was reduced to dryness in a rotary vacuum evaporator (40±1^{o}C). The residue was filtered through 0.22µ Millipore PTFE filter and dissolved in 5 ml mobile phase.

The Beckman model 322 Gradient HPLC systems equipped with 100 A pump 420 gradient microprocessor controller, 7725i rheodyne injector, 160 selectable wavelength UV detector, 5 µl loop and HP 3395 series integrator recorder. The operating parameters were Column: Supelco's ODS-II column 5µm (250 x 4.6 mm i.d.), mobile phase: Acetonitrile: Methanol: Water: (6:3:1v/v), mode: isocratic, flow rate: 1ml/min, chart speed: 1 cm/min, aufs: 0.02 and UV detection at 229 nm.

The per cent recovery values of metsulfuron-methyl in water and soil is given (Table 1). The amount of residues of metsulfuron-methyl in different fractions of leachates which were collected from 1 to 7 days are presented (Table 2). The data showed that, no residue of metsulfuron-methyl was detected in the first fraction of leachate of 1st and 2nd day. Residue starts appearing in 3rd to 7th day leachate fraction. The concentration of the herbicide in the leachate, increased from 3rd to 5th day. It was highest on 5th day, but decreased thereafter. The content of metsulfuron-methyl in 5th day fraction of leachate was 0.54 µg/ml.

Table 1. Per cent recovery of metsulfuron-methyl from water and soil

Metsulfuron-methyl (ppm)	Water	Soil
0.5	89.05± 0.01	87.30± 0.02
1.0	92.51± 0.01	89.42± 0.02
2.0	94.44± 0.03	90.39± 0.01

Table 2. Concentration of metsulfuron-methyl in the leachates

Day	Metsulfuron-methyl (µg/ml)
1	ND
2	ND
3	0.17± 0.03
4	0.36 ± 0.05
5	0.54 ± 0.07
6	0.47 ± 0.07
7	0.32± 0.08

Values are mean of three replicates

The per cent recovery values of applied metsulfuron-methyl in leachate and soil columns were out of 13 µg a.i metsulfuron-methyl added to soil column, 8.86 µg (68.75 %) was recovered from the soil, 2.06 µg (15.84%) from water and 2.08 µg (16.00 %) was lost during processing of the soil/ water samples.

The distribution of herbicide residue in soil cores at different depths after passing 1.40 liters of water has been presented (Table 3). Surface applied metsulfuron-methyl got distributed throughout the whole length of column but the distributed concentration varied at different soil depths. The residue concentration was more at the middle of column mainly at the depth of 30 to 35 cm, then it started to decrease from 40 to 60 cm indicating high mobility of metsulfuron-methyl in soil column.

Table 3. Concentration of metsulfuron-methyl in different sections of soil columns.

Soil depth (cm)	Metsulfuron-methyl (mg/kg)
0-5	0.58 ± 0.01
5-10	0.67 ± 0.07
10-15	0.75± 0.10
15-20	0.79 ± 0.07
20-25	0. 89± 0.08
25-30	0.92 ± 0.07
30-35	1.08 ± 0.02
35-40	1.00± 0.02
40-45	0.84 ± 0.08
45-50	0.74 ± 0.01
50-55	0.66 ± 0.08
55-60	0.38 ± 0.04

Values are mean of three replicates

As metsulfuron-methyl has low affinity to organic carbon and therefore more susceptible to leaching, this might have added further on movement of metsulfuron-methyl under saturated moisture conditions. In this study, soil columns received continuous 200 ml water per day (equivalent to 1730 mm annual rainfall) that may be the reason that metsulfuron-methyl could be detected at all depths and accumulated highest in the middle of the column and detected in the leachates.

The reason for this pattern is also related to soil pH and organic carbon content. Metsulfuron-methyl is adsorbed poorly in acidic soils (pH 5.6-6.5) and soil column experiments with freshly treated acid soils (pH 5.6-6.7) showed that 85 to 100% of the applied radio labeled compound leached through the columns

(Anonymous 1987). In soils with a higher pH, the mobility of metsulfuron-methyl is expected to increase because of increased solubility, increased ionization of the chemical and decreased adsorption and organic matter which lowers the pesticide degradation by adsorption processes (Pal *et al*. 2005). Walker *et al.* (1989) reported adsorption of metsulfuron-methyl herbicide and found negative correlation of the herbicide with soil pH, while positive correlation with soil organic matter content and microbial biomass.

Metsulfuron-methyl degradation mainly resulted in the formation of the amino-triazine. In the acidic soil, degradation was characterised by rapid hydrolysis giving two specific unidentified metabolites. Low recovery of metsulfuron-methyl could be due to the result of chemical hydrolysis, mineralization of metsulfuron-methyl, formation of different metabolities as well as formation of bound residues (Pons and Barriuso 1997). Results of the controlled laboratory studies cannot be reliably extrapolated to field conditions and field studies will be a more realistic approach.

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SUMMARY

Leaching potential of metsulfuron-methyl herbicide was evaluated under laboratory conditions in Mollisol soil of Pantnagar, Uttarakhand with simulated rainfall. Metsulfuron- methyl was applied at recommended dose (4 g/ha) on 60 cm long soil columns. After seven days of experiment, maximum concentration was observed in 30-35 cm column depth and some amount of herbicide leached out and was detected in leachates. Study indicated high mobility of metsulfuron-methyl under saturated moisture conditions which may pose significant ground water contamination.

REFERENCES

Anonymous. 1987. *Agriculture : Canada Food Production Direction and Inspection* Branch Production Pesticide Information Division of the Plant Industry Directorate. *www. pmra_publication@hc-sc.gc.ca.*

James TK, Rahman A, Mellsop JM and Trolov M. 2004. Effect of rainfall on the movement and persistence of metsulfuron-methyl and clopyralid applied to pasture. *New Zealand Plant Protection* **57**: 271-276.

Pal R, Chakrabarti K, Chakraborty A. and Chowdhury A. 2005. Pencycuron application to soils: degradation and effect on microbiological parameters. *Chemosphere* **60**(11): 1513-1522.

Pons N and Barriuso E. 1997. Fate of metsulfuron-methyl in soils in relation to pedo-climatic conditions. *Pesticide Science* **53**(4): 311-323.

Sachan HK, Misha OP and Tandon S. 2007. Studies on harvest time residue of butachlor in soil, rice grain and straw. *Pestology* **31**(6): 43-44.

Singh N, Raunaq and Singh SB. 2014. Effect of fly ash on metsulfuron-methyl sorption and leaching in soils. Journal of Environmental Science and Health, Part B: Pesticides, *Food Contaminants and Agricultural Wastes* **49**(5): 366-373.

Sondhia S. 2009 Leaching behaviour of metsulfuron in two texturally different soils. *Environmental Monitoring and Assessment* **154**(1): 111-115.

Walker A, Cotteril EG and Welch SJ. 1989. Adsorption and degradation of chlorsulfuron and metsulfuron-methyl in soils from different depths. *Weed Research* **29**(4): 281-287.