Indian Journal of Weed Science

Print ISSN 0253-8040
Online ISSN 0974-8164

Volume – 50 | Number – 3
July – September, 2018

Available Online @ www.indianjournals.com

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

Indian Journal of
Weed Science

Volume 50 Number 3 July– September, 2018

Review articles

Research articles

Research notes

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

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

Indian Journal of Weed Science **50**(3): 201–208, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Intractable weed problems need innovative solutions using all available technologies

Jonathan Gressel*

Plant & Environmental Sciences, Weizmann Institute of Science, Rehovot, 76100 Israel

**Email: jonathan.gressel@weizmann.ac.il*

Article information

DOI: 10.5958/0974-8164.2018.00049.7

Type of article: Review article

Received: 29 September 2018
Revised : 03 October 2018
Accepted: 16 October 2018

Key words
Gene drives
Herbicide resistance
Herbicide safeners
Herbicide synergists
Innovation
Multisite herbicides
Transgenics

ABSTRACT

There is often strong public dissent to innovations, typically fanned by those who lose out economically, but the reasons they promulgate are not economic and are targeted to public emotions. Agriculture has some problems that have been intractable to present technologies and we have no choice but to utilize new technologies to overcome them. These include developing new herbicides that affect multiple targets, new selective synergists and safeners, transgenic herbicide resistant plants that will not have the transgenes expressed in related weeds, using transposons or gene drives to disseminate deleterious genes in weeds, sterile pollen, enhanced-virulence biocontrol agents with sustaining formulations. These might be workable for multiple resistant *Amaranthus* and *Echinochloa* species, parasitic weeds, *Phalaris* in wheat as well as weedy rice in rice. Per force, most of the innovations must originate in the public sector, by weed scientists who have a broad training in basic sciences, in collaboration with experts from other fields.

INTRODUCTION

Innovation and its enemies

There are a growing number of seemingly intractable weed problems that are globally prevalent on a large scale, as discussed in the following sections. The present solutions are often not realistic solutions, as they may include compromises such as lower yield, more costly or expensive herbicides, or more environmentally-degrading cultivations, growing alternative less effected but lower yielding varieties or other crop species that are less appropriate. Innovative solutions may be out there already, or can be conceived and tested but are not – because too many weed scientists feel uncomfortable when out of the box, lack the basic knowledge on which to base innovation and/or are reluctant to collaborate with colleagues in other areas who could assist, as well as the many that fear the wrath of detractors who view innovation as a threat.

A book that is required reading for anyone interested in being an innovator was written by the late Kenya native, Harvard University Professor of the Practice of International Development, Calestous Juma. In "Innovation and its Enemies: Why people resist new technologies" (Juma 2016), he describes the many types of detractors of new technologies. They are all typically vested interests that will be the economic or political losers if the technology is adopted. They never tell you that their reason is their pocket book; they make up lies such as it is unsafe, will cause cancer, impotence, is unnatural, scientists are playing God, *etc*., *etc*., all targeted to achieve a hysterical response in the media, and an emotional negative response in the public. He points out that the general public typically is more convinced by pseudoscience over science.

Juma describes how these detractors may come from very different ends of the spectrum. In our case dealing with innovations in weed control they include:

- So-called environmental activists who need a target around which to garner financial contributions by generating hysteria – whether about herbicides or transgenics.

- It includes those who have anti-globalization politics and are against multinational corporations.

- It includes NGOs that want to keep the poor impoverished so that they can stay in business.

- It includes organic growers and their lobbyists who do not like seeing conventional growers using more cost-effective systems.

- Last but not least in this unholy alliance are the chemical companies who make far less profits from seeds, or herbicides with synergists and protectants, than high rate herbicides.

- The detractors are supported by an eminent (but misogynist) economist who claimed that the use of glyphosate resistant maize in Africa is a bad idea because it will take jobs (hand weeding) away from women.

Still – innovations do get adopted, as Juma points out – there is always someone wise enough to accept them. A local case in point is Bt brinjal, developed in India that replaces huge levels of insecticide. It is being grown in Bangladesh but banned in India.

This author is old enough to remember all those who were against the innovative green revolution in rice and wheat. There are still detractors claiming that it was a failure, but how many millions or billions of lives were saved by from starvation this counterintuitive innovation?

There has never been an agricultural innovation that has been sustainable forever. They all have and will have problems because weeds evolve. Let us remember that the green revolution was predicated on having adequate methods of selective weed control. If not for these chemicals, breeders would still be breeding taller and taller wheat and rice, ignoring that the weeds co-evolve to be taller and taller.

Detractors often lobby regulators that they should demand absolute proof of safety from new innovations, knowing full well that this is impossible. Safety assessments should be relative – is the innovation as safe or safer than currently used technologies used for the same purpose? If it meets those standards, farmers should be given the option of choice. In summary, we should not be afraid of being innovative – just be cognizant of the impediments that have little to do with our science. We must also conceive strategies that better explain the value and safety of our innovations that will preempt the detractors. The intractable weed problems, if not dealt with – threaten world food security. It is an existential matter of life or death.

Examples of major weed problems

We now have four species that supply 80% of the calories for humans and their livestock: rice, wheat, maize and soy. They had the genetic diversity to become global crops. Some weed species also have the genetic diversity to be camp followers and have evolved to cover most of the same agro-ecosystems as the crops they follow. Unfortunately, this same genetic diversity has allowed some of these weeds to evolve resistance to all our efforts, whether breeding, cultivation technologies, or herbicides. Herbicides are the last major innovation to be developed in this continual evolutionary race, and no new major mode of action has been released in decades, and the weeds have caught up, including to the mutational and transgenic development of new herbicide selectivities. Examples are discussed below.

Echinochloa species

Echinochloa species are especially prevalent in rice and maize where they had been effectively controlled for half a century by herbicides. They have evolved either metabolic or target-site resistance to herbicides having ten modes of action, especially in rice (Heap 2018).

Amaranthus spp

Amaranthus spp, which cross among themselves have evolved resistances to almost all the herbicides that had previously controlled them (Heap 2018). Farmers are having to perform more erosion causing tillage and other costly programs with only partial success. A major part of the problem was injudicious over and repeated use of the same herbicide until resistance evolved, then another was used, and then another, as each fell by the wayside to the inevitable forces of evolution. There are many workable strategies that could have delayed this evolution, but farmers were not willing to adopt them, often following the advice of salespeople who assured the farmers that should resistance evolve, industry would develop new compounds.

Root-attaching parasitic weeds

Striga species are widely spread throughout sub-Sahara Africa, especially on maize, the millets, sorghum, and recently in wheat. *Orobanche/ Phelipanche* species are prevalent on all solonaceous, legume and umbelliferous crops as well as sunflowers in northern Africa, the Middle East, southern and eastern Europe and to a lesser extent in India. They were never selectively controlled by herbicides while still underground. The parasites inflict sufficient crop damage that it is uneconomical to control them after they emerge. Farmers could not afford to do so to prevent seed set and spread, exacerbating the situation. Most of the claimed successes with breeding have been transient; the parasites evolve too quickly. These weeds are the subject of a recent book that discusses all aspects about them and their control (Joel *et al.* 2013).

Phalaris in wheat

Phalaris species have evolved metabolic and target-site resistances to many herbicides globally in the semi-arid regions where wheat is grown (Heap 2018). The situation is especially acute in India with *Phalaris minor* (Chhokar and Sharma 2008), due to a special agro-ecosystem that exacerbates the problem. Contrary to what some scientists claim, *Phalaris* was not recently introduced to India on foreign grain – it has been in India since it was inadvertently brought by the Moghuls centuries ago when they introduced wheat. It became a major problem where summer rice/winter wheat is grown. The flooding of the paddies killed other winter-germinating weeds providing a niche where *Phalaris* had little competition, including from high-yielding dwarfed wheat. The use of a single herbicide, too often where at least part of a field had a low, near sub-lethal dose allowed for the evolution of a non-target site resistance that already pre-conferrs a modicum of resistance to herbicides that followed, and one by one the herbicides succumbed to the powers of evolution. More labour intensive cultural practices as well as alternative rotational crops have somewhat alleviated the problems thanks to the short seedbank longevity of *Phalaris* (this too could evolve). Most farmers would far prefer to return to a single treatment with an inexpensive herbicide, especially as labour costs become dearer thanks to industrialization that provides higher wages outside of agriculture.

Weedy rice in rice

Most of the domestication traits of rice are homozygous recessive, including non-shattering, uniform germination, lack of seed pigmentation, as well as suppressed height. Constantly occurring dominant back mutations to the feral weedy form had been culled when choosing good seed for the rice nurseries. Transplanting into flooded paddies gave the true rice a long head start on the weedy forms, limiting damage.

Direct seeding was implemented in every rice-growing area when industrial incomes precluded costly hand transplanting, allowing weedy rice to prosper (Ziska *et al.* 2015). Too often bulk seed contaminated with weedy rice was planted, and together with the weedy rice in the seedbank, the effects were devastating. As rice and weedy rice are the same species and have the same metabolic pathways, there could be no selective herbicides that control weedy rice. When mutant imidazolinone-resistant rice was introduced to control weedy rice, the trait was rapidly rendered worthless for weedy rice control because it crossed into weedy rice. The same will happen when transgenic herbicide resistance is introduced (Zhang *et al.* 2018), unless innovative measures are taken to mitigate transgene flow to weedy rice. The imidazolinone-resistant rice was effective for *Echinochloa* spp control for a longer period, but this weed too mutated to resistance. In parts of the world where they have considerable amounts of available land, crop rotation together with using certified rice seed became the control method for weedy rice. Those are not places where rice is a major part of the diet. The best that can be done in other areas is delayed planting followed by a general herbicide or cultivation before plant to kill emerged weedy rice with certified seed, and other expensive alternatives, but with lower potential yield.

Some possible innovative solutions

It is clear that we cannot revert back to back-breaking labour-intensive solutions to deal with these problems. If those who propose returning to manual cultivation were made to perform such labour, their attitudes would quickly change. Thus, for food security the above problems (and many others) require innovative and not retrogressive solutions.

Some of the solutions suggested below have been on the books for decades but were not implemented because companies, scientists, and politicians were cowed by detractors and the hysteria they generate. Advanced scientific knowledge has opened more windows showing that in theory other solutions should work. Some proposed solutions are still in the realm of science fiction and others will be conceived and developed by the most innovative among the readers.

Echinochloa, spp.

Transgenic glyphosate herbicide resistant maize has been highly effective in controlling *Echinochloa*. The same genes would be effective in rice and similar strains could possibly be obtained by gene editing (e.g. CRISPR Cas9, and the like). Gene edited plants are not considered transgenic (GMOs) by regulators in the USA, Japan, Israel, but are in technologically backward Europe. Most other jurisdictions have yet to decide. From a scientific point of view this is moot, as there is no credible evidence of danger from either transgenic or gene-edited technologies.

In at least one case, it was shown that adding a synergist that blocked resistant *Echinochloa* from catabolizing the herbicide allowed adequate control without affecting the crop (Leah *et al.* 1997). This and the following approach have not been followed up by the chemical industry.

Safeners (sometimes called protectants) are chemicals that activate a herbicide degradation pathway in the crop rendering the crop resistant to the herbicide. In sorghum, such compounds have allowed protection against members of the chloroacetamide group of herbicides. They are applied to the seed before planting and thus, the weed shattercane, which is a con-specific, feral form of sorghum, can be controlled. If there were such seed-applied safeners were marketed for rice, both *Echinochloa* spp., and weedy rice could be controlled.

With the introduction of inexpensive glyphosate, industry cut back on herbicide discovery and even more so on synergist and safener development. The US and European agrichemical and biotechnology companies pay less attention to rice, where *Echinochloa* is a major issue. It is unfortunate that the giant pesticide manufacturers in India and China do not seem to have had discovery programs that have led to new chemical control options for *Echinochloa* in rice. They should understand the local market need better than others.

***Amaranthus*, spp**

These have evolved resistance somewhere to all the major herbicides, often in different locations using different modes of resistance for the same herbicide. This is especially evident with glyphosate due to the clearly unsustainable use of glyphosate as the sole herbicide multiple times per season, year after year on glyphosate-resistant maize and soy. The use of glyphosate mixtures with other herbicides might have delayed the evolution of resistance, had they been chosen based on criteria of similar biological half-lives, different control mechanisms, *etc*. (Wrubel and Gressel 1994). This is because the likelihood of a weed having mutations of resistance to two herbicides is like the mutation frequency of resistance to one herbicide multiplied by the mutation frequency to the second herbicide. The unbased and untenable view of the manufacturer was that it was nigh impossible for weeds to solve resistance to glyphosate (Bradshaw *et al.* 1997), a view that was contradicted before the Pollyanna view was published (Gressel 1996).

None of the resistances to glyphosate seem to be metabolic in nature, so classical synergists that prevent catabolism are out of the question. A new class of synergists, chemically synthesized double stranded interference RNA (RNAi) with a specific sequence that binds and prevents the messenger RNA expression that confers resistance, was trumpeted a few years ago (Arnason 2014), but little has been heard since, and there is no published evidence that it got further than a greenhouse. It would require a different synthetic RNAi for each mode of resistance as well as knowing what resistance occurs in each field.

A theoretical approach first suggested for insect control (Grigliatti *et al.* 2001) and later (theoretically) adapted for weeds. The suggestion for *Amaranthus* was to release transgenic *Amaranthus* seeds that contain multi-copy transposons that are either engineered to have deleterious genes that must be induced by a chemical treatment, or contain an RNAi that targets the mRNA that confers resistance (Gressel and Levy 2014). The advantage of using multicopy transposons to carry deleterious genes vs. engineering the same genes into the nucleus is that there is no genetic segregation with multi-copy transposons. The multicopy transposons appear in all subsequent progeny. To the best of my knowledge, no one has yet to try to convert this concept from science fiction to reality.

A possibly easier to regulate system for dealing with intractable weeds that are obligatory out-crossers or even predominantly out-crossers; the use of gene drive systems, was recently proposed (Neve 2018). Gene drive systems introduce deleterious genes or mutations into a population using gene-editing systems such as CRISPR-Cas9, but with a twist. The constructs are made in such a way that the Cas9, which cuts the genes targeted by CRISPR cannot be bred out. Thus a CRISPR that suppresses a gene, whether by directly rendering the weed unfit, or rendering it susceptible to a herbicide, will spread throughout the population of weeds bearing the construct after being planted in the field. The system has worked well mosquitoes, but is not infallible, and thus a weed such as an *Amaranthus*, will not go extinct but will eventually be reduced to a low frequency.

One start-up company is testing another concept – this one has proven highly successful in insects – the use of sterile males. In their case they collect pollen from *Amaranthus*, sterilize it and disseminate sterile pollen on patches of just flowering *Amaranthus* (Weedout 2018). They have shown that the sterile pollen successfully competes with fertile pollen and the resulting seeds have but vestiges of shrunken embryos. Their idea is to integrate their technology as a last resort with other technologies, and use it late in the season on remaining *Amaranthus* patches that were not otherwise controlled. Their first field trials are being evaluated. If successful, this technology could be used against other weeds that are obligate out-crossers.

Instead of long-ago using mixtures when they might have helped delay resistance, mixtures are now being developed especially for low canopy soy, which gets towered over by *Amaranthus* species. Most *Amaranthus* biotypes have yet to evolve resistances to auxin type herbicides, so the approach was to make transgenic soy resistant to these herbicides (Montgomery *et al.* 2018). The mixtures are not true mixtures against the resistant amaranths, as they are already resistant to one component. The soy transformations were successful, but the dicamba, which was formulated in such a way that the chemical companies were sure would not drift caused extensive damage in neighboring fields – drifting quite a distance damaging non-transgenic soy as well as other dicamba susceptible crops (WSSA 2018).

Root-attaching parasitic weeds

Over two decades ago it was demonstrated that transgenic crops, engineered to have target site resistance to systemic herbicides would allow control of these parasitic weeds (Joel *et al.* 1995). The systemic herbicides glyphosate, chlorsulfuron, and asulam were translocated undegraded from leaf to root, in such transgenic herbicide resistant crops where they killed the parasite. The costs of regulatory approval and the fear of the wrath of technology detractors prevented adoption. A modification of this technology was adapted for *Striga* control in eastern Africa; the use of mutant imidazolinone-resistant maize developed in the USA. The gene was backcrossed into African maize hybrids in the homozygous form and instead of expensively spraying the herbicide, tenfold less herbicide per hectare was applied as a seed treatment, and remained highly concentrated beneath the seed (Ransom *et al.* 2012). The concentration throughout the season of their 12-14 week to harvest maize is such that *Striga* would require having a simultaneous mutation to resistance on both alleles to become resistant to this local concentration. Despite widespread use of the technology, resistance has yet to evolve. It probably will evolve when adapted to western Africa 20-22 week maize, unless far more herbicide and/or slow release formulated herbicide is used. At the currently used herbicide level, by mid-season enough herbicide will probably be degraded to allow heterozygous resistant individuals to thrive in these long season varieties. Some of their progeny will have homozygous resistance, ending the utility of the technology.

Nucleic acids travel at least short distances between host and parasite. Host plants were engineered to produce an RNAi that targets a gene specific to the parasite. This resulted in a statistically significant but agronomically insignificant suppression of the parasite (Aly *et al.* 2009), and the concept was dropped nearly a decade ago. We now know more about how RNAi works, and it has given total suppression of some pathogen genes when multiple sites are targeted by having different RNAi producing segments in a construct (Gressel and Polturak 2018). These RNAi encoding segments are very short, so such constructs with many RNAi generating segments are easy to engineer. It was proposed to retry the process using this technique, while targeting genes that are heavily expressed at the time of parasite attachment to the crops (Gressel 2018).

There is a plethora of reports of finding specific pathogens against parasitic weeds, but except for one, all have been failures in the field. This is to be expected; if a weed-specific pathogen provided the high level of weed control desired by a farmer, the pathogen and the weed would have become extinct. Still, a hypervirulent pathogen can be produced and be continuously cultivated in the lab and continuously be disseminated in the field. This is still not sufficient; the biocontrol agent needs sustenance until it encounters the weed in the soil and can attack it. The one recently successful case had nearly double than average crop yield in 500 trials in *Striga* infested farmers' fields over two seasons (Nzioki *et al.* 2016). Their solutions were to mutagenize their fungal pathogen to overproduce and excrete amino acids that are lethal to the parasite and without effect on maize, affording the needed hypervirulence. The second issue was solved by having the farmers inoculate freshly boiled rice with pure strains of the pathogen supplied on toothpicks in sealed plastic drinking straws. When the pathogen had actively infected the rice, grains with pathogen were placed with maize seeds in the planting holes. The rice provides nutrition for the *Striga*-pathogenic mycelia to penetrate far afield in the soil profile near the germinated crop until it reaches a *Striga* seedling.

Phalaris in wheat

Transgenic, or possibly gene editing, derived wheat with target site or metabolic resistance to glyphosate as well as to other herbicides that control *Phalaris* would clearly be effective. It might last quite a long time if some of the lessons learnt with *Phalaris* and isoproturon (as well as glyphosate with other herbicides) are remembered and adopted. Under-dosing must be avoided (Gressel 2017), whether the under-dosing is due to adulterated herbicide, attempts to save by using lower doses, non-uniform application and/or late treatments where the dose is insufficient at that growth stage. The ability to have more than one wheat variety with resistances to different herbicides and have them used in rotation would clearly delay the evolution of resistance.

Industry has developed a safener/herbicide mixture pinoxaden, which selectively allows wheat to degrade the selective herbicide, allowing control of *Phalaris*. Alas, *Phalaris* has evolved resistance to this as well (Das *et al.* 2014). A better approach might be to develop a synergist that selectively prevents *Phalaris* degrading a herbicide, without affecting wheat. That would be a useful innovation. Modern computational predictive technologies for new chemical structures that affect specific enzymes have become highly advanced and should be used to innovate new synergists and safeners. The problem is that the multinational chemical companies are not that interested in problems outside their multi-storey headquarters in Europe, Japan, or the USA, far from most fields with intractable weed problems. Despite having large chemical companies in India and China, these produce generic products and buy their innovations elsewhere, which is unfortunate, as they best understand their home markets. Still, there is a spate of start-up companies using these tools that could possibly result in novel chemical synergists and safeners.

Weedy rice in rice

There is a recent report of a seed-applied safener that protected rice while controlling weedy rice (Shen *et al.* 2017). To the best of my knowledge, this is not yet commercial.

Generating genetically herbicide resistant rice is a tricky issue, because rice and weedy rice are the same species and there is gene flow between them. The rate of gene flow is quite low as rice is cleistogamous and most ovules are pollinated before the flowers open. The extreme selection pressure of herbicides makes up for the very low rate of gene flow. Once a resistance gene is in the weed, the herbicide further selects it and the spread is rapid. Thus, if one were to generate transgenic herbicide resistant rice, the gene flow to weedy rice would be as rapid as it was for the mutant imidazolinone resistant rice. Still, there is a way to use transgenic herbicide resistant rice while mitigating the problem of gene flow that cannot be done with the mutant or gene editing derived herbicide resistance. This is to tandemly attach a gene to the herbicide resistance gene that is neutral or positive for the rice but deleterious to weedy rice. The initially proposed “transgenic mitigator” genes were genes that induced dwarfing, non-shattering of seeds, anti-seed pigmentation, establishment of secondary dormancy (Gressel 1999), all of which would have no effect on the rice crop (or could increase yield) but would render weedy rice into a non-competitive weed. Because the mitigator gene is in tandem with the herbicide resistance gene, inheritance is linked, and there is no segregation of the traits. All further progeny are mitigated.

The technology was proven to be effective in model species such as tobacco and oilseed rape (Rose *et al.* 2009), and then in rice, but in rice with a new twist (Lin *et al.* 2008). Instead of using any of the mitigator genes described above, their mitigator was an anti-sense gene that suppresses the production of the enzyme that naturally degrades the herbicide bentazon (Lin *et al.* 2008). Thus, if rice that does not contain this gene construct is grown the following season, and bentazon is used for weed control, escapes and hybrids from the previous season will be killed. This was taken conceptually forward by suggesting that a series of different transgenic herbicide resistance rice varieties could be generated, each with a different mitigator, allowing suppression of any weedy rice x rice hybrids or their progeny in a system that should remain sustainable for a very long duration (Gressel and Valverde 2009). Such a system would also control *Echinochloa* spp and delay the evolution of resistance in that weed as well.

The chemical industry needs to change its herbicide discovery paradigm

The emphasis of industry discovery programs has been for many years on finding new target sites for herbicides and finding herbicides that control weeds by inhibiting a single target. Thus, there has been an emphasis on genomics for finding targets for potential herbicides. There is also the feeling that registration of single target herbicides is simpler as one can state that its mode of action is known. Conversely, if one looks at resistance with an epidemiological view to see which herbicides have been the most recalcitrant to evolutionary forces, it is those that have multiple targets of actions: the thiocarbamates, the long-chain fatty acid biosynthesis inhibitors and cell division inhibitors that affect more than one target, *etc*.

Metabolic or other non-target site resistances can evolve to multisite inhibitors, but these resistances can typically be overcome by structural modification of the herbicide. Industry has looked at weed-toxic natural products as herbicide leads, but abandoned those where they can find no single target of action. Perhaps nature has been more intelligent than discovery chemists and evolved natural products that are multi-site inhibitors and that is why the natural products have been active for millennia? Perhaps industry should be learning from nature by developing chemicals that inhibit more than one target? Such multisite inhibitors will usually be superior to herbicide mixtures, as they are more likely to meet the criteria for delaying resistance (Wrubel and Gressel 1994).

Training of weed scientists must be modified to meet the needs

Lets face the facts, most of today's weed scientists are under trained to meet the needs and provide the necessary innovations. Most weed science curricula are a sub-curriculum of agronomy. The other areas of plant protection that deal with insects and pathogens in agronomic crops are not sub-curricula of agronomy but are part of mycology and entomology curricula (respectively). Their students are much more broadly trained to understand and deal with their target pests. The innovative weed scientists of the future will come from the plant sciences, broadly trained in plant physiology, ecology, chemistry, molecular biology and genetics. One must have a deep understanding of the enemy in order to develop winning strategies. Spray and pray are not the answer. When this new generation have an innovative idea, they will know with whom to collaborate to bring it to fruition. The few innovations described in the above sections did not come from traditionally trained weed scientists.

An innovative concept always begins with a hypothesis to be tested. Roger Cousens (pers. comm.), a top Australian weed ecologist, analyzed the posters at a weed meeting and found that very few began with a hypothesis, most repeated what was already known. If research is not novel hypothesis driven, it cannot be innovative. This clearly demonstrates a lacuna in the education provided weed science students.

CONCLUSIONS

Despite the ag-chemical and ag-biotech's profits coming from products that control weeds, most of their research interest targets pathogens and insects. They are interested in but a few crops and most of their R & D is about problems they perceive to be tractable, ignoring the intractable. Of the problems described above, industry is dealing mainly with *Amaranthus* spp., and not too successfully. This means that it is up to innovative weed scientists in the public sector and start-ups to conceptualize innovations, collaborate with specialists in other areas, whether chemists, breeders, molecular biologists, agricultural engineers, specialists in remote sensing and analysis, as well as other *in silico* technologies (Smalley 2018), depending on the proposed innovation. Only the biological/chemical innovations were discussed above, but genetic engineering is not the only type of engineering where innovations are being made. Agricultural engineering is also coming up with innovative tools, including robots that distinguish between crops and weeds, and either physically remove the weeds or spot treat them (Fennimore *et al.* 2016). The weed scientist will discover that these people often have insufficient understanding of the weed problems, such that the collaboration with weed scientists will be synergistic. Only together will intractable problems be solved. Weed scientists should not fear new technologies. They should find ways to use them to the utmost to solve the intractable.

REFERENCES

Aly R, Cholakh H, Joel D, Leibman D, Steinitz B, Zelcer A, Naglis A, Yarden O, Gal-On A. 2009. Gene silencing of mannose 6-phosphate reductase in the parasitic weed *Orobanche aegyptiaca* through the production of homologous dsRNA sequences in the host plant. *Plant Biotechnology Journal* **7**: 487–498.

Arnason R. 2014. RNAi may hold key to glyphosate resistance. *https://wwwproducercom/daily/rnai-may-hold-key-to-glyphosate-resistance/ (accessed 27 Sept 2018).*

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

Chhokar RS, Sharma RK. 2008. Multiple herbicide resistance in littleseed canarygrass (*Phalaris minor*): A threat to wheat production in India. *Weed Biology and Management* **8**: 112–123.

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

Fennimore SA, Slaughter DC, Siemens MC, Leon RG, Saber MN. 2016. Technology for automation of weed control in specialty crops. *Weed Technology* **30**: 823–837.

Gressel J. 1996. Fewer constraints than proclaimed to the evolution of glyphosate-resistant weeds. *Resistant Pest Management* **8**: 2–5.

Gressel J. 1999. Tandem constructs: preventing the rise of superweeds. *Trends Biotechnol* **17**: 361–366.

Gressel J. 2017. Catch 22: All doses select for resistance. When will this happen and how to slow evolution?, pp 61–72 In: *Pesticide Dose: Effects on the Environment and Target and Non-Target Organisms*, Duke SO, Kudsk P, Solomon K (Eds) American Chemical Society, Washington DC.

Gressel J. 2018. Hit parasitic weeds hard with HIGS: They possibly can be transgenically controlled. *Haustorium* **73**: 4–7.

Gressel J, Levy AA. 2014. Use of multicopy transposons bearing unfitness genes in weed control: four example scenarios. *Plant Physiology* **166**: 1221–1231.

Gressel J, Polturak G. 2018. Suppressing aflatoxin biosynthesis is not a breakthrough if not useful. *Pest Management Science* **74**: 17–21.

Gressel J, Valverde BE. 2009. A strategy to provide long-term control of weedy rice while mitigating herbicide resistance transgene flow, and its potential use for other crops with related weeds. *Pest Management Science* **65**: 723–731.

Grigliatti TA, Pfeifer TA, Meister GA. 2001. TAC-TICS: Transposon-based insect control systems, pp 201–216 In: *Enhancing Biocontrol agents and Handling Risks*, Vurro M, Gressel J, Butt T et al. (Eds) IOS Press, Amsterdam.

Heap IM. 2018. International survey of herbicide-resistant weeds. *http://wwwweedscienceorg*: (accessed 27 Sept. 2018).

Joel DM, Gressel J, and Musselman L (eds). 2013. *Root Parasitic Orobanchaceae: Parasitic Mechanisms and Control Strategies*. Springer, Berlin.

Joel DM, Kleifeld Y, Losner-Goshen D, Herzlinger G, Gressel J. 1995. Transgenic crops against parasites. *Nature* **374**: 220–221.

Juma C. 2016. *Innovation and Its Enemies: Why People Resist New Technologies* Oxford University Press, Oxford UK.

Leah JM, Caseley JC, Riches CR, Valverde BE. 1997. Effect of mono-oxygenase inhibitors on uptake, metabolism and phytotoxicity of propanil in resistant biotypes of jungle-rice, *Echinochloa colona*. *Pesticide Science* **49**: 141–147.

Lin C, Jun F, Xu X, Te Z, Cheng J, Tu J, Ye G, Shen Z. 2008. A built-in strategy for containment of transgenic plants: creation of selectively terminable transgenic rice. *PLoS ONE* **3(3)**: e1818.

Montgomery GB, McClure AT, Hayes RM, Walker FR, Senseman SA, Steckel LE. 2018. Dicamba-tolerant soybean combined cover crop to control palmer amaranth. *Weed Technology* **32**: 109–115.

Neve, P. 2018. Gene drive systems: do they have a place in agricultural weed management? Pest Management Science (In press) available online. DOI 10.1002/ps.5137

Nzioki HS, Oyosi F, Morris CE, Kaya E, Pilgeram AL, Baker CS, Sands DC. 2016. *Striga* biocontrol on a toothpick: a readily deployable and inexpensive method for smallholder farmers. *Frontiers in Plant Science* **7**: Article 1121.

Ransom J, Kanampiu F, Gressel J, De Groote H, Burnet M, Odhiambo G. 2012. Herbicide applied to imidazolinone resistant-maize seed as a control option for small-scale African farmers. *Weed Science* **60**: 283–289.

Rose CW, Millwood RJ, Moon HS, Rao MR, Halfhill MD, Raymer PL, Warwick SI, Al-Ahmad H, Gressel J, Stewart CN. 2009. Genetic load and transgenic mitigating genes in transgenic *Brassica rapa* (field mustard) x *Brassica napus* (oilseed rape) hybrid populations. *BMC Biotechnology* **9**: Article 93.

Shen CC, Tang WW, Zeng DQ, Xu HL, Su WC, Wu RH. 2017. Isoxadifen-ethyl derivatives protect rice from fenoxaprop-P-ethyl-associated injury during the control of weedy rice. *Weed Science* **65**: 579–587.

Smalley E. 2018. *In silico* farming drives the next wave in agriculture. *Nature Biotechnology* **36**: 783–784.

Weedout. 2018. https://www.weedout-ibs.com/ (accessed 27 Sept. 2018).

Wrubel RP, Gressel J. 1994. Are herbicide mixtures useful for delaying the rapid evolution of resistance? A case study. *Weed Technology* **8**: 635–648.

WSSA. 2018. WSSA Research Workshop for Managing Dicamba Off Target Movement: Final Report *http://wssanet/wp-content/uploads/Dicamba-Report_6_30_2018pdf (accessed Sept 27, 2018).*

Zhang JX, Kang Y, Valverde BE, Dai WM, Song XL, Qiang S. 2018. Feral rice from introgression of weedy rice genes into transgenic herbicide-resistant hybrid-rice progeny. *Journal of Experimental Botany* **69**: 3855–3865.

Ziska LH, Gealy DR, Burgos N, Caicedo AL, Gressel J, Lawton-Rauh AL, Avila LA, Theisen G, Norsworthy J, Ferrero A, Vidotto F, Johnson DE, Ferreira FG, Marchesan E, Menezes V, Cohn MA, Linscombe S, Carmona L, Tang R, Merotto A. 2015. Weedy (red) rice: An emerging constraint to global rice production. *Advances in Agronomy,* **129**: 181–228.

Indian Journal of Weed Science 50(3): 209–217, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Importance of allelopathy in agriculture: Bioavailability and functions of allelochemicals in soil environment

Prasanta C. Bhowmik*

Stockbridge School of Agriculture, University of Massachusetts, Amherst, MA, USA

**Email: pbhowmik@umass.edu*

Article information

DOI: 10.5958/0974-8164.2018.00050.3

Type of article: Review article

Received : 28 September 2018
Revised : 1 October 2018
Accepted : 7 October 2018

Key words
Allelochemicals
Adsorption
Allelopathy
Cover crops
Plant residue
Weed suppressing crop cultivars
Soil factors

ABSTRACT

Weed invasion and subsequent infestation represents a major problem in crop production. Chemical weed control is the major management tactic used in conventional agriculture. Complementary strategies to herbicides are increasingly being investigated. The importance of allelopathy has been considered for weed management over the years. However, the relevance of allelopathy has been highly discussed due to the lack of phytotoxic concentrations of allelochemicals under field conditions. *Avena fatua*, *Brassica nigra*, *Fagopyrum esculentum*, *Secale cereale*, *Sorghum bicolor*, *Triticum aestivum* and other cover crops have been used in weed management on a limited basis. Crop residues from existing crop or rotational crops can provide selective weed suppression through their physical presence on the soil surface and/or through the release of allelochemicals. Some of the allelochemicals have been reported to play a role in weed management, including phenolic acids, DIBOA, DIBOA-glycoside, and BOA, dhurrin, fatty acids, hydroxamic acids, isoflavonoids, isothiocyanate, juglone, momilactone, scopoletin, and sorgoleone. The soil system, a living and dynamic, influences the fate and functions of allelochemicals in time and space. The bioavailability of allelochemicals in the soil is dependent on processes such as adsorption, leaching and degradations by abiotic and biotic factors. The clay types, organic matter, and soil pH can affect the bioavailability of allelochemicals in the soil. Thus, the allelopathic potential of many compounds may not be expressed in some soils because of the chemical adsorption to soil colloids. The resulting concentrations (sub-toxic) of any of these allelochemicals in soil matrix may have a variety of functions that influence seed germination, seedling emergence, plant growth suppression, nutrient acquisition or soil microbial activity. Examples of such compounds are benzoic acid, catechin, coumaric acid, dihydroxyphenylalanine, ferulic acid, hydroxybenzoic acid, sorgoleone, vanillic acid, and others.

In my view, future allelopathic research should be focused on mechanisms facilitating persistence of allelochemicals in soil environment and characterization of complementary roles of these compounds in plant growth and development. The bioavailability of allelochemicals under field conditions must be established for its effective role in weed management. Currently, we face challenges and opportunities in using allelopathy as a part of weed management strategies in today's production agriculture.

INTRODUCTION

An Austrian plant physiologist, Hans Molisch coined term allelopathy in 1937. Later, allelopathy was defined as the effect(s) of one plant (including microorganisms) on another plant through the release of a chemical compound(s) into the environment (Rice 1984). This definition includes both inhibitory and stimulatory effects, depending on the concentration of the compound(s). However, inhibitory effects of plants or crop residues are of great importance in relation to weed management. Allelopathic research through the last several decades has demonstrated many aspects of allelopathy, including the applied nature of allelopathy in weed management. To demonstrate allelopathy, one must identify one or more phytotoxins produced by the putative allelopathic plant or identify a compound(s) produced by the donor plant that is converted to a phytotoxin in the soil complex. The compound(s) must be present in sufficient quantity (in time and space) in the soil for allelopathic effects in controlling weeds. Allelochemicals are generally weak phytotoxins. Most of the allelochemicals are present at low concentrations, and undergo rapid chemical and biological degradation in the soil. The focus of this presentation is to discuss (i) the importance of cover crops residues in weed management, (ii) the nature of allelochemicals, and (iii) the role of soil factors in allelopathic activity, and iv) challenges in implementing allelopathy in weed management.

Cover crops residues

Cover crop residues such as *Avena fatua*, *Brassica nigra*, *Fagopyrum esculentum*, *Secale cereale*, *Sorghum bicolor*, *Triticum aestivum*, *Vicia vilosa* and others have been used in weed management on a limited basis. Crop residues from existing crop or rotational crops can provide selective weed control through their physical presence on the soil surface and through the release of allelochemicals (Fay and Duke 1977, Bhowmik and Doll 1982, Alsaadawi *et al.* 1986, Teasdale 1993, Weston 1996, Barker and Bhowmik 2001, Jabran *et al.* 2015). The allelochemicals are concentrated and exuded through roots or are released during decomposition of plant litter (Siqueira *et al.* 1919, Bonanomi *et al.* 2006).

Earlier reports have shown that weed control could be achieved by growing cover crop of rye, barley, wheat or sorghum to a height of 40–50 cm, then desiccating the crop by either contact herbicides or winter freezing, and allowing their residues to remain on the soil surface (Putnam *et al.* 1983, Barker and Bhowmik, 2001). Barnes and Putnam (1983) reported that *Secale ce*reale residue used as mulch reduced total weed biomass by 63%. It was found that disappearance of rye allelochemicals was more closely related to weed suppression than to the disappearance of rye residues. Duration of cover crops residue on the soil surface often determines the extent of an effective weed control period. Yenish *et al.* (1995) studied the disappearance of *Secale cereale* residue and allelochemicals, DIBOA (2,4-dihydroxy-1,4-benzoxazin-3-one), DIBOA-glycoside and BOA from *Secale cereale* residues. These authors found that 50% of the initial content of *Secale cereale* residue disappeared by 105 days after clipping. However, the combined active compound concentrations of DIBOA-glucoside, DIBOA, and BOA disappeared 168 days after clipping.

Allelopathy can play a beneficial role in various cropping systems (Haramoto and Gallandt 2005, Macias *et al.* 2014, Jabran *et al.* 2015). In a 5–yr field study with *Helianthus annuus* and *Avena fatua* rotation, the weed density increase was significantly less in sunflower plots than in control plots (Leather, 1983). It was found that sunflower plants possess chemicals, which inhibit the growth of common weed species.

Allelochemicals for weed management

Thousands of allelopathic substances have been isolated from plants and their chemical structure has been determined. However, the mode-of-action (MOA) has only been elucidated for a limited number of allelochemicals (Vyvyan 2002). Some of the allelochemicals such as allyl isothiocyanate (*Brassica* sp., black mustard), fatty acids (*Polygonum spp*.), isoflavonoids and phenolics (*Trifolium spp*., *Melilotus spp*.), phenolic acids and scopoletin (*Avena sativa*), hydroxamic acids (*Triticum* sp.), phenolic acids, dhurrin, and sorgoleone (*Sorghum bicolor*) have been reported for weed control (Duke *et al.* 2002). Artemisinin, a sesquiterpenoid lactone, has been shown to inhibit the growth of *Amarantus retroflexus*, *Ipomoea lacunosa*, *Artemisia annua* and *Portulaca oleracea* (Duke *et al.* 1987). The phytotoxic activity of sorgoleone against weed species was first reported by Einhellig and Souza (1992). Mushtaq and Siddiqui (2010) reported that plants belonging to Asteraceae family are the most studied species for allelopathic potential to control weeds in India. Some of the species including *Parthenium hysterophorus*, *Ageratum conyzoides* and others received more attention.

Allelopathic activity in soil environment

The soil system, a living and dynamic, influences the fate and functions of allelochemicals in time and space. The bioavailability of allelochemicals in the soil is dependent on processes such as adsorption, leaching and degradations by abiotic and biotic factors. The clay types, organic matter, and soil pH can affect the bioavailability of allelochemicals in the soil. An excellent review in this area has been published by Kobayashi (2004).

The allelopathic activity of many compounds is not expressed in some soils because of the chemical adsorption to soil colloids. For instance, sorgoleone binds strongly to soil colloids because it is a highly lipophilic allelochemical, with a logP (logoctanol-water partition coefûcient) of 6.1 (Trezzi *et al.* 2016). The allelopathic compounds l-3,4dihydrox phenylalanine and catechin are also strongly adsorbed by soil colloids, possibly due to the catechol group present in these molecules (Furubayashi *et al.* 2007). Reduced allelopathic potential of benzoxazinoid compounds 2-aminophenoxazin-3-one and DIBOA (2,4-dihydroxy-(2H)-1,4-benzoxazin-3(4H)-one) have been reported due to their adsorption by soil colloids (Teasdale *et al.* 2012). The chemical compounds that are not adsorbed onto colloids or minerals are usually in the soil solution. Thus, they can be absorbed by plants or leached (Kobayashi 2004, Kong *et al.* 2007, Li *et al.* 2013). Kong *et al.* (2007) reported that ûavonoids with a high mobility in the soil proûle were less phytotoxic than those with reduced soil mobility with rice plants. Similarly, an analysis of ten potential allelochemicals revealed an inverse relationship between soil mobility and their toxic effect on target plants (Li *et al.* 2013).

Preferential absorption allelochemicals in soil

Use of allelopathy is gaining its application in current agricultural science. However, the role of sorption to soil in modifying the bioavailability of components in complex allelochemical mixtures is still not well understood. Soils are capable of altering the phytotoxicity of plant secondary metabolites by changing their bioavailability, persistence, and fate under field conditions. Sorption is one of the prominent factors affecting the phytoavailability of allelochemicals in soil.

In one of our studies, the role of preferential sorption to soil in altering the chemical composition of plant exudates was studied in a silt loam soil using representative mixtures of plant phenolic acids, namely, hydroxybenzoic acid, vanillic acid, coumaric acid, and ferulic acid Tharayil *et al.* (2006). Removal of organic matter substantially decreased the sorption affinity of all phenolic acids. Direct competition for sorption sites was observed even at low concentrations of phenolic acids. The kd value of hydroxybenzoic acid was decreased more than 90% in the presence of coumaric acid. About 95% of sorbed vanillic acid was displaced into the soil solution in the presence of ferulic acid. Hydroxybenzoic acid did not affect the sorption affinity of other phenolic acids significantly, whereas ferulic acid showed low displacement by other phenolic acids. The displacement pattern indicated directional sorption of phenolic acids with -OH and -COOH groups. Soil organic matter was associated with preferential sorption. The preferential sorption to soil can alter the availability of plant exudates in mixtures and thus may mediate their phytotoxic effects (Tharayil *et al.* 2006).

Soil sorption can also protect compounds from microbial degradation and thus indirectly alter their phytotoxic effects (Dalton, 1989, Wauchope *et al.* 2002). The soil sorption properties of some individual allelochemicals have previously been studied. Various soil components such as organic matter, sesquioxides, and clay minerals have been found to affect the phytoavailable concentration of allelochemicals (Dalton *et al.* 1989, Ohno, 2001, Wang *et al.* 1978). Considering the fact that compounds in the soil solution are more phytoavailable than those sorbed to the soil matrix (Lehman and Blum, 1999, Ito *et al.* 1998), the varied sorption affinity of compounds in a mixture will change the composition of plant exudates that become bioavailable. Different compounds in plant exudates differ widely in their phytotoxicity (Wu *et al.* 2002, Uren, 2001) and therefore preferential sorption to soil could in turn alter the phytotoxicity of these exudates.

Microbial degradation in soil

Biotic processes are involved in determining the fate of allelopathic compounds in soil. Microorganisms produce enzymes which catalyze the oxidation and polymerization reactions of phenolic acids (Huang *et al.* 1999, Lou *et al.* 2016). Microbial activity will alter phenolic compounds in soil and subsequently alter the expressed level of phytotoxicity (Blum 1998).

Phenolic acids are readily converted from one structure to another with different phytotoxicities (e.g., ferulic acid to vanillic acid) by soil-borne microbes (Blum 1998). Schmidt and Ley (1999) suggested that carbon-limited soil organisms would rapidly mineralize phenolic compounds due to their higher energy content on a per weight basis than simple sugars. Zikmundová *et al.* (2002) studied the biotransformation of the phytoanticipins BOA and HBOA by four endophytic fungi isolated from *Aphelandra tetragona*. It was shown that the metabolic pathway for HBOA and BOA degradation leads to o-aminophenol as a key intermediate.

Microorganisms play important roles in releasing additional allelochemicals bound up in the recalcitrant fractions of cover crop residues (Barnes *et al.* 1987).These insoluble allelochemicals can constitute a significant fraction of total allelopathic potential of a cover crop residue (Harper and Lynch 1982), so microbes may slowly release residue-derived allelochemicals, extending the longevity of a cover crop’s effectiveness. Microbes can deactivate water soluble allelochemicals released soon after cover crop residue incorporation (Jilani *et al.* 2008). As agricultural soils are not sterile, it is important to understand how microbial activity moderates allelopathic potential of cover crop residues (Blum 1998, Inderjit 2005). Mohler *et al.* (2012) recently showed that unsterilized live soil (*i.e.*, with a natural microbial community) reduces seedling germination rates when cover crop residues are incorporated, and the combined effect of residues and live microorganisms is greater than the effect of either of these components alone.

The degradation of allelochemicals in the soil may be altered, reducing their efûcacy. In non-sterilized soil, for instance, DIBOA showed a half-life of 43h. However, 2-aminophenoxazin-3-one (APO), the ûnal degradation product of DIBOA, has a low mineralization rate and therefore, a half-life greater than 90 days (Macías *et al.* 2005). In addition, some ûavonoid glycoside molecules exuded by rice plants can suffer high mineralization by soil microorganisms, resulting in a glycosylated compounds. Flavonoid glycosides and a glycoside have a half-life of 2 h and 30 h, respectively, suggesting a higher allelopathic activity for the second group (Kong *et al.* 2007). The biodegradation of the sorgoleone quinone ring is relatively slow, with only 21% being mineralized 77 d after incubation in soil. However, the sorgoleone methoxy group was biodegraded within a few days, particularly in soils with a low colloid content (Gimsing *et al.* 2009).

Bioavailability of allelochemicals

Soils may also influence the relative activity of allelochemicals in combination(s). Because allelochemicals are generally exuded in mixtures of metabolites that often include other allelochemicals (Wu *et al.* 1999, Uren *et al.* 2001), preferential sorption of compounds onto the soil matrix could further alter availability.

The persistence of allelochemical mixtures may be enhanced in soil environment. In one of our studies, we found that one compound in combination can make the bioavailability and half-life of others greater in soil, because of competitive sorption and preferential degradation. Allelochemicals may also help plants to acquire nutrients in infertile soils which give competitive advantage to the donor plant over its neighbors.

The interaction of allelochemicals in the soil matrix remains as one of the least understood areas in the research on allelopathy (Tharayil *et al.* 2006). Most of the allelopathic interactions take place in the soil, where allelochemicals are concentrated and exuded through roots (Bias *et al.* 2003) or are released during decomposition of plant litter (Bonanomi *et al.* 2006, Siqueira *et al.*, 1991). Thus, soil matrix forms the primary medium for the transport of allelochemicals from a donor to a receiver plant. During this transportation, the soil matrix is capable of altering the bioavailability of allelochemicals by various processes including sorption and chemical and microbial degradation (Tharayil *et al.* 2006, Ohno 2001). Because allelochemicals are secreted in quantities far less than needed to overwhelm the soil processes, at the ûeld level, the soil matrix becomes the governing factor in the allelopathic activity. Thus, in many cases allelochemicals are not found in phytotoxic quantities under ûeld conditions (Perry *et al.* 2007, Blum 1992).

A less attention has been made in the fact that the allelochemicals may be released as mixtures with other compounds (Wu *et al.* 2002). The degradation pattern of individual allelochemicals in soil matrices has been studied before (Dalton 1989, Ohno 2001). The disappearance of allelochemicals was delayed when present in a multi-solute mixture from both soils. This slow disappearance of allelochemicals in a mixture could be due to the combined effect of preferential degradation, where compounds with a stable ring structure and without a 3-C (acrylic) side chain are less susceptible to degradation, and competitive sorption, where less hydrophobic molecules are displaced into soil solution (Tharayil *et al.* 2006).

Microbial degradation of substrate in soil matrix is related to biological activity of the compound, where toxic compounds are degraded slowly (Kurt-Karakus *et al.* 2007). Addition of a more soluble and energy-efûcient carbon source has been shown to reduce the microbial decomposition accompanying complex substrates (Pue *et al.* 1995). Competition for sorption sites arises if the same sites can be occupied by more than one non identical molecule (Xing *et al.* 1996, Tharayil *et al.* 2006). This competition for sorption sites in a soil matrix could increase the effective concentration of phenolic acids in soil solution (Tharayil *et al.* 2006).

Litter decomposition of *Centauria maculosa* in sandy loam soil yielded ûve phenolic acids, namely, hydroxybenzoic, vanillic, protocatechuic, p-coumaric, and ferulic acids (Tharayil *et al.* 2008). The degradation studies were conducted by exogenous application of catechin, the primary allelochemical exuded by *C. maculosa*, and the phenolic acid co-solutes in a sandy loam and silt loam soil. Compared to a single-solute system, in a multi-solute system the persistence of individual allelochemicals was signiûcantly increased in both soils. Oxidation and sorption were primarily involved in the disappearance of allelochemicals. Catechin rapidly underwent polymerization to form procyanidin dimer both in soil and in bioassay medium, resulting in reduced persistence and phytotoxicity. Hence, catechin phytotoxicity could occur only under conditions that would inhibit these condensation reactions. This study clearly demonstrates that various soil mechanisms including competitive sorption and preferential degradation would increase the persistence of allelochemical mixtures in a soil matrix (Tharayil *et al.* 2008).

Allelopathic crop cultivars

Researchers have screened crop cultivars for their differential allelopathic activity for the last three decades (Gealy *et al.* 2000, Wu *et al.* 1998, Kato-Noguchi *et al.* 2010, Mahmood *et al.* 2013, Mahajan and Chauhan 2013, Masum *et al.* 2018). In general, more monocot crop species have been searched for allelopathy compared to broadleaf species. Several members of the family Poaceae have been identified as allelopathic. Significant amount of literature is available on the differential production of hydroxamic acids in cereals. The main hydroxamic acids reported from cereals are DIBOA and DIMBOA (2,4-dihydroxy-7-methoxy-1,4benzoxazin-3-one); their distribution with cultivated Poaceae, however, is uneven (Niemeyer 1988). While wheat has both DIMBOA and DIBOA, *Secale cereale* contains only DIBOA.

The allelopathic activity of *Avena* species has been established by Fay and Duke (1977). They examined 3000 accessions of the USDA world collection of *Avena sp.* germplasm for their ability to exude scopoletin. Twenty-five accessions exuded more scopoletin from their roots than a standard oat cultivar, 'Garry'. They found that four accessions exuded up to three times as much scopoletin as 'Garry' oats. One of these accessions grown in sand culture for 16 days with *Brassica caber* significantly reduced Brassica plant growth more than that obtained when the weed was grown with 'Garry' oats.

Over the last decade, *Oryza* spp. accessions or cultivars have been examined for their allelopathic activity in suppressing weed species (Dilday *et al.* 1998, Hassan *et al.* 1998, Gealy *et al.* 2000, Olofsdotter 2001, Olofsdotter *et al.* 1995). Dilday and his colleagues (1998) evaluated the phytotoxic effects of 12,000 rice accessions against *Heteranthera limosa* and 5000 against *Ammannia coccinea* . They found that 412 rice accessions developed an allelopathic zone around rice plants for *Heteranthera limosa* and 145 for *Ammannia coccinea*. A hybrid (stg 94L42-130) between p1 338046 (allelopathic) and Katy (non-allelopathic) was reported to increase the yield by almost 2000 kg/ha compared to the yield of Katy.

Eight cultivars of *Oryza sativa* inhibited shoot and root growth of *Echinochloa crus-galli* when co-cultured with rice seedlings in a bioassay medium (Koto-Noguchi *et al.* 2010). They identified momolactone A and B in the bioassay medium of all rice cultivars. The concentrations of mamolactone A and B varied from 0.21-1.5 and 0.66-3.8 umol/L, respectively demonstrating the evidence of secretion of these two compounds from all rice cultivars into the medium.

Allelopathic activity of rice species has been reported by screening 50 rice cultivars from Bangladesh against *Echinochloa crus-galli* (barnyardgrass) and *Echinochloa colona* (jungle rice) by using Equal Compartment Agar Method (Masum *et al.* 2016). They reported 7 to 37% suppression of *Lactuca sativa*, *Lepidium sativum*, and *Raphanus sativus*. Recently, Masum and his group (2018) identified four potential allelochemicals from four indigenous rice cultivars. Aqueous methanol extracts of the Bangladesh indigenous rice (*Oryza sativa* L.ssp. *indica*) variety 'Boterswar' inhibited the germination and seedling growth of *Lepidium sativum* and *Echinochloa crus-galli* which suggested that this variety may contain phytotoxic substance(s). Four biologically active compounds, syringaldehyde (4-hydroxy-3,5-dimethoxybenzaldehyde), (-) loliolide, 3*â*-hydroxy-5*á*,6*á*-epoxy-7-megastigmen-9-one and 3-hydroxy-*â* –ionone, were isolated. The biological activity of these compounds showed that concentration > 10 ìM significantly inhibited the root and shoot growth of *E. crus-galli* seedlings, and the *I*50 (50% growth inhibition) values ranged from 16.03 to 27.23 ìM and 23.94 to 75.49 ìM for root and shoot growth, respectively (Masum *et al.* 2018).

Sorghum plants have been demonstrated for allelopathic effects on weed species (Nimbal *et al.* 1996, Czarnota *et al.* 2003, Weston *et al.* 2013). Root exudates of 100 cultivars of *Sorghum bicolor* were evaluated for their potency to affect the seed germination and growth of *Amaranthus retroflexus* (Alsaadawi *et al.* 1986). Some cultivars were more toxic than others.

Allelopathic activity of 526 accessions of *Cucumis sativus* and 12 accessions of eight related *Cucumis* species, representing 41 nations of origin, was evaluated on *Brassica hirta* and *Panicum miliaceum* (Putnam and Duke 1974). One accession inhibited growth of test species by 87%, and 25 accessions inhibited growth by 50% or more. *Helianthus annuus* has been studied over the years for allelopathic effects (Leather 1983, Macias *et al*. 1999). Some sesquiterpene lactones with germacranolide and guaianolide skeletons and heliannuol from different cultivars of *Helianthus annuus* were reported (Macias *et al*. 1999). These authors discussed their potential role as natural herbicides. *Mucuna prursens* has been reported to be a candidate to smother weed species (Fujii *et al*. 1992). They identified L-DOPA (L-3,4-dihydroxyphenylalanine) in *Mucuna prursens*.

Use of allelopathic plant extracts for weed management

Use of allelochemicals from plant extracts has been searched for weed management in agriculture. In Pakistan, for example, an aqueous extract deriving from sorghum shoots with a 10% concentration is left to ferment for several weeks and is subsequently sprayed post-emergence for weed control. This fermented water extract, known as “Sorgaab”, reduced weed density and weed dry weight up to 50% in ûeld trials, depending on the weed species (Cheema and Khaliq 2000, Cheema *et al*. 2002).

Limitations of allelopathic cover crop uses in agriculture

Using residues of cover or rotational crops for weed management in the field is challenging. There are limitations in using cover crops for various cropping systems. Delayed planting, delayed crop emergence, phytotoxic effects to major crops, and increased pest pressure are some of the limitations. In addition, cover crops are not much effective in managing perennial weed species. It is also believed that regrowth of certain perennial weeds may be favored due to far-red light environment under cover crops. *Vicia villosa* has been used as a cover crop and has been demonstrated potential use in weed management. Total weed density and biomass were lower in live *Vicia villosa* treatment compared to desiccated *Vicia villosa* plots (Teasdale and Daughtry 1993). Red (660 nm) and far-red (730 nm) light ratio of transmitted light was reduced by 70% in live *Vicia villosa* and by 17% under *Vicia villosa* desiccated by paraquat. They concluded that factors such as light, soil moisture and temperature are responsible for the weed suppression by *Vicia villosa*.

The question remains whether residues from crops or cover crops can provide successful weed management (100%) in the field. Under the best management practices, it is possible to integrate alllelopathic crop residues and other chemical control strategies (such as pre- or post-emergence herbicides.

Challenges in implementing allelopathic concepts

In nature, plant products represent a vast diversity of compounds with a variety of biological activity (Duke *et al*. 2002, Bhowmik and Inderjit 2003, Weston and Duke 2003, Duke 2015). The natural products represent a diverse class of chemical compounds. These allelochemicals will have impact on different species of plants.

There are limitations for using allelochemicals for successful weed management. Some of these factors in implementing natural products for effective weed management include (i) compounds are present in very low concentration, (ii) allelochemicals have generally short half-lives, (iii) narrow spectrum weed selectivity, and (v) high cost of production.

Conclusion

Numerous examples of allelopathic effects have been established decades ago. Today, we are still looking for other allelopathic plants or weed species. We have made significant advances in this direction over the last three decades. However, we still have a long way to go in terms of using allelochemicals or developing plant cultivars that would be used for complete weed management. The environmental fate of allelochemicals is a complex issue that is affected by the donor and receiver target plant species, as well as soil and environmental variables that affect the fate of the chemicals in the soil complex. Knowledge concerning the variation in these factors is essential to use the allelopathic relationship among plants in agroecosystems to promote weed control.

In spite of many challenges in implementing the allelopathic concept in weed management, there is tremendous scope for exploring allelopathy phenomena for successful weed management. Biotechnology may eventually allow for the production of highly allelopathic crop cultivars that may effectively suppress many weeds. The bioavailability of allelochemicals under field conditions must be established for its effective role in weed management. Continued research on these areas is important and we must invest our resources in exploring allelopathy as a complimentary component in successful weed management.

REFERENCES

Alsaadawi IS, Al-Uqaili JK, Alrabeaa AJ and Al-Hadithy M. 1986. Allelopathic suppression of weed and nitrification by selected cultivars of *Sorghum bicolor* (L.) Moench. *Journal of Chemical Ecology* **12**: 209.

Barker AV and Bhowmik PC. 2001. Weed control with crop residues in vegetable cropping systems. *Journal of Crop Production* **4**(2): 163–183.

Barnes JP and Putnam AR. 1983. Rye residues contribute to weed suppression in no–tillage cropping systems. *Journal of Chemical Ecology* **9**: 1045–1057.

Barnes JP, Putnam AR, Burke BA and Aasen AJ. 1987. Isolation and characterization of allelochemicals in Rye Herbage. *Phytochemistry* **26**: 1385–1390.

Bhowmik PC and Doll JD. 1982. Corn and soybean response to allelopathic effects of weed and crop residues. *Agronomy Journal* **74**: 601–606.

Bhowmik PC and Inderjit. 2003. Challenges and opportunities in implementing allelopathy for natural weed management. *Crop Protection* **22**(4): 661–671.

Bias HP, R. Vapachedu R, Gilroy S, Callaway R and Vivanco J. 2003. Allelopathy and exotic plant invasion: from molecules and genes to species interactions. *Science* **30**1: 1377–1380.

Blum U. 1992. Allelopathic interactions involving phenolic acids. *Journal of Nematology* **28**: 259–267.

Blum U. 1998. Effects of microbial utilization of phenolic acids and their phenolic acid breakdown products on allelopathic interactions. Journal of Chemical Ecology **24**: 685-708.

Bonanomi G, Sicurezza MG, Caporaso S, Esposito A, and Mazzoleni S. 2006. Phytotoxicity dynamics of decaying plant materials. *New Phytology* **169**: 571–578.

Cheema ZA and Khaliq A. 2000. Use of sorghum allelopathic properties to control weeds in irrigated wheat in a semi-arid region of Punjab. *Agricultural Ecosystem Environment* **79**: 105–112.

Cheema ZA, Khaliq A and Ali K. 2002. Efûcacy of sorgaab for weed control in wheat grown at different fertility levels. *Pakistan Journal of Weed Science Research* **8**: 33–38.

Czarnota MA, Rimando AM and Weston LA. 2003. Evaluation of root exudates of seven sorghum accessions. Journal of Chemical Ecology **29**: 2073–2083.

Dalton BR. 1989. Physiochemical and biological processes affecting the recovery of exogenously applied ferulic acids from tropical forest soil. *Plant Soil* **115**: 13–22.

Dilday RH, Yan WG, Moldenhauer KAK and Gravois KA. 1998. Allelopathic activity in rice for controlling major aquatic weeds. pp. 7–26. In: *Allelopathy in Rice*. (Ed. Olofsdotter M), IRRI Press, Manila.

Duke S. 2015. Proving allelopathy in crop-weed interactions. *Weed Science* **63**(spl): 121-132.

Duke S, Vaughn KC, Croom EM and Elsohly HN. 1987. Artemisinin, a constituent of annual wormwood (*Artemisia annua*) is a selective phytotoxin. *Weed Science* **35**: 499–505.

Duke S, Dayan FE, Rimando RM, Schrader KK, Aliotta G, Oliva A and and Romagni JG. 2002. Chemicals from nature for weed management. *Weed Science* **50**: 138–151.

Einhellig FA and Souza IF. 1992. Phytotoxicity of sorgoleone found in grain sorghum root exudates. *Journal of Chemical Ecology* **18**: 1–11.

Fay PK and Duke WB. 1977. An assessment of allelopathic potential of *Avena* germplasm. *Weed Science* **2**5: 224–228.

Fujii Y. 1992. The potential biological control of paddy weeds with allelopathy – Allelopathic effect of some rice cultivars. pp. 305–320. In: *Proceedings of the International Symposium on Biological Control and Integrated Management of Paddy and Aquatic Weeds* (Tsukuba, Japan). *National Agriculture Research Center.*

Furubayash A, Hiradate S and Fujii Y. 2007. Role of catechol structure in the adsorption and transformation reactions of L-DOPA in soils. *Journal of Chemical Ecology* **33**: 239–250.

Gealy DR, J.D. Mattice JD, Moldenhauer KA and Dilday RH. 2000. Allelopathy in rice as a weed control strategy. Proceedings of the International Weed Science Congress, Foz do Iguassu, *Brazil* **3**: 33–34.

Gimsing AL, J. Baelum J, Dayan FE, Locke MA, Sejero LH and Jacobsen CS. 2009. Mineralization of the allelochemical sorgoleone in soil. *Chemosphere* **76**: 1041–1047.

Haramoto ER and Gallandt ER. 2005. Brassica cover cropping:I. Effects of weed and crop establishment. *Weed Science* **53**: 695–701.

Harper SHT and Lynch JM. 1982. The role of water-soluble components in phytotoxicity from decomposing straw. *Plant and Soil* **65**: 11–17.

Hassan SM, Aidy IR, Bastawisi AO and Draz AE. 1998. Weed management using allelopathic rice varieties in Egypt. pp. 27–37. In: *Allelopathy in Rice.* (Ed. Olofsdotter, M.), IRRI Press, Manila.

Huang PM, Wang WC and Wang MK. 1999. Catalytic transformation of phenolic compounds in the soils. pp. 287–306 In: *Principles and Practices in Plant Ecology: Allelochemical Interactions*, (Eds. Inderjit, Dakshini KMM and Foy CL), CRC Press, Boca Raton, FL.

Inderjit. 2005. Soil microorganisms: an important determinant of allelopathic activity. *Plant and Soil* **274**: 227–236.

Ito I., Kobayashi K and Yoneyama T. 1998. Fate of dehydromatricaria ester added to soil and its implications for the allelopathic effect of *Solidago altissima* L. Annals of Botany, London **82**: 625–630.

Jabran K, Mahajan G., Sardana V and Chauhan BS. 2015. Allelopathy for weed control in agricultural systems. *Crop Protection* **72**: 57–65.

Jilani G, Mahmood S, Chaudhry AN, Hassan I and Akram M. 2008. Allelochemicals: sources, toxicity and microbial transformation in soil – a review. *Annals of Microbiology* **58**(3): 351–357.

Kato-Noguchi H, Hasegawa M, Ino T, Ota K and Kujime H. 2010. Contribution of momilactone A and B to rice allelopathy. *Journal of Plant Physiology* **167**: 787–791.

Kobayashi K. 2004. Factors affecting phytotoxic activity of allelochemicals in soil. *Weed Biology and Management* **4**: 1–7.

Kong CH, Zhao H, Xu XH, Wang P and Gu Y. 2007. Activity and allelopathy of soil of ûavone O-glycosides from rice. *Journal of Agriculture and Food Chemistry* **55**: 6007–6012.

Kurt-Karakus PB, Stroud JL, Bidleman T, Semple KT, Jantunen L and Jones KC. 2007. Enantio selective degradation of organochlorine pesticides in background soils: variability in ûeld and laboratory studies. *Environmental Science & Technology* **41**: 4965–4971.

Leather GR. 1983. Sunflowers (*Helianthus annuus*) are allelopathic to weeds. *Weed Science* **31**: 37–42.

Lehman ME and Blum U. 1999. Evaluation of ferulic acid uptake as a measurement of allelochemical dose: Effective concentration. *Journal of Chemical Ecology* **25**: 2585–2600.

Li XJ, Xia ZC, Kong CH and Xu XH. 2013. Mobility and microbial activity of allelochemicals in soil. *Journal of Agricultural and Food Chemistry* **61**: 5072–5079.

Luo Yi, Davis AS and Yannarell AC. 2016. Interactions between allelochemicals and he microbial community affect weed suppression following cover crop residue incorporation into soil. *Plant Soil* **399**: 357–371.

Macias FA, Varela RM, Torres A and Molinillo JMG. 1999. Potential of cultivar sunflowers (*Helianthus annuus* L) as a source of natural herbicide template. pp. 531–550. In: *Principles and Practices in Plant Ecology: Allelochemical Interactions*. (Eds. Inderjit, Dakshini KMM and Foy CL),CRC Press, Boca Raton, FL.

Macías FA, Oliveros-Bastidas A, Marin D, Castellano D, Simonet AM and Molinillo JMG. 2005. Degradation studies on benzoxazinoids: soil degradation dynamics of (2R)-2-O-beta-D-glucopyranosyl-4hydroxy-(2H)-1,4-benzoxazin-3(4H)-one (DIBOA-Glc) and its degradation products, phytotoxic allelochemicals from gramineae. *Journal of Agricultural and Food Chemistry* **53**: 554–561.

Macías FA, Oliveros-Bastidas A, Marín D, Chinchilla N, Castellano D and Molinillo JMG. 2014. Evidence for an allelopathic interaction between rye and wild oats. *Journal of Agricultural and Food Chemistry* **62**: 9450–9457.

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

Mahmood K., Khaliq A, Cheema ZA and Arshad M. 2013. Allelopathic activity of Pakistani wheat genotypes against wild oat (*Avena fatua* L.). *Pakistan Journal of Agricultural Science* **50**: 169–176.

Masum S, Hossain A, Akamine H, Sakagami Jun-Ichi and Bhowmik PC. 2016. Allelopathic potential of indigenous Bangladeshi rice varieties. *Weed Biology and Management* **16**: 119–131.

Masum S, Hossain A, Akamine H, Sakagami Jun-Ichi, Ishii T, Gima S, Kensaku T and Bhowmik PC. 2018. Isolation and characterization of allelopathic compounds from the

indigenous rice variety "Boterswar' and their biological activity against *Eichornia* crus-galli L.

Allelopathy Journal **43**(1): 31–42.

Mohler CL, Dykeman C, Nelson EB and Ditommaso A. 2012. Reduction in weed seedling emergence by pathogens following the incorporation of green crop residue. *Weed Research* **52**: 467–477.

Molisch H. 1937. *Der Einfluss einer Pflanze auf die andere-Allelopathie*; Fischer: Jena

Mushtaq W and Siddiqui MB. 2017. Allelopathy studies in weed science in India – A review. *International Journal of Natural Research Ecology and Management* **2**(6): 99–103.

Niemeyer HM. 1988. Hydroxamic acids (4-hydroxy-1,4-benzoxazin–ones) defense chemicals in the gramineae. Phytochemistry **27**: 267–292.

Nimbal CI, Pedersen JF, Yerkes CN, Weston LA and Weller SC. 1996. Phytotoxicity and distribution of sorgoleone in grain sorghum germplasm. *Journal of Agricultural and Food Chemistry* **44**: 1343–1347.

Olofsdotter M. 2001. Rice - a step toward use of allelopathy. *Agronomy Journal* **93**: 3–8.

Olofsdotter M, Navarej DC and Moody K. 1995. Allelopathic potential of rice (*Oryza sativa* L.) germplasm. *Annals of Applied Biology* **127**: 543–560.

Ohno T. 2001. Oxidation of phenolic acid derivatives by soil and its relevance in allelopathic activity. *Journal of Environmental Quality* **30**: 1631–1635.

Perry LG, Thelen GC, Ridenour WM, Callaway RM, Paschke MW and Vivanco JM. 2007. Concentration of allelochemical (()-catechin in *Centaurea maculosa* soils. *Journal of Chemical Ecology* **33**: 1573–1561.

Pue KJ, Blum U, Gerig M and Shafer SR. 1995. Mechanisms by which non- in inhibitory concentrations of glucose increase inhibitory activity of p-coumaric acid on morning glory seedling biomass accumulation. *Journal of Chemical Ecology* **21**: 833–847.

Putnam AR and Duke WD. 1974. Biological suppression of weeds: evidence for allelopathy in accessions of cucumber. *Science* **185**: 370–372.

Putnam AR, DeFrank J and Barnes JP. 1983. Exploitation of allelopathy for weed control in annual and perennial cropping systems. *Journal of Chemical Ecology* **9**: 1001–1010.

Rice EL. 1984. Allelopathy. 2nd. Edn., Academic Press, New York, USA.

Schmidt SK and Ley RE. 1999. Microbial competition and soil structure limit the expression of allelochemicals in nature. pp. 339–351. In: *Principles and Practices in Plant Ecology: Allelochemical Interactions*, (Eds. Inderjit, Dakshini KMM and Foy CL), CRC Press, Boca Raton, FL.

Siqueira J, Nair MG, Hammerschmidt R and Saûr GR. 1991. Signiûcance of phenolic compounds in plant-soil-microbial systems. *Critical Review Plant Science* **10**: 63–121.

Teasdale JR 1993. Interaction of light, soil moisture, and temperature with weed suppression by hairy vetch residue. *Weed Science* **41**: 46–51.

Teasdale JR and Daughtry CST. 1993. Weed suppression by live and desiccated hairy vetch (*Vicia villosa*). *Weed Science* **41**: 207–212.

Teasdale JR, Rice CP, Cai GM and Mangum RW. 2012. Expression of allelopathy in the soil environment: soil concentration and activity of benzoxazinoid compounds released by rye cover crop residue. *Plant Ecology* **213**: 1893–1905.

Tharayil N, Bhowmik PC and Xing B . 2006. Preferential sorption of phenolic phytotoxins to soil: implications for altering the availability of allelochemicals. *Journal of Agricultural and Food Chemistry* **54**: 3033–3040.

Tharayil N, Bhowmik PC and Xing B. 2008. Bioavailability of allelochemicals as affected by companion compounds in soil matrices. *Journal of Agricultural and Food Chemistry* **5**: 3706–3713.

Trezzi M, Vidal RA, Babinot Junir AA, Bittencourt H.vonH and da Silva Souza Fiho AP. 2016. Allelopathy: driving mechanisms governing its activity in agriculture. *Journal of Plant Interactions* **11**(1): 53–60.

Uren NC 2001. Types, amount and possible functions of compounds released into the rhizosphere by soil-grown plants. *In* The Rhizosphere: Biochemistry and Organic Substances at the Soil Plant Interface; Pinto, R., Varanini, Z., Nannipieri, P., Eds.; Marcel Dekker: New York, pp 19–40.

Vyvyan J. 2002. Allelochemicals as leads for new herbicides and agrochemicals. *Tetrahedron* **58**:1631–1646.

Wauchope D, Yeh S, Linders J, Kloskowski R, Tanaka K, Rubin B, Katayama A, Kordel W, Gerstl Z, Lane M and Unsworth J. 2002. Pesticide soil sorption parameters: Theory, measurement, uses, limitations and reliability. *Pest Management Science* **58**, 419–445.

Wang TSC, Li SW, and Feng YL. 1978. Catalytic polymerization of phenolic compounds by clay minerals. *Soil Science* **126**: 15–20.

Weston LA. 1996. Utilization of allelopathy for weed management in agroecosystems. *Agronomy Journal* **88**: 860–866.

Weston LA and Duke SO. 2003. Weed and crop allelopathy. Critical Review. *Plant Science* **22**: 367–389.

Weston LA, Alsaadawi IS and Baerson SR. 2013. Sorghum allelopathy from ecosystem to molecule. *Journal of Chemical Ecology* **39**: 142–153.

Wu H, Pratley J, Lemerle D, Haig T and Verbeek B. 1998. Differential allelopathic potential among wheat accessions to annual ryegrass. pp. 567–571. *In*: *Proceedings, of the Ninth Australian Agronomy Conference*. (Eds. Michalk, DL and Prately JE), Wagga Wagga, Australia.

Wu H, Pratley J, Lemerle D, Haig T and Verbeek B. 1999. Crop cultivars with allelopathic capability. *Weed Research* **3**9: 171–180.

Wu H, Haig T, Pratley J, Lemerle D and An M. 2002. Biochemical basis of wheat seedling allelopathy on the suppression of annual ryegrass (*Lolium rigidum*). *Journal of Agricultural and Food Chemistry* **50**: 4567–4571.

Xing B, Pignatello JJ and Gigliotti B. 1996. Competitive sorption between atrazine and other organic compounds in soils and model sorbents. *Environmental Science & Technology* **30**: 2432–2440.

Yenish JP, Worsham AD and Chilton WS. 1995. Disappearance of DIBOA- glucoside, DIBOA, BOA from rye (*Secale cereal* L.) cover crop residue. *Weed Science* **43**: 18–20.

Zikmundová M, Drandarov K, Bigler L, Hesse M and Werner C. 2002. Biotransformation of 2-benzoxazolinone and 2-hydroxy-1,4-benzoxazin-3-one by endophytic fungi isolated from *Aphelandra tetragona*. *Applied Environmental Microbiology* **68**(10): 4863–4870.

Indian Journal of Weed Science **50**(3): 218–222, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Conservation agriculture-based resource-conserving practices and weed management in the rice-wheat cropping systems of the Indo-Gangetic Plains

Ram K. Malik*, Virender Kumar[1] and Andrew McDonald

International Maize and Wheat Improvement Centre, NASC Complex, New Delhi 110 012

[1]International Rice Research Institute, Los Banos, Philippines

**Email: RK.Malik@cgiar.org*

Article information

DOI: 0.5958/0974-8164.2018.00051.5

Type of article: Review article

Received : 22 September 2018
Revised : 4 October 2018
Accepted : 7 October 2018

Key words

Conservation agriculture

Direct-seeded rice

Indo-Gangetic Plains

Herbicide resistance

Rice-wheat

Zero tillage

ABSTRACT

Conservation agriculture (CA) was used interchangeably with terms like conservation tillage, no tillage, zero tillage (ZT), direct drilling *etc*. ZT has been the function of weed management, not just in wheat but in rice too. ZT in India was at the dead end in the early 1990s. Until the evolution of herbicide resistance (HR) in *Phalaris minor.* By now ZT machines are recognised not only as a commercial venture but also attracts major technological step towards intensification of agriculture. With the availability of the "*Happy Seeder*"– a ZT machine that can plant rice and wheat in high-residue conditions – has made it possible to retain the residues on the soil surface, thereby providing an alternative to residue burning. It has been reported that ZT in combination with residue mulch reduced the weed problem over time in ZT wheat than CT wheat. In direct-seeded rice (DSR), no single method can provide effective and sustainable weed management solutions. Therefore, combining cultural methods in tandem with judicious use of modern herbicides is crucial. For successful weed control in DSR, pre-emergence (pendimethaline or oxadiargyl or pretilachlor with safner) followed by post-emergence (bispyribac or bispyribac based tank mixture including bispyribac + pyrazosulfuron/ azimsulfuron/2,4-D/halosulfuron or fenoxaprop with saftner or fenoxaprop based tank mixture including fenoxaprop + ethoxysulfuron) herbicide application has provided effective weed control in DSR.

INTRODUCTION

Conservation agriculture (CA), a term used in 1970s was adopted by FAO in 1990s (FAO CA website 2004). This term was used interchangeably with terms like conservation tillage, no tillage, zero tillage, direct drilling *etc*. But, it is much more than that. Zero tillage (ZT) is one of the three pillars of that. Others are permanent cover and crop rotation. From its evolution to its sustainability, ZT has been the function of weed management, not just in wheat but in rice too. ZT in India was at the dead end in the early 1990s. Until the evolution of herbicide resistance (HR) in *Phalaris minor*, a major grass weed in wheat against isoproturon in the early 1990s, farmers could dodge the question of ZT but the crisis of HR convinced them to take the new initiative. In addition, this time, an innovative approach was conceptualized and popularized for its wide-scale dissemination. The approach was a major shift towards a bottom-up farmer's participatory rather than a top-down linear model approach of technology dissemination. By now ZT machines are recognised not only as a commercial venture but also attracts major technological step towards intensification of agriculture. Numbers of ZT machine manufacturers have increased from almost one or two in the early 1990s to hundreds of them now. Over the time, ZT machine was modified to sow the wheat crop in full rice residue load to address the problem of residue burning. With the availability of the "Happy Seeder"– a ZT machine that can plant rice and wheat in high-residue conditions – has made it possible to retain the residues on the soil surface, thereby providing an alternative to residue burning. Agriculture Engineers brought ideas and design for the machines but agronomist brought it to the forefront as a tool to intensify agriculture, to conserve resources, and to bring about resilience in agriculture against climate change.

Three factors have brought about the wide-scale adoption of ZT in wheat. One of them is the mind-set issue which took a bit longer than expected but could be resolved through farmer's participatory process and by demonstrating the clear benefits of the technology in reducing the cost of cultivation and improving wheat yield. Second is the investment that came from machines manufacturers. With the availability of machines, it went into new areas. The third is that resistance in *Phalaris minor* which facilitated the adoption of ZT to reduce the cost of cultivation to enable farmers to use new but expensive herbicides to manage resistant *P. minor* populations which otherwise could have done significant harm to wheat production in the grain bowl of India. A major advantage of ZT technology in wheat is that it facilitates early planting by reducing the turnaround period by reducing land preparation time because of directly drilling in ZT conditions. Early wheat planting has demonstrated a positive impact on wheat yield by mitigating the negative effect of terminal heat stress (Kumar *et al.* 2018, CSISA 2015). These results suggest that ZT provides resilience in the changing climate change conditions.

Because of clear and positive impacts of ZT technology in wheat on productivity, profitability, resource use efficiencies and resilience to terminal heat stress (Keil *et al.* 2015, Erenstein and Laxmi 2008), ZT wheat has been widely adopted in north west India (e.g. 0.26 Mha in Haryana state alone) and now it is gaining popularity in the eastern Indo-Gangetic Plains (IGP) (e.g. >0.05 Mha in Bihar and Eastern Uttar Pradesh) (CSISA 2015, CSISA 2016, CSISA 2017). Keil *et al.* (2005) based on 40 village survey in Bihar observed an additional yield gain of 498 kg/ha (19%) and economic gain of US$ 110/ha with the adoption of ZT wheat as compared to farmer's practice of conventional till wheat.

The performance of ZT technology will be different in different ecologies and different crops, and will depend on stage of its development and refinement. Recent work shows that ZT direct-seeded rice (ZTDSR) is not yet fully ready for its wide-scale dissemination at farmer's field until weed management issues are resolved. DSR followed by ZT wheat (ZTW) has the potential to increase the system productivity with lower environmental footprint (Kumar *et al.* 2018, Laik *et al.* 2014, Bhushan *et al.* 2007). There is no technological difficulty in introducing ZT DSR followed by ZT wheat as part of full-conservation agriculture (full-CA) as this is economically and environmentally more attractive. The temptation to introduce ZTDSR *fb* ZTW could be costly because weed management is still a concern in ZTDSR but not in ZTW. Till full CA for the rice-wheat system is fully perfected at farmer's field, partial CA (DSR in non-puddled condition instead of under ZT *fb* ZT wheat) can be more economical with lower resource use.

Weed management in CA-based resource conserving practices

CA-based practices are promoted to address the emerging issues of resource scarcity (e.g. labor and water), declining factor productivity, and climate change. Despite multiple benefits with these alternative CA-based resource efficient practices, weed control remains a major bottleneck in their wide-scale adoption. In addition, one of the major criticisms associated with CA-based practices is more dependence on herbicide for weed control. Therefore, integrated weed management strategies are needed to reduce dependence on herbicides and minimize risks associated with their overuse, including the evolution of herbicide resistance in weeds and shift in weed flora towards more difficult-to-control weeds.

Weed management in zero tillage wheat

With shift from CT to ZT in wheat, weed control did not pose a major constraint in its adoption as this shift also created non-favourable conditions for some of the most important weeds of wheat such as *P. minor* and also opened up new opportunities to use for weed control (*e.g.* residue mulching) which ultimately resulted in crop-weed competition in favour of wheat crop. The lower emergence of *P. minor* under ZT may be attributed to (1) higher soil strength in ZT because of crust development in the absence of tillage after rice harvest, which can mechanically impede seedling emergence (Chhokar *et al.* 2007), and (2) higher weed seed predation under ZT (Kumar *et al.* 2013). Other possible factors could be (1) less soil temperature fluctuation because ZT helps in moderating soil temperature (Gathala *et al.* 2011) or (2) lower levels of light stimuli, N mineralization, or gas exchange, all of which are known to stimulate germination of many weed species following tillage (Franke *et al.* 2007).

It has been reported that ZT in combination with residue mulch reduced the weed problem over time in ZT wheat than CT wheat (Kumar *et al.* 2015). In a medium-term permanent plot experiment, the seedbank of wheat weeds including *P. minor*, *Rumex dentatus*, *Melilotus indica* and *Coronopus didymus* decreased by 90-100%, 75-100%, 70% and 78%, respectively in four years under CA-based systems (ZTDSR *fb* ZT wheat or PTR *fb* ZT wheat) with full retention of rice residue as mulch compared to conventional-till system (PTR *fb* CT wheat) (Kumar *et al.* 2015). Seed predation of *P. minor* was also found higher in CA-based compared to conventional systems.

In ZT wheat, integration of rice residue mulch, early wheat sowing, use of certified/clean seeds, and crop rotation has been found effective in reducing weed problems. If not managed well, shift in weed flora has been observed in partial CA-based system (PTR *fb* ZT wheat without residue). Higher population of *Rumex dentatus* has been observed in farmer's field with shift from CT to ZT in partial CA-based systems (Chhokar *et al.* 2007 and 2009). The higher population of *R. dentatus* may be due to higher concentration of their seed on soil surface because after puddling seeds of *Rumex* float being light with perianth and remained on soil surface in ZT wheat, whereas in CT, seeds are buried during tillage, hence emergence is reduced in CT wheat. Also there is risk of shift in weed flora towards difficult to control perennial weeds with shift from CT to ZT wheat if these perennial weeds are not controlled by glyphosate prior to sowing of ZT wheat.

At research farm of CCS Haryana Agricultural University, zero-tillage has been practiced for more than 17 years in pearl-millet-wheat rotation and for 15 years in sorghum – wheat rotation. Perennial weeds in the rainy season have been managed by using glyphosate applied few days before seeding pearl-millet or sorghum. Such plots continue to fare better during all years and the perennial weed pressure continued to be more under conventional tillage. The decline in the overall perennial weed pressure is even more impressive because both glyphosate in the rainy season and excellent wheat canopy cover in the month of March and beginning of April does not allow accumulation of food into the underground parts of perennials. Another way to look at this is that net flow of food material into the underground parts of perennials is less. On the whole, once the pre-seeding herbicides are used on case by case basis, ZT is set to reduce the stress of perennials.

Herbicide resistance management

Herbicide resistance was the most serious problem in wheat in the Rice-Wheat Cropping System during early 1990s. Efforts on herbicide resistance management before 1996-97 were concentrated around alternate crops (Malik *et al.* 2002). The problem of resistance was so serious that farmers in Haryana started sowing sunflower to exhaust the seed bank of *P. minor*. Crop rotation was possible only in small area and farmers needed a viable technology for herbicide resistance management. Zero tillage made is possible to achieve three major objectives leading to create competition in favour of crop. These are optimum plant population, seeding at a time, which is not conducive to *P. minor* emergence and accurate fertilizer placement. Reduced population of this weed doesn't mean that *Phalaris* problem will be solved by ZT alone. It also does not mean that farmers will stop using herbicides. Our long-term trials at five sites in different villages indicated that farmers can skip herbicide once in 3-4 years. There is a constant danger that this weed will constantly evolve resistance to new herbicides and the cross resistance was expected to happen (Malik *et al.* 2002), which has happened now. Using herbicides alone is not a long term solution for managing resistance. Emergence of very heavy population during early phases of crop cycles can be prevented with ZT. Details of resistance development and its management using integrated approach with focused attention on zero-tillage have been published (Malik *et al.* 2002 and Franke *et al.* 2007)

Weed management in DSR

In spite of best efforts during last 20 years, we have seen weakest growth in area under direct-seeded rice (DSR) throughout except some successes in basmati rice areas of Haryana and also in low productivity areas of Punjab. Two factors were important: one competitive varieties and the other water with assured irrigation. Both these factors are not prevalent in the Eastern India as most of rice is rainfed in these ecologies and access to new herbicide molecules is limited because of poor market development. Availability of right moisture at the time of pre- and post-emergence herbicide application and afterward is questionable in these ecologies because of rainfed nature.

In DSR, no single method can provide effective and sustainable weed management solutions. Therefore, combining cultural methods in tandem with judicious use of modern herbicides is crucial. Preliminary evidence suggests that practices which stimulate germination of rice weeds and their termination prior to rice planting may be extremely beneficial for reducing weed populations, particularly of problematic species such as weedy rice (*Oryza sativa* L.), *Dactyloctenium aegyptium* Willd. (crowfootgras), *Leptochloa chinensis* (L.) Nees (Chinese sprangletop) *etc*. that are difficult to control with herbicides. For example, inclusion of mungbean or through stale seedbed techniques during the fallow period between wheat and rice resulted in an 84 and 40% reduction in population of *D. aegyptium* in the subsequent rice crop under ZT and CT systems respectively (Rao *et al.* 2017).

Similarly, creating dust/soil mulch is very effective in suppressing weeds and conserving soil moisture in DSR. It has been observed that DSR fields established after pre-sowing irrigation (dust mulching) under conventional tillage have less weed infestation than when established in dry condition followed by immediate post-sowing irrigation because of dust mulch effect created in former (Malik *et al.* 2015). Irrigation immediately after sowing creates conditions favourable for weed emergence and growth. In contrast, in DSR with dust mulch in which rice is seeded after pre-sowing irrigation followed by tillage, the first post sowing irrigation is delayed for almost 2-3 weeks because broken capillaries (as a result of tillage) minimize continuum of moisture loss from lower soil layer to atmosphere and create dust mulch; hence conditions are less favourable for weeds to emerge. Detailed quantification of dust mulch on weeds and moisture conservation is going on.

For successful weed control in DSR, several herbicide combinations have shown promise. Based on our studies in Bihar/EUP, Odisha, and Haryana, pre-emergence (pendimethaline or oxadiargyl or pretilachlor with safner) followed by post-emergence (bispyribac or bispyribac based tank mixture including bispyribac + pyrazosulfuron/azimsulfuron/ 2,4-D/halosulfuron or fenoxaprop with saftner or fenoxaprop based tank mixture including fenoxaprop + ethoxysulfuron) herbicide application has provided effective weed control in DSR. In the absence of pre-emergence application, bispyribac or bispyribac based tank mixture mentioned above followed by one hand weeding/mechanical weeding effectively controlled weeds in DSR. Nutsedge (*Cyperus rotundus*)-dominated weed flora in rice commonly found in eastern India was effectively controlled with the tank mix combination of bispyribac with pyrazosulfuron, applied 15-20 days after sowing (DAS).

Weed management in DSR in rainfed ecologies of eastern India is more challenging and complex because of more intensified and diversified weed flora, uncertainly of time of weed management due to uncertainty of rains, and also lack of herbicide availability and knowledge on application methodology. Current experiences through CSISA efforts in these ecologies clearly revealed that an approach of integrated weed management including use of suitable pre- and post-emergence herbicides in sequence, and then also supplemented by manual or mechanical weeding (cono-weeder or Power-weeder) and other cultural practices as discussed above depending on case-by-case will provide more effective weed management than any of these options in isolation. In these ecologies, effective land preparation is critical to kill existing weeds prior to rice seeding.

Ploughing/tillage just prior to crop establishment in wet season is relatively less effective in killing existing weed because of sufficient soil moisture following tillage operation which allows weeds to re-grow. Therefore, a summer ploughing could be more effective in killing existing weeds because of dry period following tillage which create conditions for desiccation of uprooted weeds. If weed pressure is high and tillage is delayed till rainy season starts, applying non-selective herbicide such as glyphosate (1-2 days prior to tillage) followed by tillage has been found effective in killing existing weeds than by tillage alone.

Weedy rice in direct-seeded rice

Weedy rice is also emerging and important problem in areas where DSR is practiced. Stalebed technique to exhaust the existing seedbank and use of weedy rice free clean seed including use of hybrid seed to solve seed contamination problem should be an effective strategy. This will help facilitating the adoption of DSR especially under conventional tillage (CT). Like any other technology, such practicalities may get in the way forward. Hybrid rice also makes it possible to boost the early crop canopy cover.

REFERENCES

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

CSISA. 2015. *Cereal Systems Initiative for South Asia (CSISA)-Phase-II Annual Report 2015*. International Maize and Wheat Improvement Center (CIMMYT), New Delhi, India Available at. http://csisa.org/annual-reports/.

CSISA. 2016. *Cereal Systems Initiative for South Asia (CSISA)-Phase-III Annual Report 2016*. International Maize and Wheat Improvement Center (CIMMYT), New Delhi, India Available at. http://csisa.org/annual-reports/.

CSISA. 2017. *Cereal Systems Initiative for South Asia (CSISA)-Phase-III Annual Report 2017*. International Maize and Wheat Improvement Center (CIMMYT), New Delhi, India Available at. http://csisa.org/annual-reports/.

Chhokar RS, Sharma RK, Jat GR, Pundir AK and Gathala MK. 2007. Effect of tillage and herbicides on weeds and productivity of wheat under rice– wheat growing system. *Crop Protection* **26**: 1689–1696.

FAO. 2004. Conservation Agriculture—http://www.fao.org/agAGS/ages/main.htm

Malik RK, Kumar V, Yadav A and McDonald A. 2015. Weed science and sustainable intensification of cropping systems in South Asia. pp. 67–78. In: *Weed Science for Sustainable Agriculture, Environment, and Biodiversity*. (Eds. Rao AN and Yaduraju NT). Proceedings of the Plenary and Lead Papers of the 25th Asian-Pacific Weed Science Society Conference, Hyderabad, India.

Malik RK, Yadav A, Singh S, Malik RS, Balyan RS, Banga RS, Sardana PK, Jaipal S, Hobbs PR, Gill G, Singh S, Gupta RK and Bellinder R. 2002. *Herbicide Resistance Management and Evolution of Zero-tillage—A Success Story*. Research Bulletin, CCS Haryana Agricultural University, Hisar, India, 43p.

Erenstein O and Laxmi V. 2008. Zero tillage impacts in India's rice–wheat systems: a review. *Soil & Tillage Research* **100**: 1–14.

Erenstein O, Malik RK and Singh S. 2007. Adoption and impacts of zero tillage in the irrigated rice-wheat systems of Haryana, India. *Research Report*. New Delhi: International Maize and Wheat Improvement Center and Rice-Wheat Consortium

Franke AC, Singh S, McRoberts N, Nehra AS, Godara S, Malik RK and Marshall G. 2007. *Phalaris minor* seedbank studies: longevity, seedling emergence and seed production as affected by tillage regime. *Weed Research* **47**: 73–83.

Gathala MK, Ladha JK, Saharawat YS, Kumar V, Kumar V and Sharma PK. 2011. Effect of tillage and crop establishment methods on physical properties of a medium-textured soil under a seven-year rice-wheat rotation. *Soil Science Society of America Journal* **75**: 1851–1862.

Keil A, D'souza and McDonald A. 2015. Zero-tillage as a pathway for sustainable wheat intensification in the Eastern Indo-Gangetic Plains: does it work in farmers' fields? *Food Security* **7**(5): 983–1001 doi: 10.1007/s12571-015-0492-3

Kumar V, Brainard DC, Sharma PC, Jat HS, Malik RK, Sharma DK and McDonald A. 2015. Conservation agriculture (CA)-based practices reduced weed problem in wheat and caused shifts in weed seedbank community in rice-wheat cropping systems. p. 142. In: *Weed Science for Sustainable Agriculture, Environment, and Biodiversity.* (Eds. Rao AN and Yaduraju NT), Proceedings of 25th Asian Pacific Weed Science Society Conference, Hyderabad, India. October 13-16, 2015.

Kumar V, Jat HS, Sharma PC, Balwinder-Singh, Gathala MK, Malik RK, Kamboj BR, Yadav AK, Ladha JK, Raman A, Sharma DK and McDonald A. 2018. Can productivity and profitability be enhanced in intensively managed cereal systems while reducing the environmental footprint of production? Assessing sustainable intensification options in the breadbasket of India. *Agriculture Ecosystems and Environment* **252**: 132–147.

Kumar V and Ladha JK. 2011. Direct-seeding of rice: recent developments and future research needs. *Advances in Agronomy* **111**: 297–413

Laik R, Sharma S, Idris M, Singh AK, Singh SS, Bhatt BP, Saharawat YS, Humphreys E, Ladha JK. 2014. Integration of conservation agriculture with best management practices for improving system performance of the rice–wheat rotation in the Eastern Indo-Gangetic Plains of India. *Agriculture, Ecosystems & Environment* **195**: 68–82.

Malik RK and Singh S. 1993. Evolving strategies for herbicides use in wheat: Resistance and integrated weed management. pp. 225-238. In: *Proceedings International Symposium IIndian Society of Weed Science,* Hisar, India, 18-20 Nov. 1993.

Malik RK and Singh S. 1995. Littleseed canary grass (*Phalaris minor Retz.)* resistance to isoproturon in India. *Weed Technology* **9**(3): 419–425.

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

Rao AN, Brainard DC, Kumar V, Ladha JK and Johnson DE. 2017. Preventive weed management in direct-seeded rice: targeting the weed seedbank. *Advances in Agronomy* **144**: 45–142.

Indian Journal of Weed Science **50**(3): 223–238, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Herbicide resistant biotech crops and their import to Indian agriculture

V.S. Rao*

Affiliate Faculty Member, Department of Plant Sciences, University of California, Davis, CA, USA

**Email: dr_vs_rao@yahoo.com*

Article information

DOI: 10.5958/0974-8164.2018.00052.7

Type of article: Review article

Received : 30 September 2018
Revised : 2 November 2018
Accepted : 4 November 2018

Key words
Biotech

Economies

Genetically modified

Herbicide resistant

Soil ecosystem

ABSTRACT

Herbicide resistant (HR) biotech crops which include both the transgenic and non-transgenic ones are being grown in several countries for over 24 yr. Transgenic biotech crops are derived when an exogenous herbicide-resistant gene/s from non-plant sources is/are inserted into the desired crop plant. When the inserted genes stably integrate and express in the plant genome, the concerned plant behaves like a normal plant but with the acquired character, *i.e.* herbicide resistance. On the other hand, the non-transgenic biotech crops are generated for some herbicides (ALS-inhibiting and ACCase-inhibiting cyclohexane-diones) by selecting for target mutations in plant populations or by tissue culture or by mutation breeding. HR varieties have been developed for soybean, maize, cotton, canola, wheat, rice, sugar beet, alfalfa, *etc.* while the herbicides included glufosinate, dicamba, 2,4-D, phenmedipham, paraquat, imidazolinones, mesotrione, sulfonylureas, *etc.*

About 190 million ha around the world have been under HR transgenic crops in 2017. Around 80% of this area was under HR ones either alone or stacked with insect resistance. Biotech crops have made a positive contribution to global crop production and the economies of farmers, while they certainly raised concerns about biosafety to consumers. Several countries led by USA have widely adopted HR biotech crops, while India has been growing only the insect-resistant (IR) Bt cotton since 2002. With adoption of Bt varieties, the country has achieved a great stride in cotton production, accounting for a quarter of market share in global cotton production in 2017. Although no HR biotech crop is adopted in India, it is grown illegally by farmers in key cotton-growing states. The concerns and limitations about HR biotech crops are related to agro-ecology, evolution of herbicide-resistant weeds, food safety, soil ecosystem, coexistence of biotech and conventional crops, socio-economic consequences, coexistence of biotech and conventional food products, etc. This paper also discusses management of HR biotech crops in greater detail.

Herbicide resistant biotech crops

Biotech crops are designed to become resistant (tolerant) to specific broad-spectrum herbicides which kill the surrounding weeds, but leave the cultivated crop unaffected. Resistance is imparted into the crop by changing the genetic makeup of crop plants. In this process, known as genetic engineering, one or more traits that are not already present are introduced. It involves the use of laboratory tools to insert, alter or cut out pieces of DNA that contain one or more genes of interest. Genes are molecules of DNA that code for distinct traits or characteristics. Biotech crops, also referred as genetically modified (GM) crops or genetically engineered (GE) crops, are of two types: transgenic and non-transgenic.

Transgenic biotech crops

The process of transferring an exogenous gene, called transgene, is referred to as transgenic engineering or transgenesis. When this new gene is inserted, the plant will exhibit a new property and transmit that property to its offspring. Once inserted, transgenes behave like normal plant genes if they are stably integrated and expressed. This genetic engineering technology changes the phenotype of an organism.

Once a transgenic plant is created, the transgenes can be inherited along with the rest of the plant's genes through normal mating by pollination. The offspring are also transgenic when they acquire the transgenes this way. Plant breeders can take a transgenic plant made in the laboratory and use conventional breeding methods to develop different transgenic varieties of the crop that are adapted for specific uses.

Genetic engineering allows the direct transfer of one or just a few genes of interest, between either closely or distantly related organisms to obtain the desired agronomic trait. Not all genetic engineering techniques involve inserting DNA from other organisms. Plants may also be modified by removing or switching off their own specific genes by using 'recombinant technology.' It is a laboratory gene-splicing procedure in which the DNA of the donor organism is cut into pieces using restriction enzymes followed by insertion of one of these fragments into the DNA of the host plant. Using recombinant DNA (rDNA) technology, we can isolate and clone single copy of a gene or an rDNA fragment into an indefinite number of copies, all identical. This technology allows bringing together genetic material from multiple sources, creating sequences that would not otherwise be found in biological organisms. Most of the time, a bacterial or virus plasmid is used to insert the donor DNA.

The process of transgenic engineering requires the successful completion of, a) locating and identifying genes of interest, b) isolation and extraction of DNA, c) cloning, designing and constructing the gene of interest for plant infiltration, d) transformation and e) testing and plant breed-back crossing (Rao 2014, 2018).

Once a new transgenic crop variety is developed, it needs to be assessed in terms of food and safety to the environment. This is carried out in conjunction with testing of plant performance. In this phase, the transgenic varieties need to be assessed for altered nutrient levels, known toxicants, new substances, antibiotic resistance markers, non-pathogenicity to animals and humans, toxicity to non-target organisms, stable integration of the introduced gene(s) in the plant's chromosomes, risk of creating new plant viruses, effects on plant biology and ecosystem, spread of the transgene to other crops and wild relatives, allergenicity, *etc*.

Transgenic herbicide-resistant crop events/ Varieties

Several transgenic herbicide resistant crop varieties/events have been developed since 1994. It was that year which saw the commercial release of the first herbicide-resistant transgenic crop variety, BXN cotton line, developed by CalGene and Rhône-Poulenc. The same year also witnessed the release of the first glyphosate-resistant (GR) crop variety, MON4030-2-6 (GTS 40 3 2) of soybean. In 2005, this event was grown on approximately 87% of the U.S. acreage and 60% of the global acreage under soybean crop (USDA-NASS 2005). Later, another GR event, MON89788, was made available in 2007 and several other countries by 2010. It provided farmers flexibility, simplicity and cost-effective weed control options. These two 'Roundup Ready Soybean' varieties transformed global soybean production significantly.

Since then, scores of herbicide-resistant transgenic crop varieties have been developed for several herbicides. These crops included soybean, maize, cotton, canola, wheat, rice, sugar beet, alfalfa (lucerne), etc. while those of herbicides were glyphosate, glufosinate, dicamba, 2,4-D, phenmedipham, paraquat, imidazolinones, mesotrione, sulfonylureas, etc.

Some of the transgenic crop lines resistant to different herbicides are presented in **Tables 1, 2 and 3**. As it is impossible to include all the events and stacks developed in the world thus far, only a few selected ones are included here.

Gene stacking

Crops are also engineered or "stacked" to express multiple traits to enable them become resistant to multiple herbicides or to herbicides and insecticides together. In this stacking (pyramiding) process, two or more genes (traits) of interest with different modes (sites) of action are inserted into a single plant. An example of a stack is a plant transformed with two genes (e.g., glyphosate-resistant and glufosinate-resistant; glyphosate-resistant and dicamba-resistant) or more that code for proteins having different modes of action. It is a hybrid plant expressing both herbicide resistant genes derived from two parent plants. For example, this is done by combining glyphosate resistance gene *epsps* with the *pat* gene to confer resistance to glufosinate and/or with *dmo* gene to confer resistance to dicamba.

Biotech stacks are engineered to broaden weed control efficiency as also to have better chances of overcoming other myriad of problems in the field such as diseases, abiotic stresses, etc. so that farmers can increase crop productivity. Some of the stacked varieties and hybrids are presented in **Table 4**.

Table 1. Transgenic crop events/varieties developed for glyphosate resistance from 1994

Crop	Event/Variety	Gene(s)	Developer	First Approval (Yr)
Soybean	MON04030-2-6 (GTS 40 3 2)	*cp4 epsps* (*aroA*:*CP4*)	Monsanto	1994
	MON89788	*cp4 epsps* (*aroA*:*CP4*)	Monsanto	2007
Maize	GA21	*mepsps*	Monsanto	1997
	NK603 (603)	*cp4 epsps* (*aroA*:*CP4*)	Monsanto	2000
	MON832	*cp4 epsps* (*aroA*:*CP4*) *goxv247*		
	MON87427	*cp4 epsps* (*aroA*:*CP4*)	Monsanto	2012
	HCEM485	*2mepsps*	Stine Seed Farm	2012
	VCO-01981-5	*epsps grg23ace5*	Genective S.A.	2013
Cotton	MON1445	*cp4 epsps* (*aroA*:*CP4*)	Monsanto	1995
	MON 88913	*cp4 epsps* (*aroA*:*CP4*)	Monsanto	2005
	GHB614	*2mepsps*	Bayer CropScience	2009
Canola	GT73 (RT73)	*cp4 epsps* (*aroA*:*CP4*)	Monsanto	1995
	GT200 (RT200)	*cp4 epsps* (*aroA*:*CP4*)	Monsanto	2002
	MON88302	*cp4 epsps* (*aroA*:*CP4*)	Monsanto	2012
	73496	*gat4621*	DuPont (Pioneer)	2012
Wheat	MON71800	*cp4 epsps* (*aroA*:*CP4*)	Monsanto	2004
Sugar beet	GTSB77	*cp4 epsps* (*aroA*:*CP4*)	Novartis/ Monsanto	1998
	H7-1	*cp4 epsps* (*aroA*:*CP4*)	Monsanto	2004
Alfalfa (lucerne)	J101	*cp4 epsps* (*aroA*:*CP4*)	Monsanto	2010
	J163	*cp4 epsps* (*aroA*:*CP4*)	Monsanto	2004

Genes: *aroA:CP4*: *Agrobacterium tumefaciens* strain CP4; *cp4 epsps*: gene which is the herbicide tolerant form of 5-enolpyruvylshikimate-3-phosphatesynthase; *cp4 epsps (aroA:CP4)*: this gene is called by either name; *epsps grg23ace5*: synthetic gene, similar to natural *epsps grg23* gene from soil bacterium *Arthrobacter globiformis*; *mepsps*: modified 5-enolpyruvylshikimate; *2mepsps*: double mutant version of 5-enolpyruvylshikimate; *gat4621*: glyphosate *N*-acetyltransferase (*gat*) gene derived from *Bacillus licheniformis*; *goxv247*: this gene, derived from *Ochrobactrum anthropic* stain LBAA, produces a modified enzyme GOX that catalyzes glyphosate into aminomethylphosphonic acid and glyoxylate.

Table 2. Transgenic crop events/varieties developed for glufosinate (phosphinothricin) resistance

Crop	Event/Variety	Gene(s)	Developer	First Approval (Yr)
Soybean	GU262	*bar*	Bayer CropScience	1995 (U.S.)
	W62, W98	*pat*	Bayer CropScience	1995 (U.S.)
	A2704-12; A5547-127	*pat*	Bayer CropScience	1996 (U.S.)
Maize	T14, T25	*pat* (syn)	Bayer CropScience	1995 (U.S.)
	DLL25 (B16)	*bar*	Monsanto	1996 (U.S.)
Cotton	LLCotton25	*bar*	Bayer CropScience	2003 (U.S.)
Rice	LLRICE06, LLRICE62	*bar*	Bayer CropScience	2000 (U.S.)
	LLRICE601	*bar*	Bayer CropScience	2008 (U.S.)
Canola	HCN92 (Topas 19/2)	*bar*	Bayer CropScience	1995 (Canada)
	HCN28 (T45)	*pat* (syn)	Bayer CropScience	1996 (Canada)
	MS8, RF3 (male-sterile)	*bar*	AgrEvo	1996 (U.S.)
Sugar beet	T120-7	*pat*	Bayer CropScience	2001 (Canada)

Genes: *bar*: bialaphos resistance gene derived from *Streptomyces hygroscopicus* which eliminates phosphinothricin N-acetyltransferase activity by acetylation; *pat*: gene derived from *Streptomyces viridochromogenes* strain Tü 494 which eliminates phosphinothricin N-acetyltransferase activity by detoxifying L-phophinothricin through acetylation.

Table 3. Transgenic crop events/varieties developed for bromoxynil, dicamba, 2,4-D and imidizolinones

Herbicide	Crop	Event	Gene	Developer	First Approval (Yr)
Bromoxynil	Cotton	BXN	*bxn*	Calgene/Monsanto	1994
	Canola	Oxy-235	*bxn*	Bayer CropScience	1997 (Canada)
Dicamba	Soybean	MON87708	*aad-1*	Monsanto	2011
2,4-D	Maize	DAS40278	*aad-1*	Dow AgroSciences	2012 (Canada)
Imidazolinones	Soybean	CV127	*csr1-2*	BASF	2009 (Brazil)

Genes: *aad-1*: the synthetic form of this gene, *aryloxyalkanoate dioxygenase 1*, detoxifies 2,4-D by side-chain and also r-enantiomers of aryloxyphenoxypropionate herbicides; *bxn*: derived from *Klebsiella pneumoniae* subsp. *Ozaenae* which produces nitrilase enzyme. *csr1-2*: modified acetohydroxyacid synthase large subunit (AtAHASL) derived from *Arabidopsis thaliana*.

Table 4. Some of the transgenic stacked varieties/hybrids developed in different crops since 2008

Herbicide	Crop	Event	Gene	Developer	First Approval (Yr.)
Dicamba+glyphosate	Soybean	MON87708	*dmo+cp4 epsps* (*aroA*:*CP4*)	Monsanto	2015
Glyphosate+isoxaflutole	Soybean	FG72	*2mepsps + hppdPF W336*	Bayer CropScience	2013
Glyphosate+chlorsulfuron	Soybean	DP 356043	*gat4601+gm hra*	DuPont Pioneer	2008
Glufosinate+2,4-D	Soybean	DAS 68416-4	*pat+aad12*	Dow AgroSciences	2011
Glufosinate+mesotrione	Soybean	SYHT0H2	*pat+avhppd-03*	Syngenta & Bayer	2014
Glyphosate+glufosinate + 2.4-D	Soybean	DAS-44406-6	*2mepsps+pat+aad12*	Dow AgroSciences	2014
Glyphosate+ ALS Inhibitor	Maize	98140	*gat4621+gm-hra*	DuPont	2009
Glyphosate+ Glufosinate	Maize	GA21 x T25	*mepsps+pat* (syn)	Syngenta	2014 (S. Korea)
Glyphosate+2,4-D	Maize	DAS-40278-9 x NK603	*cp4 epsps* (*aroA*:*CP4*)*+aad-1*	Dow AgroSciences	2013 (Canada)
2,4-D+ACCase inhibitors+ glyphosate	Maize	DAS-40278-9 NK603	*aad-1+zm-hra+cp4 epsps* (*aroA*:*CP4*)	Dow AgroSciences	2014
Imidazolinones+glyphosate	Maize	--	--	DuPont Pioneer	2009
Glufosinate+dicamba	Cotton	MON 88701	*bar+dmo*	Monsanto	2013
2,4-D+glufosinate+glyphosate	Cotton	--	*aad-1+bar+cp4 epsps* (*aroA*:*CP4*)	Dow AgroSciences	---
Dicamba+glufosinate+glyphosate	Cotton	MON 88701 x MON 88913	*dmo+bar+ cp4 epsps* (*aroA*:*CP4*)	Dow AgroSciences	2015 (Japan)
Glufosinate+glyphosate+fertility restorer	Canola	MON88302 x RF3	bar+ *cp4 epsps* (*aroA*:*CP4*)*+barstar*	Monsanto	2014
Glufosinate+glyphosate+male sterile+fertility restorer	Canola	MON88302 x MS8 x RF3	bar+ *cp4 epsps* (*aroA*:*CP4*)*+barnase+ barstar*	Monsanto	2014

Genes: *aad-1*: aryloxyalkanoate dioxygenase 1 from *Sphingobium herbicidovorans*; *bar*: bialophos resistance gene from *Streptomyces hygroscopicus*; *barnase*: (a portmanteau of "**BA**cterial **R**ibo**N**ucle**ASE**) from *Bacillus amyloliquefaciens*; *barstar*: *barnase* inhibitor from *Bacillus amyloliquefaciens*: *dmo*: dicamba mono-oxygenase derived from *Stenotrophomonas maltophilia* strain D1-6; *gm hra*: (*Glycine max* herbicide-resistant acetolactate synthase) which encodes GM-HRA protein: *gat4621*: glyphosate *N*-acetyltransferase (*gat*) gene derived from *Bacillus licheniformis.*

Non-transgenic herbicide resistance

Herbicide resistant crops can be generated for some herbicides by selecting for target mutations in plant populations or tissue culture or by mutation breeding (Green and Castle 2010, Green and Owen 2011). This approach to produce HR crops has worked for herbicides (ALS and ACCase inhibitors) with relatively plastic molecular targets in which resistance evolves easily (Van Alfen 2014). This plasticity was proven by the fact that 160 and 48 species, respectively, have evolved resistance to ALS and ACCase herbicides that target these two enzymatic sites, almost exclusively due to target site mutations (Heap 2018).

There are different non-transgenic techniques to create crops with resistance to a number of ALS- and ACCase-inhibiting herbicides. These include, a) tissue culture selection, b) pollen mutagenesis, c) microsopore selection, d) seed mutagenesis and e) gene transfer from close weedy relatives that have evolved resistance. As the mutated genes only generate isoforms of enzymes that are already in the crop, and there is no insertion of new DNA into the genome, unintended consequences of the mutation are considered highly unlikely. Due to this, regulatory approval of the genetics of such crops is not needed. The first non-transgenic HR crop was developed in 1993 when a sulfonylurea-resistant soybean was commercialized. This was before the first transgenic HR soybean was commercialized.

Imidazolinone (IMI)-resistant crops have been the most successful non-transgenic HR crops. Evolution of weeds resistant to ALS-inhibiting herbicides occurs relatively quickly. Therefore, one might expect a problem with IMI-resistant weeds in these crops after only a few years.

IMI-resistant crops can be used to control parasitic weeds, in that imidazolinones translocate to metabolic sinks, thus affecting these weeds (e.g., *Striga* spp.). Seeds of resistant maize can be coated with IMI herbicide to provide *Striga* control (Kanampiu *et al.* 2009) and it can provide season-long control of this parasitic weed (Ransom *et al.* 2012).

Several non-transgenic events have been developed in soybean, maize, canola, rice, wheat, sunflower and sugarcane. Herbicides include the ALS-inhibiting imidazolinones (imazethapyr) and sulfonylureas and the ACCase-inhibiting cyclohexanediones (sethoxydim).

Non-transgenic crop events/varieties

BPS-CV127 is imidazolinone-resistant soybean event was developed by inserting the *csr1-2* gene derived from *Arabidopsis thaliana* to express AtAHASL (altered acetohydroxyacid synthase large unit) protein of 670 amino acids to confer resistance to IMI herbicides. This process involves transformation of embryonic axis tissue obtained from apical meristem of a soybean Brazilian cultivar 'Conquisita'. This line was first approved by Brazil in 2009, followed by several countries.

Non-transgenic IMI herbicide-tolerant maize lines have been developed by using selection-based and mutagenesis-based approaches. Using the former approach, maize embryonic cell cultures were subjected to sub-lethal doses of IMI herbicides and sectors of rapidly growing tissue are subsequently sub-cultured. These subcultures were then treated in successive selection cycles of increasing herbicide concentrations. The resistant cell lines were selected and plants regenerated in the presence of IMI herbicides. This method enabled development of two lines 'XA17' and 'XI12'. Selection-based approach was used by Pioneer Hi-Bred to develop 3417R maize line which was approved by Canada in 1994 (Health Canada 1999a).

In the mutagenesis-based approach, IMI-resistance is induced through chemical mutagenesis. In this, the pollen of a maize line is exposed to chemical mutagens followed by employing the mutagenized pollen to fertilize the parent line and screening the progeny for IMI herbicide tolerance. This method was used by Zeneca Seeds to develop the imazethapyr-resistant line EXP1910IT (Health Canada 1999b).

Regarding sethoxydim, two re-generable, friable, embryogenic callus cultures have been selected from a maize tissue culture of 'A188' x 'B73' cross in a medium containing this cyclehexanedione herbicide (Parker et al. 1990; Tan and Bowe 2012). These sethoxydim-tolerant callus culture lines, S1 and S2, exhibited 100- and >100-fold increases in sethoxydim resistance, respectively, compared to the unselected control callus lines. ACCase activity from S1 and S2 was inhibited 50% by sethoxydim concentrations that were 4-fold and 40-fold higher than concentrations required for 50% inhibition in wild type ACCase activity.

The sethoxydim resistance trait was introduced by BASF Canada into the registered maize hybrids 'DK412' and 'DK381' via tissue culture by a phenomenon known as somaclonal variation (Health Canada 1997; CERA 2001b). Somatic embryos of these maize hybrids were grown on sethoxydim-enriched culture media. The original sethoxydim tolerant mutant lines, which produced an altered ACCase enzyme while retaining its original catalytic properties, were selected from somaclonal variants from maize embryo tissue grown under sethoxydim selection pressure. From the somatic embryos that survived, the somaclonal variant cell line S2 was selected and subsequently regenerated. The regenerated plants were backcrossed at least six times with both parental lines of the hybrid DK412SR and DK404SR to transfer the sethoxydim-resistant trait. There was no new genetic material introduced into the genomes of these sethoxydim-tolerant lines as a result of the modification. Performance factors to measure the growth and development of DK412SR and DK404SR maize lines were comparable to the performance factors for unmodified maize lines and were within the normal ranges for the characteristics tested. These non-transgenic maize lines, primarily intended for animal feeding, were made available for commercial use in Canada in 1997 (Health Canada 1997).

Global adoption of biotech crops

Ever since the first commercialization of transgenic herbicide resistant crops on 1.73 million ha in 1996 in the U.S., beginning with the glyphosate-resistant (GR) maize, farmers around the world have readily adopted transgenic crops such as maize, soybean, cotton, rapeseed (canola), lucerne (alfalfa) and sugar beet. With an area of 189.8 million ha (469 million acres) under biotech crops in 2017 and 3% annual growth, global agriculture has witnessed about 110-fold growth during the past 22 yr. This makes biotech crops the fastest adopted crop technology in the history of modern agriculture.

Among the four major transgenic crops in 2017, soybean led with 94.1 million ha at 49.6% global biotech crop adoption. This was followed by maize (59.7 million ha; 31.4%), cotton (24.21 million ha; 12.8%) and canola (10.2 million ha: 5.4%). Other biotech crops accounted for just 1.29 million ha (0.8%).

The area under transgenic cultivation, doubled every 5 yr, now accounts for some 12% of global arable land. Biotech crops represented 35% of the global commercial seed market. Most of the commercially grown transgenic crops have one or both of two traits: herbicide (glyphosate) resistance and *Bt* (*Bacillus thuringiensis*) insect resistance. About 91% of the 18 million farmers who planted biotech crops in 29 countries in 2017 were risk-averse and resource-limited small farmers. The nine major countries which adopted biotech crops include USA (75 million ha), Brazil (50.2), Argentina (23.6), Canada (13.1), India (11.4), Paraguay (3.0), Pakistan (3.0), China (2.8) and South Africa (2.7) in that order which together account for 97% of biotech crops (ISAAA 2018). These nations excluding USA planted 109.8 million ha, accounting for over 58% of the global biotech crop area.

The herbicide-resistant (HR) transgenic (including the stacked herbicide-cum-insect-resistant ones) lines accounted for 80% of the global biotech area. Currently, two traits dominate the global biotech crops: herbicide resistance accounting for 65%, insect resistance 15% and a combination of the two (stacked) for 15%. Stacked-trait transgenics, whose use has been on the rise since 2000, are currently an important feature of biotech crops.

The HR maize event NK603 has the most number of global approvals. It is followed by herbicide- resistant soybean GTS 40-3-2, insect-resistant maize MON810, insect-resistant maize Bt11, insect resistant maize TC1507, herbicide-resistant maize GA21, insect-resistant maize MON89034, herbicide-resistant soybean A2704-12, insect-resistant maize MON88017, insect-resistant cotton MON531, herbicide-tolerant maize T25 and insect-resistant maize MIR162.

Biotech crops are considered to have made a positive contribution to global crop production and food security and improved the economic status of farmers who adopted them. However, they also accelerated changes in farming styles, affecting genetic diversity in agro-ecosystems of many countries that have adopted the biotechnology. For example, the adoption of HR biotech crops has changed traditional weed management practices and the biodiversity of crop and weed species. It also raised concerns about the biosafety to consumers besides the long-term profitability to farmers.

Benefits

The rapid adoption of HR biotech crops and their associated farm management practices suggest that they have become an important tool for managing weeds. These crops have changed weed management practices to a certain extent and made a significant contribution to the global production of crops, particularly maize, soybean, cotton and canola. Their adoption is generally attributed to low cost, simplified, more flexible and selective weed management options through the use of broad-spectrum, intrinsically non-selective herbicides (primarily glyphosate), a lower risk for crop injury and their compatibility with no-till or reduced-tillage systems. The benefits are of two kinds: pecuniary and non-pecuniary.

Pecuniary benefits

Pecuniary or direct benefits includes net farm income or profitability which is based on crop yields, market value of crop produce, production costs (seed and crop protection expenditure), and costs of fuel and labour. The most obvious pecuniary benefit is yield increase which is tangible and quantifiable.

HR crops have certainly increased the incomes of farmers who adopted them and countries which commercialized them. The incomes rose when biotech crops first became available in 1996 and they continued to rise even after 20 yr of their adoption. The cumulative global income benefit is also on the rise. Brookes and Barfoot (2018) reported that net economic benefits derived by four main GM-HR crops soybean, maize, cotton and canola at the farm level accounted to US$18.2 billion in 2016 and US$186.1 billion over the 21-yr period of 1996-2016. These benefits, derived by more than 16 million farmers, have been divided roughly 50% each to farmers in developed and developing countries. About 65% of these gains were due to yield and production gains while the remaining 35% coming from cost savings. GM soybean and maize have added 213 million tonnes and 405 million tonnes, respectively to the global production since their introduction in the mid-1990s. This gain is expected to increase over the years as area under biotech crops increase.

In 2017, the global market value of biotech crops was US$17.2 billion. It represented 30% of the US$56.02 billion global commercial seed market. The country-wise gains during the 1996-2017 period were in the order of US$80.3 billion in USA, US$23.7 billion in Argentina, US$21.1 billion in India, US$19.8

billion in Brazil, US$19.6 billion in China US$8 billion in Canada, with other countries accounting for US$13.6 billion. For 2016 alone, six countries gained the most economically from biotech crops. These were USA (US$7.3 billion), Brazil (US$3.8 billion), India (US$1.5 billion), Argentina (US$2.1 billion), China (US$1 billion), Canada (US$0.7 billion), and others (US1.8 billion) for a total of US$18.2 billion.

Adoption of biotech crops uplifted the economic situation of 16-17 million small farmers and their families totaling >65 million people around the world (Brookes and Barfoot 2018).

Non-pecuniary benefits

Non-pecuniary or indirect benefits include the intangible impacts influencing the adoption of transgenic crops. These include greater weed management flexibility, reduced crop toxicity, increased savings in time and equipment usage, improved quality of the crop produce, lesser impact on the environment, lower potential damage of soil-incorporated residual herbicides to rotation crops, etc. Some of these benefits are discussed in two categories: farm level and environmental level.

The primary impact of transgenic HR technology at the farm level is on providing a more cost-effective, easier and better weed control as against only a better weed control (regardless of cost) obtained from conventional method, even if crop yields remain the same in both technologies. In conventional cultivation, broad-spectrum, nonselective postemergence herbicides such as glyphosate, glufosinate, etc. are applied after the crop is established. When these are applied, the crop is very likely to be sensitive so as to suffer a setback in growth. This problem is eliminated when HR crop variety is used because the crop has already been engineered to be resistant to the herbicide.

HR technology allows for the 'over the top' spraying of biotech crops with broad-spectrum herbicides such as glyphosate, glufosinate, etc. that target both grass and broadleaf weeds but do not harm the crop itself.

HR crops and their associated farm management practices also enabled the control of several weed species congeneric to the crop. One example is weedy rice (*Oryza sativa* f. *spontanea*: red rice) (Gealy et al. 2009), considered as one of the most troublesome, difficult-to-manage and economically damaging weeds in cultivated rice (Ziska *et al.* 2015). Herbicide selectivity is generally based on the crop being able to metabolize and inactivate the herbicide more rapidly than the weed species. In the case of weedy and cultivated rice, no such difference exists due to their genetic similarity. With the introduction of imazamox-tolerant non-transgenic conventionally-bred herbicide resistant (CHR) rice varieties, effective control of weedy rice became possible (Ziska *et al.* 2015). Similar problems occur with sexually-compatible weeds in other crops such as oilseed rape (canola) and sunflower (Muller *et al.* 2009).

Another indirect farm level impact of HR technology is to provide more cost-effective and better weed control. The main source of additional production is the facility to adopt conservation production systems (no-till and reduced-till) and shorten the production cycle, thus enabling taking second crop in a relatively weed-free situation. Growing another crop following a HR crop would certainly raise farm income. Besides, conservation system eliminates or reduces pre-planting soil cultivation or seedbed preparation to eliminate weed growth. As a result, tractor fuel use for tillage is reduced, soil quality is possibly enhanced and soil erosion lowered. Conservation systems also contribute to reducing soil erosion and moisture loss, fossil fuel use carbon dioxide emissions, nitrogen and pesticide leaching and improving soil structure (Cerdeira and Duke 2010, Basso *et al.* 2011, Carpenter 2011). This provides for additional monetary savings in the form of lower labour and fuel costs associated with plowing, besides aiding in additional soil moisture retention and reduced soil erosion (Brookes and Barfoot 2012).

Improved weed control may contribute to reduced harvesting time and enhanced quality of the harvested crop. Higher quality of crop produce may fetch higher market prices. Adoption of HR crop avoids the potential damage caused by soil-incorporated residual herbicides to follow-on (rotational) crops while reducing the need to apply herbicides to them because of earlier improved levels of weed control.

Another non-pecuniary benefit is the impact of HR biotech crops on the environment. Their adoption saved 671 million kg (ai) of herbicides and insecticides during 1996-2016, with a gross saving of 8.2%. In 2016 alone, these crops saved 48.5 million kg pesticides, a saving of 8.1%. About 70% these savings were attributed to herbicides. These gross savings reduced impact on environment (Environmental Impact Quotient: EIQ) to the tune of 18.3% over the 21 yr period, with 18% being in 2016 alone.

Increases in atmospheric levels of greenhouse gases such as carbon dioxide, methane and nitrous oxide are detrimental to the global environment. Therefore, if the adoption of HR crop technology contributes to a reduction in the level of greenhouse gas emissions from agriculture, this represents a positive development for the world. Brookes and Barfoot (2018) reported that biotech crops reduced CO_2 emissions in 2016 by 27.1 million kg, equivalent to taking 16.7 million cars off the road during the year. The largest fuel-related reductions in CO_2 emissions have come from where HR soybean varieties have been adopted.

Based on savings arising from the rapid adoption of no till/reduced tillage farming systems in North America and South America in 2011, an extra 5,751 million kg of soil carbon was estimated to have been sequestered. This was equivalent to 21,107 million tonnes of CO_2 that has not been released into the global atmosphere. The cumulative savings over a longer period of growing transgenic HR crops would certainly be much higher. The reduction in GHG emissions and its quantification are dependent on several variables like crop type, crop duration, cropping system, soil type and environmental conditions, etc. Thus, transgenic HR crops have the potential to reduce emissions of greenhouse gasses in substantial quantities.

Among the GM-HR crops, maize reduced herbicide use by 193.1 million kg, a 10.1% reduction, and this led to a concomitant reduction (12.5%) in the impact on the environment. Regarding transgenic soybean, with largest area under it, herbicide use came down by 12.5 million kg and it translated into a 15.5% decrease in impact on the environment. Of the environmental benefits derived by using HR crops, developed countries have been the major beneficiaries (55%) than developing nations (45%). This situation may very soon turn in favour of developing countries as they bring in larger area under transgenic crops.

Biotech crops have the potential to lower greenhouse gas (GHG) emissions by saving on the fuel by reducing the number of herbicide applications. In the case of HR crops, particularly those engineered for resistance to glyphosate and glufosinate, adopting conservation (reduced or no-tillage) farming systems would lead to savings in CO_2 emissions. Brookes and Barfoot (2013) estimated that the reduction of CO_2 emissions consequent to growing biotech crops in 2011 was to the tune of 1,886 million kg and this lowered the fuel usage by 706 million L. The cumulative reduction in gas emission over the period of 1996-2011 was 14,610 million kg arising from a saving of 5,472 million L of fuel.

Import of herbicide-resistant biotech crops to India

India has adopted biotech crops in 2002, but this was restricted to insect-resistant (IR) *Bt* (*Bacillus thuringiensis*) cotton as it introduced Monsanto's lepidopteran-insect tolerant Event MON531 (Bollgard I) and its three modified hybrids (Mech-12 *Bt*, Mech-162 *Bt*, and Mech-184 *Bt*} developed by Monsanto and its partner Maharashtra Hybrid Seed Company (Mahyco). These hybrids, which control bollworm, were developed by crossing Monsanto's Event MON531 (Bollgard) with local elite Indian varieties. In 2006, Monsanto commercialized another variety, Event MON15985 (Bollgard II), which carried two IR genes, *cry1Ac* and *cry2Ab2*.

Consequently, the country achieved a great stride in cotton production with a quarter of market share in global cotton production in 2017 when it harvested 6.21 million tonnes, the most by any nation. Beginning with an area of 50,000 ha in 2002, the biotech cotton area increased 6% from 10.8 million ha in 2016 to 11.4 million ha in 2017, equivalent to 93% of gross cotton area of 12.24 million ha. This IR (*Bt*) technology boosted cotton yields to 500 kg ha^{-1}. India gained economic boost to the tune of US$21.1 billion (¹ 2110 crore) during the 1996-2017 period. The benefit in 2017 alone was US$ 1.5 billion (¹ 150). The country now aims to reach the next level of yield target of 700 kg ha^{-1}. However, this can only be achieved with the introduction of new generation biotech traits including stacked traits, smart agronomy and high yielding cotton cultivars. *Bt* cotton varieties are considered to have helped minimize the damages caused by bollworm, reduce insecticide use and enhance net income of farmers.

Currently, there is no herbicide resistant biotech crop that is permitted by the national government to grow. The glyphosate-resistant cotton has not received the approval Genetic Engineering Approval Committee (GEAC) of Government of India.

Glyphosate, commercialized in 1974 by Monsanto, was approved in India for perennial weed management in mature tea in 1981 after a series of field tests for six years at Tocklai Tea Research Institute, Jorhat, Assam. Later, its use has been extended to a few perennial crops only when used as directed spray. Currently, there are many players involved in making glyphosate available.

Glyphosate is not recommended for use in cotton. No license of approval has been granted by Government of India for growing HR cotton varieties. However, farmers have been using glyphosate in insect-tolerant cotton (Bollgard III) fields. Besides, some seed companies have been producing and selling glyphosate-resistant ‘Roundup Ready Flex’ (MON88913: Table 1) cotton seeds illegally for unauthorized use by farmers in key cotton growing states across India. Farmers are swayed by the multiple benefits that genetically modified varieties offer. Currently, around one million kg of glyphosate are being sold, with much of this quantity being used in IR cotton crop in several states.

In a bid to curb the illegal use of glyphosate in insect-tolerant cotton, state governments have suggested restrictive use of glyphosate in agricultural and horticultural crops in general and especially in cotton in order to stop the spread of illegal HR cotton.

Future of HR biotech crops

Herbicide resistant biotech crops have the potential to adopt effective weed management practices. In many a case, they will also lead to cost-effective weed management both in the short-term and medium-term. However, in the long-term their impact needs to be considered very carefully in the light of limitations and concerns discussed below.

Limitations and concerns

Commercial production of biotech crops has aroused serious concerns about their biosafety. Biosafety issues have become a crucial limitation to their further development. Genetically engineered crops are a heterogeneous group. As such, it is not reasonable to lump all of them together. Therefore, it would be prudent to assess the biosafety of each of the transgenic crops separately.

Development of transgenic crops is seen more a profit-driven rather than need-driven process. Therefore, the thrust of the genetic engineering industry is not really viewed to solve agricultural problems, but to create profitability (Altieri 1998). Although several universities and research institutions are also simultaneously involved in this field, their research agenda is being increasingly influenced by private sector in ways never seen in the past. The challenge for these organizations is how to ensure that ecologically sound aspects of biotechnology are researched and developed while carefully monitoring and controlling the provision of applied non-proprietary knowledge to the private sector, farmers and consumers while making such knowledge available in the public domain for the benefit of society (Altieri 1998).

Currently, there is a great deal of confusion on the concerns, both real and perceived, attributed to biotech crops. These concerns are related to agro-ecology, evolution of resistant weeds, food safety and soil ecosystem.

Agro-ecological concerns

These are related to gene flow from biotech crops to, a) conventional crop varieties, b) landraces and wild/weedy relatives and c) to unrelated organisms.

When genes move from biotech crops to their non-biotech counterparts through seed-, vegetative organ-, or pollen-mediated gene flow, it could lead to ‘adventitious mixing’ of varieties of both crops. This ‘gene-pollution’ often occurs where both are planted in close proximity. The frequencies of gene movement mediated by pollen depend essentially on the breeding systems and quantity of pollen of crops (Lu 2008). A significant gene flow to non-biotech crops may subsequently move to weedy and wild relative populations.

The pollen-mediated gene flow is dependent on crop. For soybean, cross-pollination is not a problem, but considerable outcrossing can occur with maize, rice, sugar beet and canola. Wheat and rice are predominantly self-pollinating, but cross-pollination does occur at a low range.

Evolution of herbicide resistant weeds

In reality, crops do not select for HR weeds, but herbicides do. Therefore, development of HR weeds is not due to a biotech crop, but it is a due to the herbicide used. When an herbicide is used continuously over a time period, evolution of resistance is a natural phenomenon, regardless of crop culture.

Currently, glyphosate resistant (GR) transgenic crops account for about 90% of HR biotech crops. Resistance of weeds to glyphosate began in 1996 when the monocot *Lolium rigidum* Gaudin was found resistant in Victoria, Australia. This was 22 yr after glyphosate became commercially available. This was also about the time GR transgenic crops (soybean, maize, cotton and canola) were being adopted. Since then, 41 more species (22 dicots and 19 monocots) became resistant to this non-selective herbicide (Heap 2018). Around 30 of them were from

GR transgenic crops in countries which adopted them, particularly USA, Brazil, Argentina, Canada and Colombia. The major weed species include *Amaranthus palmeri* S. Watson, *Amaranthus tuberculatus* (Moq.) Sauer (= *A. rudis* Sauer), *Ambrosia artemisiifolia*,L, *Ambrosia trifida*L., *Eleusine indica* L. (Gaertn.), *Kochia scoparia* (L.) Schard. *Poa annua* L., *Sorghum halepense* (L.) Pers. and various *Conyza* and *Lolium* species. The over-reliance on glyphosate to control weeds contributed to the evolution of multiple-resistant weed populations.

As more global acreage is treated continuously with other herbicides like ALS, ACCase and PS II inhibitors, in both cropping systems, faster and greater emergence of weed species resistant to them may become a serious problem in future. This will invariably cause weed shifts, thus requiring newer weed management strategies to combat the problem.

Food safety

The widespread consumer concern about transgenic crops is the potential risks they have on human and animal health. These risks associated with consumption of the edible parts of crops and foods derived from them. The issues surrounding foods and feeds of HR biotech crops are broadly grouped into: a) nutrient levels, b) allergenicity, c) horizontal transfer and antibiotic resistance, d) consumption of foreign DNA and e) the promoter such as CaMV used during genetic modification.

Nutrient Levels. A major concern about transgenic crops is whether the transgene will alter nutrient levels of foods and feeds derived from them. Transgene integration and/or transformation and tissue culture during transgenic process may induce unintended genomic alterations such as deletions, insertions and rearrangements, which may generate secondary or pleiotropic effects in transgenic plants (Cellini *et al.* 2004, Garcia-Canas *et al.* 2011, Herman and Price 2013).

Allergenicity. The possibility of allergic reactions to food as a result of genetic engineering is a powerful emotional issue because exposure of individuals to biologically active genes from non-plant sources can have major effects on their gastrointestinal tract. Even people who have never experienced an allergic reaction may worry that they are being exposed to new substances for which there is little track record of safety or harm. It is also likely that in addition to the effects on the gastrointestinal tract, the size, structure and function of the internal organs will be affected, particularly in young and rapidly growing humans and animals.

Horizontal Gene Transfer and Antibiotic Gene Resistance. Horizontal gene transfer (HGT) refers to the transfer of genetic material between organisms as in the case of plants and microorganisms, unlike the parent-to-offspring channel in vertical transfer. The main concern of HGT is the possibility of transfer of transgenes to humans from plants used directly as food (also processed food) or indirectly as feed to animals used for food. Transfer occurs by the passage of donor genetic material across cellular boundaries, followed by heritable incorporation to the genome of the recipient organism. HGT plays an important role in the evolution of bacteria that can degrade novel compounds such as insecticides, herbicides, *etc*.

Consumption of Foreign DNA. When a food derived from a transgenic crop is consumed, we eat the DNA of bacteria and viruses without knowing that we do so. Some of this DNA is similar to human DNA, but much of it is foreign to us. Most of the ingested DNA is broken down into more basic molecules during digestion process, while a small amount is not. This may either be absorbed into the blood stream or excreted in the feces. In fact, DNA can persist in the gastrointestinal tract and become available for uptake by intestinal bacteria. Although the colon is the preferential site for transformation of these bacteria, the amount of DNA reaching it may only be a fraction of what is consumed.

CaMV Promoter. The cauliflower mosaic virus 35S is used as a preferred promoter in transgenic crops. It is used to “turn on” the gene inserted in the host genome. It causes CaMV disease in cauliflower, broccoli, cabbage and rapeseed. It can be horizontally transferred and cause disease, carcinogenesis, mutagenesis, reactivation of dormant viruses and generation of new genes (Hodgson 2000, Artemis and Arvanitoyannis 2009). However, normal foods containing CaMV is not highly-infectious and cannot be absorbed by mammals (Ho et al. 2000). In fact, humans have been ingesting CaMV and its 35S promoter at high levels, but have never been reported to cause disease or recombine with human viruses (Paparini and Romano-Spica 2004).

Soil ecosystem

Soil ecosystem, 80% of which is accounted by soil-borne communities dominated by microbes, is one of the least understood areas in the risk assessment of biotech crops. Rhizosphere microbes play a major role in nutrient mobilization, and cycling and decomposition of wastes. Any impact that biotech plants have on the dynamics of the rhizosphere and root-interior microbial community may cause either positive or negative effects on plant growth and health and, in turn, ecosystem sustainability. Soil microbial communities have several opportunities to interact with novel plant gene products during crop growth. After harvest, decomposition of plant litter and straw can release novel proteins into the soil environment.

A manifold increase in glyphosate application in GR biotech crops since 1996 has been reported to have several adverse effects, including immobilization of nutrients, increase in plant diseases due to weakened plant defenses and enhancement of pathogen virulence. These changes have apparently been caused by root exudates released by GR crops following glyphosate application (Bromilow *et al.* 1993). Thus, considerable concern exists regarding the potential detrimental effects of rhizosphere microbes on GR transgenic crop productivity resulting from either direct effects of glyphosate or its indirect effects on plant physiological functions (Zobiole *et al.* 2011).

Application of glyphosate results in reduced root nodulation in GR soybean crop, while delaying nitrogen fixation and plant biomass accumulation (Zablotowicz and Reddy 2004). However, the severity of these effects was dependent upon formulation and number of applications of glyphosate aside from GR cultivar. Powell et al. (2009) reported significant differences in nodulation among six GR and three near-isoline GR cultivars, but these were not related to glyphosate resistance.

Glyphosate application in GR soybean field may cause reduced nutrition uptake, leading to enhanced occurrence of many diseases which, in turn, detrimentally impact many beneficial soil microbes. The EPSPS enzyme present in GR soybean is considerably less efficient than wild-type enzyme, producing insufficient amounts of phytoalexins (key defense components associated with shikimate pathway) to prevent fungal infection (Gressel 2002). Besides, EPSPS also lowers the shikimate-dependent lignification of cell walls at or around the infection site. Decreased lignin content may also be due to the reduced photosynthesis in soybean caused by glyphosate (Zobiole *et al.* 2010).

Although glyphosate is rapidly inactivated by soil adsorption, it may serve as a substrate for some microorganisms. Kremer and Means (2009) found higher colonization of roots by *Fusarium* spp. when field-grown GR transgenic soybean cultivars were applied with glyphosate over a 10-yr period (1997-2007), while plants receiving no or conventional postemergence herbicides exhibited low *Fusarium* colonization. The non-transgenic cultivars had the lowest root colonization by *Fusarium*. This colonization increased as soybean growth progressed and glyphosate rate increased (Zobiole *et al.* 2011). Reduced production of both lignin and phytoalexin allows increased root colonization by *Fusarium* in plants injured by glyphosate (Johal and Rahe 1988).

Socio-economic consequences

Ensuring coexistence of biotech and conventional crops and products derived from them will inevitably entail additional costs in several ways. The costs include those required to, a) enforce coexistence measures imposed by regulators, both during and after cultivation, b) for testing of crop produce and products, c) for identifying and quantifying the content of transgenic material in non-transgenic material and d) for compliance of labelling and traceability requirements. Additionally, farmers may suffer income losses due to restrictions in crop choice and management. Neighbouring farmers could impose restrictions if a farmer decides to grow a transgenic crop. Besides, spatial restrictions, temporal cultivation may occur due to irreversibility. In a field where transgenic crop is raised, it could temporarily be difficult to meet the 0.9% tolerance threshold if a farmer decides to go back to a non-transgenic cropping system. In this process, a conversion time might be required to deplete transgenic seeds from the seedbank and/or control of volunteers and weedy/wild relatives that may contain the transgene.

Coexistence of biotech and non-biotech crops in the same region also has social consequences. Farmers who decide to grow transgenic crops need to, a) seek approval of neighbouring farmers, b) notify their crop details and seek permission from government regulators, c) consider ethical issues that may arise in connection with the use genes from non-plant sources, d) study the positive and negative effects of biotech crops in relation to sustainable development, e) assess the risks of the extinction of traditional varieties, f) weigh corporate control of seed and g) bear in mind the legal liability of biotech crop cultivation.

Coexistence of biotech and conventional crops

Adventitious mixing and preventive measures

As agriculture is an open system, certain amount of adventitious mixing is unavoidable. The on-farm sources of such mixing between biotech and conventional crops include seed impurities, pollen flow between neighbouring fields, volunteer plants originating from seeds or vegetative plant parts from previous biotech crops and seeds left behind inside the equipment used for various operations.

The existing measures to ensure seed purity in conventional crop production may also be applied within the context of limiting the adventitious content of transgenic material in seeds and plant products. These include: a) the use of certified seed, b) spatially isolating fields of the same crop, c) erecting pollen barriers around fields, d) scheduling different sowing and flowering periods, wherever possible, e) limiting carryover of transgenic volunteers into the following crop through the extension of cropping intervals, f) cleaning agricultural machinery and transport vehicles for seed remnants, g) controlling volunteers and wild/weedy relatives, h) applying effective post-harvest tillage operations, i) retaining records of field history and j) the voluntary clustering of fields. The drastic preventive coexistence measure is probably banning the cultivation of transgenic crops in a certain region.

Development of illegal HR biotech crops in India is seen more a profit-driven rather than need-driven process. Therefore, the thrust of the genetic engineering industry is not viewed to solve agricultural problems, but to create profitability.

The amount farmers pay for use of the technology varies by country. Pricing of technology (all forms of seed and crop protection technology including HR technology) depends on the level of benefit that farmers are likely to derive from it. In addition, it is influenced by intellectual property rights (patent protection, plant breeders' rights and rules relating to use of farm-saved seed). In countries (e.g. India) where governmental regulations on price control are weak, biotech crop seed suppliers may tend to price their seed at abnormally higher rates. The concerned countries need to have strict price control structures in place for biotech crops seeds.

Coexistence of biotech and conventional food products

Labelling, a prerequisite for coexistence of transgenic and non-transgenic foods, is an important issue related to biotechnology. There is no federal or state law in the U.S. that requires food producers to identify whether foods were produced using genetic engineering. Despite such heavy consumption of transgenic foods by American consumers, the US Food and Drug Administration does not require safety studies of such foods. Considering that transgenes have been derived from bacteria and viruses, 9 out 10 people want these foods labelled (Bartolotto 2013). The biotech companies, however, do not.

Consumers in many parts of the world are now demanding labelling so they can exercise choice between foods that have originated from biotech, conventional, or organic crops. This requires a labelling and traceability system as well as the reliable separation of transgenic and non-transgenic foods at production level and throughout the whole processing chain.

Since recently, several food products derived from biotech crops grown outside of India have been flooding the super markets in the country. These imported "fancy" products such as pan-cake syrups, multigrain cereals, corn puffs, oils from canola and cotton, silken tofu, etc. Some of the imported infant food products have their origin in biotech crops. These packages do not carry GM labels. Besides, local manufacturers are supplying the oil from seeds derived from biotech cotton. The Food Safety and Standards Act, 2006 (Section 22) does not allow manufacture, import or selling of GM food products in India unless approved by it.

Basically, consumers have the right to know what is in the foods they consume. It will be a travesty of justice to deny it. It may not be too long before consumers' demands are met by global governments.

Management of herbicide-resistant crops

Depending on the specific herbicide regime, the adoption of HR transgenic crops can pose several environmental and socio-economic challenges, one of which is to exacerbate evolution of HR in weeds. The use of a single herbicide for a longer period changes the weed flora, and increases the selection of HR weed biotypes. Diversification in crop systems and weed management tactics reduces the risk of weeds evolving herbicide resistance(s) and promotes biodiversity.

Therefore, the most effective and sustainable use of HR crops would be to make it a component of an integrated weed management (IWM) approach. IWM prescribes the use of multiple tactics, both chemical and non-chemical, to suppress weed populations, and to prevent or delay HR evolution. The potential benefits of IWM with HR crops are seldom realized because a wide range of technical and socio-economic factors hamper the transition to IWM (Lamichhane *et al.* 2016).

Therefore, several tactics may be used to integrate HR crops within the framework of IWM. These include a) herbicide-based practices, b) rotation of crops, c) cover crops and intercropping, d) tillage, e) using competitive crop genotypes, f) biological management and g) manual and mechanical weeding.

Herbicide-based practices

The herbicide-based practices should take into account factors affecting evolution of weed resistance such as frequency, number, dominance and fitness of genes conferring resistance to an herbicide. Herbicide rotations and mixtures can delay evolution of HR evolution. Rotation of effective herbicides with different action sites is the most widely implemented HR management strategy. This can delay the evolution of HR (except for non-target site resistance which may continue to evolve under this strategy) (Beckie and Reboud 2009). A better tactic would be the use of herbicide mixtures, and this is considered more effective than rotating herbicides with different modes of action (Beckie and Reboud 2009, Evans *et al.* 2016). However, neither tactic is likely to prevent evolution of HR in weeds in the long run, and therefore is not a permanent solution. Herbicidal mixtures may delay evolution of resistance, but they do not prevent it. Applying reduced rates may support a more efficient use of herbicides. Although this is not a viable practice, it may be effective on more susceptible weed species. Weed species differ in their susceptibility to herbicides, and a low rate of one herbicide may be more effective than a full rate of another herbicide. Similarly, a low rate applied under optimal conditions may be more effective than a full rate applied at sub-optimal conditions (Kudsk 2014). However, sub-lethal herbicide rates can select for non-target site resistance, which is quantitatively inherited through accumulation of minor genes (Neve *et al.* 2014). They also increase the risk for cross-resistant evolution. As HR crops, in most cases, are tolerant to highly effective and broad-spectrum herbicides, it is likely that their adoption will promote the use of reduced rates of ALS inhibitors in imidazolinone-tolerant crops.

Crop rotation

Crop rotation can favour a more diverse composition of weed communities. It allows alternative weed control strategies to be used, and enables alteration of patterns and timings of soil disturbance, light transmission through the crop canopy and natural enemies infesting the crop, thereby diversifying the selection pressures on weed populations and making it ecologically more difficult for one weed species to dominate a weed community (Lamichhane *et al.* 2016). Diversity in crop systems (which include both the crops grown in rotation and the associated farm management practices) represents the best practice to mitigate risks related to herbicide resistance.

Despite obvious benefits, diverse crop rotations are difficult to implement. The benefits may only become apparent in the long-term. Moreover, the adoption of crop rotation will inevitably be hampered by market-driven production strategies. Major limiting factors in adoption of rotational crops include, a) the lack of markets available for a new crop introduced in the rotation, b) low economic returns, c) lack of suitable herbicide options for all rotational crops in the crop rotation and d) the necessity to implement weed management systems that are in tune with other pest management measures.

HR biotech crops may provide more effective herbicide solutions than currently available, enabling them to control a broader spectrum of weeds. Thus, it can be envisaged that access to HR crops and their associated farm management practices will incite some farmers to neglect crop rotation as a weed management measure, as this may no longer be a prerequisite to achieve effective weed control. In addition, re-cropping restrictions due to herbicide residue in soil may limit cropping options in the following year.

Cover crops and intercropping

Cover crops compete with weeds for space, light, water and nutrients aside from providing a suitable habitat for organisms that feed on weeds. Besides, cover crop residues that remain on the soil surface as mulches suppress weeds by reducing light transmittance, soil temperature and by releasing allelochemicals. However, the adoption of cover crops poses some challenges when, a) labour and time are limited and b) additional costs incurred with the purchase of seeds are involved. Besides, they cause reduction in soil moisture, possible build-up of insects and diseases in soil, difficulty in soil incorporation of herbicides and delay in crop seed germination.

Significant benefits can be obtained in terms of weed control when a proper combination of crop species is grown together for spatial diversification (Bilalis *et al.* 2010). Intercropping offers weed control advantages over sole crops, a) by suppressing weed growth through competition and allelopathy and thus more effectively use available resources at the expense of weeds and b) by providing yield advantages either using resources that are not exploitable by weeds or using converting resources to harvestable material more efficiently than sole crops.

Despite the advantages of intercropping offers, growing two or more crops simultaneously on the same field leads to more complex crop management and possible additional costs that may restrict their use by farmers. In the case of HR biotech crops, applying two different weed management systems on a single field may not be practical, because the chosen crops should be tolerant to the same herbicidal active substance. If crop choices or timing differences in crop life cycles are not managed properly, then these two crops can compete for water and nutrient resources, which may have negative effects on crop yield. The complexity of intercropping can make a given cropping system more vulnerable to environmental stresses.

Tillage

When tillage is used in conjunction with other cultural tactics such as cover crops and crop rotations, it can markedly reduce densities of weed population. Overall, weed population density and herbicide use tend to be lower under conventional tillage compared to reduced tillage systems, especially for perennial weeds that are markedly decreased under conventional tillage systems. In-crop tillage has more potential to directly replace some of the postemergence herbicides used, though tolerance to in-crop tillage varies by crop type and growth stage (Nazarko *et al.* 2005).

Fuel use, erosion, greenhouse gas emissions and loss of water from soils are greater in conventional tillage. Reduced tillage or ‘no-till’ system, generally associated with HR biotech crops, can also become a part of IWM. Weed seeds left on the soil surface have a higher mortality rate, partly due to predation. Moreover, crop residues left on the soil surface can further suppress weed growth.

Competitive crop genotypes

Cultivation of competitive crop genotypes, characterized by rapid germination and emergence, vigorous seedling growth, rapid leaf expansion, rapid canopy development and extensive root systems, is a potentially attractive option for IWM, because their use does not incur additional costs. For example, crop genotypes with high competitive potential have been identified in certain crops. The use of competitive plant genotypes alone can result in a 50% reduction in recommended levels of herbicides in wheat (Travlos 2012). The adoption of HR biotech crops may reduce the focus on crop competiveness because of the availability of effective herbicidal active substances for weed control such as glyphosate. Therefore, biotechnologists need to focus on using competitive crop genotypes with greater yield potential in developing HR biotech crops.

Biological control

Biological control aims to suppress weed populations below levels that cause economic injury instead of controlling them. While there have been a number of successful biological control programmes, biocontrol of weeds presents a range of challenges. These include economic feasibility, effectiveness of control agents, statutory and regulatory constraints for product registration, technological constraints in developing bioherbicides, environmental constraints and difficulties in utilizing pathogens and herbivores as biocontrol agents. The potential impact of HR biotech crops on biocontrol agents could be negative. Therefore, the interest in bio-agents for perennial weeds would likely be reduced for biotech HR crops. However, sub-lethal doses of glyphosate can work in synergy with microbial bio-agents as the former temporarily stops the growth of the weed, allowing time for the latter to establish and inhibit growth (Boyette *et al.* 2008, 2015).

Mechanical weed management

Depending on soil characteristics and conditions, mechanical weeding has proven effective on a range of crops. The inclusion of innovative technologies, including advanced sensing and robotics, in combination with new crop systems, might lead to a breakthrough in physical weed control in row crops resulting in significant reductions, or even elimination, of the need for hand-weeding. Inter-row cultivation and band spraying with an effective herbicide in a biotech crop could potentially reduce the risk of HR weeds to evolve. However, mechanical weeding requires greater fuel use, is more time-consuming, and may result in more soil erosion, greenhouse gas emissions, loss of water from soils, and cause adverse effects on the flora and fauna if not applied correctly (Navntoft *et al.* 2007).

The adoption of biotech crops may lead to reduced interest in mechanical weeding. First, farmers consider them to be more cost-effective than mechanical weeding and they delay evolution of HR weeds. Second, they tend to promote conservation tillage systems that are less conducive to mechanical weeding.

REFERENCES

Altieri MA. 1998. The Environment Risks of Transgenic Crops: An Agroecological Assessment: Is the failed pesticide paradigm being genetically engineered? *Pesticides and You*. Spring/Summer 1998.

Artemis D and Arvanitoyannis IS. 2009. Health Risks of Genetically Modified Foods. *Critical Reviews in Food Science and Nutrition* **49**: 164–175.

Bartolotto C. 2013. Why genetically modified foods should be labeled. *Food For Thought*. 4 October.

Basso B, Sartori L, Bertocco M. Commarano D, Martin E and Grace P. 2011. Economic and environmental evaluation of site-specific tillage in a maize crop in NE Italy. *European Journal of Agronomy* **35**: 83–92.

Beckie HJ and Reboud X. 2009. Selecting for weed resistance: herbicide rotation and mixture. *Weed Technology* **23**: 363–370.

Bilalis D, Papastylianou P, Konstantas A, Patisiali S and Karkanis A. 2010. Weed suppressive effects of maize-legume intercropping in organic farming *International Journal of Pest Management* **56**: 173–181.

Boyette CD, Hoagland RE andWeaver MA 2015. Interaction of the bioherbicide *Myrothecium verrucaria* and glyphosate for kudzu control. *American Journal of Plant Sciences* **5**: 3943–3956.

Boyette CD, Hoagland RE and Weaver MA. 2008. Interaction of the fungus *Colletatrichum truncatum* and glyphosate for controlling hemp sesbania in glyphosate-resistant soybean. *Weed Biology and Management* **8**: 18–24.

Bromilow RH, Chamberlain K, Tench AJ and Williams RH. 1993. Phloem translocation of strong acids – glyphosate, substituted phosphonic, and sulfonic acids in *Ricinus communis* L. *Pesticide Science* **37**: 39–47.

Brookes G and Barfoot P. 2018. Farm income and production impacts of using GM crop technology 1996–2016. https://doi.0rg/10.1080/21645698.1464866.

Brookes G and Barfoot P. 2013. *GM Crops: Global and Socio-Economic and Environmental Impacts 1996-2011*. PG Economics Ltd, Dorchester, UK.

Brookes G and Barfoot P. 2012. *GM Crops: Global Socio-Economic and Environmental Impacts 1996-2010*. PG Economics Ltd, Dorchester, UK. May 2012.

Carpenter JE 2011. Impact of GM crops on biodiversity. GM Crops **2**: 7–23.

Cellini F, Chesson A and Colquhoun I. 2004. Unintended effects and their detection in genetically modified crops. *Food and Chemical Toxicology* **42***:* 1089–1125.

Cerdeira AL and Duke SO. 2010. Effects of glyphosate-resistant crop cultivation on soil and water quality. *GM Crops* **1**: 16–24.

Evans JA, Tranel PJ, Hager AG, Schutte B, Wu C, Chatham LA and Davis AS. 2016. Managing the evolution of herbicide resistance. *Pest Management Science* **72**(1): 74–80.

García-Cañas V, Simó C, León C, Ibáñez E and Cifuentes A. 2011. MS-based analytical methodologies to characterize genetically modified crops. *Mass Spectrometry Reviews* **30**: 396–416.

Gealy DR, Agrama HA and Eizenga GC. 2009. Exploring genetic and spatial structure of U.S. weedy red rice (*Oryza sativa*) in relation to rice relatives worldwide. *Weed Science* **57**: 627–643.

Green JM and LA Castle. 2010. Transitioning from single to multiple herbicide-resistant crops. pp. 67–91. In: *Glyphosate Resistance in Crops and Weeds: History, Development, and Management*. (Ed. Nandula VK). John Wiley & Sons, New York.

Green JM and Owen MD. 2011. Herbicide-Resistant Crops: Utilities and Limitations for Herbicide-Resistant Weed Management. *Journal of Agricultural and Food Chemistry* **59**(11): 5819–5829.

Gressel J. 2002. *Molecular Biology of Weed Control*. 504 p. Taylor & Francis Group. London, UK.

Health Canada. 1999a. Imidazolinone tolerant Corn, 3417R. 01 October

Health Canada. 1999b. Imazethapyr-tolerant EXP1910IT. FD/OFB-097-189-A. 01 October.

Health Canada. 1997. Sethoxydim Tolerant Corn (DK412SR and DK404SR). FD/OFB-97-04. 01 April.

Heap I. 2018. International Survey of Herbicide Resistant Weeds. www.weedscience.org

Herman RA and Price WD. 2013. Unintended compositional changes in genetically modified (GM) crops: 20 Years of Res. *Journal of Agricultural and Food Chemistry* **61**(48): 11695–11701

Ho MW, Ryan A and Cummins J. 2000. Hazards of transgenic plants containing the cauliûower mosaic virus promoter. *Microbial Ecology in Health and Disease* **12**(3): 189–198.

ISAAA. 2018. Global Status of Commercialized Biotech/GM Crops. Brief No. 53/2017. Executive Summary. ISAAA, Ithaca, NY, USA.

Johal GS and Rahe JE. 1988. Glyphosate, hypersensitivity and phytoalexin accumulation in the incompatible bean anthracnose host–parasite interaction. *Physiological and Molecular Plant Pathology* **32**: 267–281.

Kanampiu F, Karaya H, Burnet M and Gressel J. 2009. Needs for and effectiveness of slow release herbicide seed treatment Striga control formulations for protection against early season phytotoxicity. *Crop Protection* **28**: 845–853.

Kremer RJ and Means, NE. 2009. Glyphosate and glyphosate-resistant crop interactions with rhizosphere microorganisms. *European Journal of Agronomy* **31**: 153–161.

Kudsk P. 2014. Reduced herbicide rates: present and future. *Julius-Kuhn-Archiv* **443**: 37–44.

Lamichhane JR, Devos Y, Beckie HJ, Owen MDK, Tillie P, Messéan A and Kudsk P. 2016. Integrated weed management systems with herbicide-tolerant crops in the European Union: lessons learnt from home and abroad. *Critical Reviews in Biotechnology*. DOI: 10.1080/07388551.2016.1180588.

Muller MH, Delieux F, Fernandez-Martýnez JM. 2009. Occurrence, distribution and distinctive morphological traits of weedy *Helianthus annuus* L. populations in S Spain and France. *Genetic Resources and Crop Evolution* **56**: 869–877.

Navntoft S, Esbjerg P, Ørum JE. 2007. Effects of mechanical weed control in spring cereals – Flora, fauna and economy. *Pesticide Research,* 114. http://www2.mst. dk/Udgiv/publications/2007/978–87.

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

Paparini, A. and V. Romano-Spica. 2004. Public health issues related with consumption of the food obtained from genetically modified organisms. *Biotechnology Annual Reviews* **10**: 85–122.

Parker WB, Marshall LC and Burton, JD. 1990. Dominant mutations causing alterations in acetyl-coenzyme A carboxylase confer tolerance to cyclohexanedione and aryloxyphenoxypropionate herbicides in maize. *Proceedings of the National Academy of Sciences* USA. **87**: 7175–7179.

Powell JR, Campbell RG, Dunfield KE, Gulden RH, Hart MM, Levy-Booth DJ. 2009. Effect of glyphosate on the tripartite symbiosis formed by *Glomus intraradices*, *Bradyrhizobium japonicum*, and genetically-modified soybean. *Applied Soil Ecology* **41**: 128–136.

Ransom J, Kanampiu F, Gressel J. 2012. Herbicide applied to imidazolinoe-resistant maize seed as a Striga control option for small-scale African farmers. *Weed Science* **60**: 283–-289.

Rao VS. 2018. *Principles of Weed Science*, 3rd Ed. CBS Publishers & Distributors Pvt. Ltd. New Delhi, India. 834 p.

Rao VS. 2014. *Transgenic Herbicide Resistance in Crops*. CRC Group, Taylor & Francis Group. Boca Raton, FL. 458p.

Tan S and Bowe SJ. 2012. Herbicide-tolerant crops developed from mutations. pp. 423-436. In: Plant Mutation Breeding and Biotechnology. (Eds. Shu QY, Forster BP and Nakagawa H), CABI, Cartridge, MA, USA.

USDA-NASS. 2005. *Acreage 2005 (June Report)*. United States Department of Agriculture National Agricultural Statistics Service, Washington, D.C., USA

Van Alfen, N.K. 2014. *Encyclopedia of Agriculture and Food Systems*. Edition 2. Elsevier. 464 pp.

Zablotowicz RM and Reddy KN. 2004. Impact of glyphosate on the *Bradyrhizobium japonicum* symbiosis with glyphosate-resistant transgenic soybean: A Mini Review. *Journal of Environmental Quality* **33**: 825–831.

Ziska LH, Gealy DR, Burgos N. 2015. Weedy (red) rice: an emerging constraint to global rice production. *Advances in Agronomy* **129**: 181–228.

Zobiole LHS, Kremer RJ Oliveira RS Jr and Constantin J. 2011. Glyphosate affects micro-organisms in rhizospheres of glyphosate-resistant soybeans. *Journal of Applied Microbiology* **110**(1): 118–127.

Zobiole LHS, Bonini EA, Oliveira RS, Jr, Kremer RJ and Ferrarese-Filho O. 2010. Glyphosate affects lignin content and amino acid production in glyphosate-resistant soybean. *Acta Physiologiae Plantarum* **32**: 831–837.

Indian Journal of Weed Science **50**(3): 239–249, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Herbicides *vis-a-vis* other pesticides: An overview on use and potential hazards

Neelam Sharma*, N.T. Yaduraju[1] and S.S. Rana

CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur Himachal Pradesh 176 062

[1]Former Director, Directorate of Weed Research, Jabalpur, Madhya Pradesh 482 004

**Email: sharma_neelam29@rediffmail.com*

Article information

DOI: 10.5958/0974-8164.2018.00053.9

Type of article: Review article

Received : 29 April 2018
Revised : 2 September 2018
Accepted : 6 September 2018

Key words

Herbicide

Insecticides

Pesticides

Uses

Hazards

ABSTRACT

Modern agriculture depends on the four main factors *viz*: seed, water, fertilizers and pesticides. The total number of pests attacking major crops has increased significantly from 1940s. Therefore, the demand of pesticides especially herbicides in agriculture is increasing. Farmers are facing shortages of labour for hand weeding crop fields as people are moving to urban from rural areas. Herbicides are cheaper and more readily available than labour for hand weeding. This review article focuses on the status of using herbicides *vis a vis* other pesticides and their uses and potential hazards. All pesticides must be toxic to be effective against the pests they are intended to control. Because of being toxic, pesticides are potentially hazardous to humans, animals, other organisms, and the environment. Therefore, users of the pesticides must understand the relative toxicity and potential health effects of the products they use. Pesticides are classified based on the oral and dermal lethal dose, 50% values (to the rat) of the active principles. Globally, 35% of the 158 insecticides fall under extremely hazardous and highly hazardous categories, compared to only about 4% in case of herbicides. Under the slightly hazardous group, the number of herbicides is two times higher as compared to insecticides. The number of herbicides that are unlikely to present acute hazard is as much as 37.1% of the total as compared to 12.6% insecticides. Thus, herbicides as a pesticide category are safer or less hazardous than other pesticides especially insecticides. But it is not intended to give clear chit to herbicides because the ultimate toxicity depends on the formulation. The formulation of pesticides may be thousand times more toxic than their active principles. Thus, there is need to set maximum residue limits (MRLs) based on formulation rather than on the basis of active principles.

INTRODUCTION

Agriculture is the soul of Indian economy as it brings home the bread to nearly 60% of the population and supplies it to the remainder (Prasad *et al.* 2016). In India, agriculture has come a long way since independence, with chronic food scarcity giving way to grain self-sufficiency, despite about three-fold increase in population. This made Indian agriculture transform from subsistence farming to modern farming. Modern agriculture depends on the four main factors *viz*: seed, water, fertilizers and pesticides. About 35-45% crop production is lost due to diseases, insects and weeds, while 35% crop produces are lost during storage (OPCI, Outlook of Pesticide Consumption in India 2014).Hence, pesticides are the integral part of modern agriculture.

The total number of pests attacking major crops has increased significantly from 1940's (**Table 1**) (FICCI 2015). For instance, the number of pests which are harmful for crops such as rice has increased from 10 to 17 whereas for wheat have increased from 2 to 19. The increased damage to crops from pests and subsequent losses pose a serious threat to food security and further underscores the importance of agrochemicals.

Pesticides are inevitable to prevent pre- and post-harvest losses, which have assumed

Table 1. Crop-wise demographic increase in pest population

Crop	1940s		At present	
	Total pests	Serious pests	Total pests	Serious pests
Rice	35	10	240	17
Wheat	20	2	100	19
Sugarcane	28	2	240	43
Peanut	10	4	100	12
Mustard	10	4	38	12
Pulses	30	6	250	34

(Source: FICCI 2015)

significance during recent times in agriculture. The growing popularity of synthetic pesticides in agriculture has over shadowed the traditional methods of plant protection to manage insect-pest, diseases and weeds. Undoubtedly, pesticides are said to have contributed to the food security by way of avoidance of post-harvest losses. Pesticides like all other inputs play an important role in increasing agricultural production. However, there is a growing awareness about the ill-effect of pesticides on human and animal health, environment, natural resources and sustainability of agriculture production. The problem of pesticide usage is not over now; in many countries, the old persistent, bio-accumulative pesticides have been banned. Many new products have been developed and used in large quantities. For many of these products today we still do not have sufficient amount of knowledge about their possible risks and adverse effects on the environment and humans. Several of them appear to have a bad environmental impact.

Pesticide use and Indian market overview

Indian Agrochemical Industry size was estimated to be US$ 3.8 billion in year 2012. Over the 12th plan period, the segment is expected to grow at 12-13% per annum to reach 7.0 billion (FICCI 2015). The Indian domestic demand is growing at the rate of 8-9% and export demand at 15-16%. The per capita consumption of pesticides in India is 0.6 kg which is lowest in the world. The per ha pesticide consumption in China and the USA is 13 and 7 kg, respectively. The main reason for low per ha consumption of pesticides in India is low purchasing power of farmers and small land holdings. The majority of agricultural farmland belongs to marginal farmers but maximum contribution to the produce is also from marginal farmers. The large-scale farming is increasing and therefore, there is good scope for increase of per ha consumption of pesticides in India. (http//:www.newsagropages.com/News/News Detail—10649.htm).

The Indian crop protection industry is expected to grow at a compound annual growth rate (CAGR) of 12% to reach United State dollar (USD) 7.5 billion by 2019. Exports currently constitute almost 50% of the Indian crop protection industry and are expected to grow at a CAGR of 16% to reach USD 4.2 billion by 2019, resulting in 60% share in the Indian crop protection industry. The domestic market on the other hand would grow at 8% CAGR, as it is predominantly monsoon dependent, to reach USD 3.3 billion by 2019. Globally, India is the fourth largest producer of crop protection chemicals, after the United States, Japan and China.

The crop protection companies in India can be categorized into three types –Multi-National, Indian including public sector companies and small sector units (http://ficci.in/study page.asp?spid=20541 &sectorid=7). The Indian crop protection industry is dominated by generic products with more than 80% of molecules being non-patented. This results in very low entry barriers for the industry. Hence, strong distribution network, appropriate pricing, brand recall and dealer margins are some of the critical factors for companies to succeed. Crop protection chemicals are manufactured as technical grades and converted into formulations for agricultural use. (http://www.careratings.com/upload/NewsFiles/SplAnalysis/Outlook%20of%20Indian%20Pesticide%20Industry.pdf).

The Indian agrochemical value chain comprises of technical grade manufacturers, formulators producing the end products, distributors and end use customers. According to the Pesticide Monitoring Unit, Government Of India (GOI), there are about 125 technical grade manufacturers, including about 10 multinationals, more than 800 formulators and over 145,000 distributors in India (http://www.tsmg.com/download/reports/Indian_Agrochemicals_Industry_2013.pdf). More than 60 technical grade pesticides are being manufactured indigenously. In India, top 10 companies control almost 75-80% of the market share (FICCI 2015). The market share of large players depends primarily on product portfolio and introduction of new molecules. The market has seen a number of mergers and acquisitions with large players buying out small manufacturers. Companies are also looking for strategic alliances and partnerships in order to expand their market reach.

Domestic market by product category

The Indian crop protection market is dominated by insecticides, which form almost 60% of the domestic crop protection chemicals market (FICCI 2015). The major applications are found in rice and cotton. Fungicides and herbicides are the largest growing segments accounting for 18% and 16% respectively of the total crop protection chemicals market, respectively. Rice and wheat crops are the major application areas for herbicides. Increasing labour costs and labour shortage are key growth drivers for herbicides.

The fungicides find application in fruits, vegetables and rice. The key growth drivers for fungicides include a shift in agriculture from cash crops to fruits and vegetables and government support for exports of fruits and vegetables. Bio-pesticides include all biological materials organisms which can be used to control pests. Currently, bio-pesticides constitute only 3% of the Indian crop protection market; however, there are significant growth opportunities for this product segment due to increasing concerns of safety and toxicity of pesticides, stringent regulations and government support.

Erstwhile Andhra Pradesh (Seemandhra and Telangana), Maharashtra and Punjab are top three states contributing to 45% of pesticide consumption in India. The top seven states together account for more than 70% of crop protection chemicals usage in India.

Since 2005, the value of the herbicide market in India has doubled (Philips 2013). The Indian market for herbicides is expected to grow about 40% annually (Frabotta 2011). The adoption of herbicides has gained impetus over conventional weeding practices and has increased the herbicide consumption to approximately 90% in developed countries, Latin America 70%, Europe 67% and Asia 84% (WAP 2014).

Annual usage of herbicides in the world was about 1814369.48 tonnes in the 1953, increasing to nearly 54884676.77 tonnes at the end of 2013 (WAP 2014). Since then, at the end of each five years, 15-24% increments occurred. The herbicide industry is quite significant in dollar terms. Annual expenditures by users of herbicides totalled about USD 33 billion in 1953 and USD 998 at the end of 2013. It is clear from the figure that, there is a sharp increasing trend in consuming herbicides which triggers to increase the market expenditure for herbicides (Hossain 2015). In future, by the end of 2025, it is supposed that the herbicides consumption to be increased by 68.03 million tonnes which will costs around USD 2000.

Area treated with pesticides

As per the input surveys conducted under the aegis of agricultural census (GOI 2016), the cultivated area treated with the pesticides has increased in the last two decades. Around 40% of the total cultivated area is treated with pesticides. Approximately, 65-70% of the cultivated area treated with pesticides is irrigated. As regard to pesticide usage, land holding size-wise, medium size land holding are treated the most, followed by the small and marginal land holding. At a micro level, on an average 65% of the area under the fibre crops are treated with pesticides followed by fruits (50%), vegetables (46%), spices (43%), oilseeds (28%) and pulses (23%).(https://eands.dacnet.nic.in/PDF/State_of_Indian_Agriculture,2015-16.pdf).

Until recently in India, herbicides were used on 10% of the wheat hectares to control grass weed species and on 20–25% of the hectares to control broadleaf species (Chatrath 2006). It is inevitable that, herbicide use will increase in the world agriculture, not only because millions of people are leaving rural areas, creating shortages of hand weeders, but also the need to increase crop yields. Hand weeding has never been a very efficient method of weed control often performed too late and not frequently enough. In many parts of the world, herbicides are being increasingly used to replace tillage in order to improve environmental conditions. In comparison with tillage, herbicide use reduces erosion, fuel use, greenhouse gas emissions and nutrient run-off and conserves water (Hossain 2015).

Ecological effects of pesticides

The first warning signal about pesticides danger came in 1962, when Rachel Carson, an American courageous woman scientist, wrote down her nature observation and pointed out sudden dying of birds caused by indiscriminate spraying of pesticides (DDT). Her book, Silent Spring, became a landmark. It changed the existing view on pesticides and has stimulated public concern on pesticides and their impact on health and the environment. Silent Spring facilitated the ban of the DDT in 1972 in the United States. More research has been done and several dangerous and persistent organic pesticides like dieldrin, endosulfan and lindane have been banned or restricted since that time.

Soil contamination

Persistence of pesticides in soil can vary from few hours to many years in case of organochlorine pesticides. Despite organocarbon pesticides were banned or restricted in many countries, they are still detected in soils (Shegunova *et al.* 2007, Toan *et al.* 2007, Li *et al.* 2008, Hildebrandt *et al.* 2009, Jiang *et al.* 2009, Ferencz and Balog 2010).

Water contamination

Pesticides can get into water via drift during pesticide spraying, by runoff from a treated area, and leaching through the soil. In some cases, pesticides can be applied directly onto water surface. Pandey *et al.* (2011) reported that pesticides has caused both surface sediment and river water pollution as several registered pesticides have been detected in the river Yamuna in Delhi. Similar studies also reported the pesticides detection in other rivers in India. In addition, Pandey *et al.* (2011) also reported some cases of pesticides contamination in monitoring studies in other places in the world, such as: (1) coastal marine sediment in Singapore; (2) Ebro river delta, Mediterranean Sea; (3) Paranoa lake in Brazil; (4) Coastal lagoon watershed in Argentina; (5) Bay of Ohuira in Mexico; (6) Haleji lake in Pakistan; (7) some stream sediment in Spain; (8) Lake Orta sediments in Italy; (9) Uluabat lake in Turkey and (10) Pearl river estuary in China etc. Pesticides are in detectable level in the UK groundwater (Stuart *et al.* 2012) while, in the US, it has been reported that 100% of major rivers and streams and 33% of major aquifers contained at least one pesticide at detectable levels (Koleva and Schneider 2010).

Although quantity control and residues monitoring are important, these cannot ensure that all pesticides will be used correctly and safely. There must also be systems in place to deal with toxic chemicals if they are found in drinking water. With regard to recommendations for the future, some investment is required in training farmers on correct application methods for pesticides. Otherwise, potential dangers to drinking water can be ignored. It may be appropriate to sell pesticides only to those who can produce written evidence of having received the necessary safety training. In addition, an existing risk assessment already established should further be enhanced by which the pesticides entering groundwater, their toxicity and potential risks to drinking water and the environment can be assessed. Zhao and Pei (2012) have reviewed the four aspects of such risk evaluation including the establishment of a theoretical system, comprehensive consideration of the impact factors, the development of validation methods and combined evaluation methods and the strengthening of monitoring work and groundwater pollution risk assessment in arid areas. In relation to drinking water quality assurance, there should be an increase in the sampling rates of water supplies, especially during times of maximum pesticide application.

Effects on organisms

Fungicides were found to be toxic to soil fungi and actinomycetes and caused changes in the microbial community structure (Liebich *et al.* 2003, Pal *et al.* 2005). Nitrification bacteria are very sensitive to pesticides influence. Inhibition of nitrification was proved by sulphonylurea herbicides (Gigliotti and Allievi 2001). Some pesticides (Benomyl, Dimethoate) can also negatively affect symbiotic mycorrhizal fungi, which facilitate plant nutrient uptake (Menendez *et al.* 1999, Chiocchio *et al.* 2000). Glyphosate affected predatory arthropods (spiders and ground beetle) in agricultural field, caused behavioural changes and influenced long-term surviving even in residual exposure. These results also suggest that herbicides can affect arthropod community dynamics separate from their impact on the plant community and may influence biological control in agroecosystems (Evans *et al.* 2010). Scientific literature addressing the influence of pesticides on the growth and reproduction of earthworm is reviewed by Yasmin and D'Souza (2010). Majority of the studies have used mortality as an endpoint rather than subtler endpoints such as reproductive output. It is now emphasized that, whereas higher concentrations of a pollutant can easily be assessed with the acute (mortality) test, contaminated soils with lower (sublethal) pollutant concentrations require more sensitive test methods such as reproduction test in their risk assessment. Lower bumblebee and butterfly species richness was found in the more intensively farmed basin with higher pesticide loads (Brittain *et al.* 2010). Several articles reported negative effects of pesticides butterflies populations (Longley and Sotherton 1997, White and Kerr 2007, Adamski *et al.* 2009). Carbaryl has been found toxic for several amphibian species, additional combination with predatory stress caused higher mortality (Relyea 2003). Also, herbicide glyphosate caused high mortality of tadpoles and juvenile frogs in an outdoor mesocosms study (Relyea 2005b). Insecticide and herbicide application can lead to reduction of chick survival and bird population. Evidences of this important indirect effect of pesticides have been reported (Moreby and Southway 1999, Boatman *et al.* 2004, Taylor *et al.* 2006). A recent review about this topic and possible mitigation measures were published by Royal Society for the Protection of Birds in the UK (Bright *et al.* 2008).

Toxicity risks of agricultural pesticides to fishes are pivotal. The 96h LC_{50} and 95% lower and upper confidence limits, respectively, for the following pesticides were determined (Kreutz et al. 2008): glyphosate (7.3 mg/L; 6.5–8.3), atrazine (10.2 mg/L; 9.1–11.5), atrazine + simazine (10.5 mg/L; 8.9–12.4), mesotrione (532.0 mg/L; 476.5–594), tebuconazole (5.3 mg/L; 4.9–5.7), methylparathion (4.8 mg/L; 4.3–5.3), strobulurin and triazol (9.9 mg/L; 8.7–11.2). Diflubenzuron was also tested and caused no fish mortality up to 1 g/L. The toxic concentration of these pesticides to silver catfish fingerlings fell above the concentration used for application in the field and except following accidental application or misplacing of empty recipients, it should not cause fish mortality.

Nonetheless, the data obtained will be useful to study the long-term effect of these products on the hematological, biochemical, hormonal and immunological parameters of silver catfish and related fish species.

Effect on biodiversity

If biodiversity is to be restored, there must be a world-wide shift towards farming with minimal use of pesticides over large areas (Geiger *et al.* 2010). A recent study conducted in agriculture area in Netherlands estimated the impact of insecticides, herbicides and fungicides drift on terrestrial biodiversity outside the treated area. This study suggests that increasing unsprayed buffer zones around crops is critical to the success of any new strategy to prevent the harmful impact of pesticides (de Jong *et al.* 2008).

Pesticide hazard

Toxicity is a measure of the capacity of a substance to cause injury or death, and is related to the dose. It is an intrinsic property of the substance. The dose-response relationship is a way of quantifying acute toxicity, and the LD_{50} is a crude estimate of the dose needed to kill 50% of the test animals when they are exposed to the chemical by the oral, dermal or inhalation route. The value is usually expressed in milligrams of chemical per kilogram bodyweight of the test animal. The smaller the LD50 value, the greater is the acute toxicity of the chemical.

Hazard represents the potential for injury to occur. It is a function of the toxicity of the chemical and degree of exposure. Even a highly toxic chemical presents little hazard to man when the means of exposure are largely eliminated.

Risk is the probability of a hazard occurring under specified conditions. Safety, the reciprocal of risk, is the probability that harm will not occur under specified conditions.

When satisfied that an adequate assessment has been made of all the potentially hazardous components of the product, the next step is to assess the risks that may arise from the proposed use. These include risk to the applicator, the consumer of treated crops, beneficial species or wildlife, and to the environment. The risks are minimized if the user follows the appropriate warning and precautionary statements on the label. It is the responsibility of the manufacturer/supplier and regulator to ensure that the safety statements are adequate to minimize the risks, and that the benefits of using the product outweigh any risks involved.

Potential hazard is assessed on the formulation or product in the pack and therefore takes into account the properties of the solvents, diluents or other adjuvants, in addition to the active ingredient (WHO 2010). The WHO Recommended Classification of Pesticides by Hazard is widely used and is based on the oral and dermal LD50 values (to the rat). The more restrictive class is always chosen from the oral and dermal LD50 classifications. From these values, one of four coloured bands is assigned with a corresponding hazard statement and one of two hazard symbols, which denote classification of hazard in use, is placed along the bottom of the label.

Criteria for classification

WHO presently uses the Acute Toxicity Hazard Categories from the Global Harmonized System (GHS) as the starting point for classification. This change is consistent with the 1975 World Health Assembly Resolution which envisaged that the WHO Classification would be further developed with time in consultation with countries, international agencies and regional bodies. The Global Harmonized System (GHS) meets this requirement as a classification system with global acceptance following extensive international consultation.

Based on this system the pesticides active principles are classified (WHO 2010) (**Table 2**). However, the final classification of any product is intended to be by formulation.

Abbreviations :AC-acaricide, AP -aphicide ,B-bacteriostat (soil), FM–fumigant, F-fungicide, other than for seed treatment, FST-fungicide, for seed treatment, H –herbicide, I-insecticide, IGR-insect growth regulator, Ix-ixodicide (for tick control), L-larvicide, M-molluscicide, MT-miticide, N –nematocide, O- other use for plant pathogens, PGR-plant growth regulator , R-rodenticide, RP-repellant (species), S- applied to soil: not used with herbicides or plant growth regulators SY -synergist

As per the WHO classification (**Table 2**) of pesticides globally 35% of the 158 insecticides fall under the extremely hazardous and highly hazardous category, compared to only about 4% in case of herbicides. Under the slightly hazardous group, the number of herbicides is two times higher as

WHO Class	LD_{50} for the rat (mg/kg body weight)	
	Oral	Dermal
Ia Extremely hazardous	< 5	< 50
Ib Highly hazardous	5–50	50–200
II Moderately hazardous	50–2000	200–2000
III Slightly hazardous	Over 2000	Over 2000
U Unlikely to present acute hazard	5000 or higher	

Table 2. Classification of pesticides according to toxicity, expressed as LD_{50} (mg/kg) based on WHO classification scheme (after WHO 2010)

Class	Main use	Pesticides
Extremely hazardous (Class 1a)	I	Chlorethoxyfos; Chlormephos; Disulfoton; EPN; Mevinphos; Parathion; Parathion-methyl; Phoratek; Phosphamidon; Sulfotep; Tebupirimfos
	R	Brodifacoum; Bromadiolone; Bromethalin; Chlorophacinone; Difenacoum; Difethialone; Diphacinone; Flocoumafen; Sodium fluoroacetate
	I-S	Aldicarb (0.93 mg/kg); Ethoprophos; Terbufos
	FM	Calcium cyanide
	F	Captafol
	FST	Hexachlorobenzene; Phenylmercury acetate
	F-S	Mercuric chloride
Highly hazardous (Class 1b)	I	Azinphos-ethyl; Azinphos-methyl; Butocarboxim; Butoxycarboxim; Calcium arsenate; Carbofuran; Chlorfenvinphos; *Cyfluthrin; Beta-cyfluthrin;* Zeta-cypermethrin; Demeton-S-methyl; Dichlorvos; Dicrotophos; Ethiofencarb; Famphur; Flucythrinate; Heptenophos; Isoxathion; Mecarbam; Methamidophos; Methidathion; Methiocarb; Methomyl; Monocrotophos; Omethoate; Oxamyl; Oxydemeton-methyl; Propetamphos; Thiometon; Triazophos; Vamidothion
	R	3-Chloro-1,2-propanediol; Coumatetralyl; Fluoroacetamide; Sodium arsenite; Sodium cyanide; Strychnine; Thallium sulphate; Warfarin; Zinc phosphide
	AC	Formetanate
	I-S	DNOC; Furathiocarb; Tefluthrin; Thiofanox
	O	Mercuric oxide
	AC, MT	Coumaphos;
	N	Fenamiphos
	N,I	Cadusafos
	L	Lead arsenate; Paris green
	I,F, H	Pentachlorophenol
	F	Blasticidin-S; Edifenphos;
	H	Acrolein; Allyl alcohol; Dinoterb; DNOC
Moderately hazardous (Class II)	I	Acephate; Alanycarb; Allethrin; Azamethiphos; Bendiocarb; Benfuracarb; Bensultap; Bifenthrin; Bioallethrin; Carbaryl; Carbosulfuron; Cartap; Chlordane; Chlorpyrifos; Cyanophos; Cypermethrin; Alpha-cypermethrin; Cyphenothrin; DDT; Deltamethrin; Diazinon; Dimethoate; Endosulfan; Esfenvalerate; Ethion; Fenitrothion; Fenobucarb; Fenpropathrin; Fenvalerate; Fipronil; Gamma-HCH; HCH; Hydramethylnon; Imidacloprid; *Indoxacarb;* Isoprocarb; Lambda-cyhalothrin; Methacrifos; Metolcarb; Naled; permethrin; Phenthoate; Phosalone; Phoxim; Pitimiphos-methyl; Prallethrin; profenofos; Propoxur; Prothiofos; Pyraclofos; Pyrethrins; Pyridaphenthion; Quinalphos; Rotenone; Sulfluramid; Thiocyclam; Thiodicarb; Tralomethrin; Trichlorfon; XMC; Xylylcarb
	Ix	Cyhalothrin
	I, MT	Chlorfenapyr
	MT	Tebufenpyrad,
	AC	Amitraz; Azocyclotin; Cyhexatin; Dicofol; Fenazaquin; *Fenpyroximate;* Pyridaben;
	R	Chloralose
	M	Metaldehyde
	L	Fenothiocarb
	I, L	Fenthion
	I, AC	Phosmet
	AP	Pirimicarb; Triazamate
	FM	Dichlorobenzene
	B	Bronopol
	B-S	Nitrapyrin
	F	Azaconazole; Bromuconazole; Butylamine; Copper hydroxide; Copper oxychloride; Copper sulphate; Cuprous oxide; Cymoxanil; Cyproconazole; Dichlorophen; Difenoconazole; Diniconazole; Dithianon; Dodine; Fenpropidin; Fentin acetate; Fentin hydroxide; Ferimzone; Flufenacet; Fluoroglycofen; Flusilazole; Fuberidazole; Furalaxyl; Imazalil; Iminoctadine; Iprobenfos; Isoprothiolane; Mercurous chloride; Metalaxyl; Metconazole; Methasulfocarb; Myclobutanil; Nabam; Nuarimol; Octhilinone; Oxadixyl; Procloraz; Propiconazole; Pyrazophos; Pyroquilon; Spiroxamine; Tebuconazole; Tetraconazole; Thiram; Triadimefon; Tricyclazole; Tridemorph; Triflumizole; Ziram
	F-S	Dazomet; Metam-sodium; Methyl isothiocyanate
	F,FST	Flutriafol
	AC,F	Dinobuton; Dinocap
	FST	Guazatine; triadiamenol
	H	Acifluorfen; Alachlor; Ametryn; Anilofos; Bensulide; Bentazone; Bilanafos; Bromoxynil; Butamifos; Butralin; Butoxydim; Clomazone; Cyanazine; 2,4-D; 2,4-DB; Dicamba; Dichlorprop; Diclofop; Difenzoquat; Dimepiperate; Dimethachlor; Dimethipin; *Dimethenamid;* Dimethylarsinic acid; Diphenamid; Diquat; Endothal-sodium; EPTC; Fluchloralin; Fluxofenim; Fomesafen; Glufosinate; Haloxyfop; Hexazinone; Ioxynil; Ioxynil octanoate; Isoproturon; Isouron; MCPA; MCPA-thioethyl; MCPB; Mecoprop; Mecoprop-P; Mefluidide; Metamitron; Methylarsonic acid; Metribuzin; Molinate; Paraquat; Pebulate; Pendimethalin; Piperphos; Propachlor; Propanil; Prosulfocarb; Pyrazoxyfen; Quinoclamine; Quizalofop; Quizalofop-p-tefuryl; Simetryn; Sodium chlorate; 2,3,6-TBA; TCA; Tebuthiuron; Terbumeton; Thiobencarb; Tralkoxydim; Triclopyr
	PGR	Chlormequat; 4-CPA; Flurprimidol; Mepiquat; 2-Napthyloxyacetic acid Paclobutrazol; Uniconazole
Slightly hazardous (Class III)	I	*Bacillus thuringiensis;* Buprofezin; Chlorpyrifos methyl; Empenthrin; Flufenoxuron; tau-Fluvalinate; Halofenozide; Malathion; Resmethrin; Spinosad; Spirotetramat; Timephos; Tetrachlorvinphos
	L	Cyromazine; Diflubenzuron
	MT	Fenbutatin

Class	Main use	Pesticides
	RP (insect; dog/cats)	Diethyltoluamide (insect); Undecan-2-one (Dog/cats)
	I, F	Sulphur
	AC, F	Chinomethionate
	AC	Clofentezine; diafenthiuron; Propargite
	F	Benalaxyl; Biphenyl; Borax; Buprimate; Butylate; Chlozolinate; Dicloran; Dmethirimol; dimethomorph; Etridiazole; Fenarimol; Fenbuconazole; Fenpropimorph; Flamprop-M; hexaconazole; Iprodione; Ofurace; Oxycarboxin; Penconazole; 2-phenylphenol; Pimaricin; Probenazole; Prifenox; Pyrimethanil; Thiabendazole; Tritaconazole
	FST	Carboxin; Hymexazol
	H	Acetochlor; Alloxydim; Ammonium sulfamate; Asulam; Atrazine; Benazolin; Bensuresate; Bispyribac; Butachlor; Chloridazon; Chlorimurion; Chlorthal-dimethyl; Cinmethylin; Clopyralid; Cyloate; Cycloxydim; Dichlobenil; dichlormid; Diflufenican; Dimefuron; Dimethametryn; dinitramine; diuron; Dodemorph; Esprocarb; Fluazifop-p-butyl; fluorochloridone; Fosamine; Glyphosate; Linuron; Metazachlor;Methabenzthiazuron; methyldymron; Metobromuron; Metolachlor; Metoxuron; monolinuron; Prometon; Prometryn; Pyridate; Pyrithiobac sodium; Quinclorac; Sethoxydim; TCA; Terbuthylazine; Terbutryn; Triallate; Trietazine
	PGR	Ancymidol; Ethephon; 1-Naphthylacetic acid; Thidiazuron
	SY	N-octylbicycloheptene dicarboximide
Acute hazard	I	Bioresmethrin; Chlorantraniliprole; Cryolite; Cycloprothrin; Etofenprox; Fenoxycarb; Hexaflumuron; Methoxychlor; Methozyfenozide; Novaluron; Noviflumuron; Phenothrin
	MT	Acrinathrin
	M	Niclosamide
	IGR	Chlorfluazuron; Methoprene;
	RP (bird)	Anthraquinone (birds); Dimethyl phthalate (insect); Dipropyl isocinchomerate (fly); Ethyl butylacetylasminopropionate
	AC	Bifenazate; Bromopropylate; Flucycloxuron; Hexythiazox
	F	Azoxystrobin; Benomyl; Bitertanol; Boscalid; Captan; Carbendazim; Carpropamid; Chlorothalonil; Diclofluanid; Diclomezine; Diethofencarb; Dimethomorph; Flutolanil; Folpet; Fosetyl; Imibenconazole; Iprovalicarb; Kasugamycin; Mancozeb; Mandipropamid; Maneb; Mepanipyrim; Mepronil; Metiram; nitrithal-isopropyl; Oxine-copper; Pencycuron; Phosphorus acid; Phthalide; Procymidone; Propamocarb; Tolylfluanid; Trifloxystrobin; Triforine; Validamycin; Vinclozolin; Zineb; Zoxamide
	FST	Ethrimol; Fenfuram; Fenpiclonil
	H	Aclonifen; Aminopyralid; Amitrole; Azimsulfuron; Benfluralin; Benoxacor; Bensulfuron methyl; Bifenox; Bromacil; Bromobutide; Carbetamide; Chlorasulam methyl; Chlorotoluron; Chlorsulfuron; Cinosulfuron; Clomeprop; Cyclosulfamuron; Cyhalofop; Daimuron; Dalapon; Daminozide; Desmedipham; Diclosulam; Dithiopyr; Ethalfluralin; Ethoflumesate; Fenchlorazole; Fenclorim; florasulam; Flucarbazone-sodium; Flumetsulam; Flumeturon; Flupropanate; flupyrsulfuron; fluridone; fluroxypyr; Fluthiacet; Imazamethabenzmethyl; Imazapyr; Imazaquin; Imazethapyr; Isozaben; Lenacil, Mefenacet; Metosulam; metsulfuron methyl; Napropamide, Neburon; Nicosulfuron; Norflurazon; Oryzalin; Oxabetrinil; Oxadiazon; Oxyfluorfen; Penoxulam; Pentanochlor; Phenmedipham; Picloram; Pretilachlor; Pimisulfuron; Prodiamine; Propaquizafop; Propazine; Propham; Propineb; Propizamide; Triasulfuron; Tribenuron; Trifluralin; Triflusulfuron-methyl
	PGR	Chlorpropham; Cloxyfonac; Dikegulac; Flumetralin; Flurenol; Gibberellic acid; Inabenfide; Maleic hydrazide; 2-(1-Naphthyl) Acetamide; Naptalam; Triflumuron
	SY	Piperonyl butoxide

compared to insecticides. The number of herbicides that are unlikely to present acute hazard is as much as 37.1% of the total as compared to 12.6% insecticides. Thus it may be noted that herbicides as a pesticide category are safer or less hazardous than other pesticides especially insecticides.

The other points those can be substantiated in favour of herbicides in comparison to other pesticides are as follow:

Lower pesticide load: With the advent of new herbicides, the application rates have come down drastically. Sulfonylureas, for example, are applied at very low rates a.i (4-30 g/ha) which lead to low herbicides load in the environment. Many herbicides are tightly bound to soil organic matter with little risk of their horizontal or vertical movement. Further as the Indian agriculture is predominant by marginal and small farmers, there is little chance of a large scale use of a single herbicide and thereby possibility of contamination of surface and ground water.

Lower or no residues in food and environment: The waiting period between application and crop harvest is longer in herbicides in comparison to insecticides and fungicides. More the interval more will be the exposure of the herbicide to pressures of degradation or dissipation acting on them. Thus by default the interval between application and crop harvest is very long which ensures their degradation and dissipation to sub-toxic levels. This is in direct contrast to other pesticides which are quite often used at the later stages of crop growth especially flowering and fruiting stages. Thus, there are good chances of findings residues of such pesticides on the crop produce.

The above discussion is not intended to give clear chit to herbicides. Some are distinctly different from other pesticides as discussed below:

-Herbicides are crop specific and different chemicals are used to control the same weed. For example, atrazine is used in maize and butachlor in rice to control the same *Echinochloa* sp this is referred to as selectivity.

- Herbicide dose is of great importance. At higher dose herbicides may significantly damage the crop while other pesticides may not affect the crop.
- Uniform application is critical with herbicides. That is why these are recommended at active ingredient basis and applied after calibration of the sprayers. The other pesticides are applied at recommended concentration.
- Cautious application is of great concern as any spray drift reaching the susceptible crop plants grown in the adjoining fields may damage them.
- There is need to educate farmers about the dangers of using herbicides meant for Herbicide resistant crops(HRCs) on non-herbicide resistant crops while it is not relevant in the case of insecticides. For instance, insecticides could be safely used both in Bt-cotton as well as in non-Bt cotton.

Other methods of classification

According to its chemical structure, pesticides are classified into different families, ranging from organochlorine and organophosphorus compounds to inorganic compounds. The most common way to classify them based on their chemical structure is split into four main groups (Garcia *et al* 2012): Organochlorine (stable compounds too persistent in the environment and tend to accumulate in fatty tissue (Waliszewski *et al*. 2002, 2003 a, b, 2004); Organophosphates **(**they are esters derived from phosphoric acid. In man act on the central nervous system by inhibiting acetyl cholinesterase, Sorgob and Vilanova 2002); Carbamates **(**they are esters derived from acids or dimethyl N-methyl carbamic acid are used as insecticides, herbicides, fungicides and nematicides. Are less persistent than organochlorines and organophosphates), Pyrethroids **(**they originate from natural insecticide derived from pyrethrum extract derived from chrysanthemum flowers, known as pyrethrins) and others (triazine herbicides, ureic, hormonal, amides, nitro compounds, benzimidazoles, ftalamidas, bipyridyl compounds, ethylene dibromide, sulfur containing compounds, copper or mercury).

Effect of formulation

Pesticides are used throughout the world as mixtures called formulations. They contain adjuvants, which are often kept confidential and are called inerts by the manufacturing companies, plus a declared active principle, which is usually tested alone. Mesnage *et al*. (2014) tested the toxicity of nine pesticides, comparing active principles and their formulations, on three human cell lines (HepG2, HEK293, and JEG3). Glyphosate, isoproturon, fluroxypyr, pirimicarb, imidacloprid, acetamiprid, tebuconazole, epoxiconazole, and prochloraz constitute, respectively, the active principles of three major herbicides, three insecticides, and three fungicides. They measured mitochondrial activities, membrane degradations, and caspases 3/7 activities. Fungicides were the most toxic from concentrations 300–600 times lower than agricultural dilutions, followed by herbicides and then insecticides, with very similar profiles in all cell types. Despite its relatively benign reputation, Glyphosate was among the most toxic herbicides and insecticides tested. Most importantly, eight formulations out of nine were up to one thousand times more toxic than their active principles. Their results challenge the relevance of the acceptable daily intake for pesticides because this norm is calculated from the toxicity of the active principle alone. Chronic tests on pesticides may not reflect relevant environmental exposures if only one ingredient of these mixtures is tested alone.

The previous investigation by Mesnage *et al.* (2013) showed unexpected active principles for human cell toxicity in the adjuvants of glyphosate-based herbicides. Ethoxylated adjuvants found in glyphosate based herbicides were up to 10000 times more toxic than the so-called active AP glyphosate (Mesnage *et al.* 2013) and are better candidates for secondary side effects. This may explain in vivo long-term toxicity from 0.1 ppb of the formulation and other toxicities that were not explained by a consideration of glyphosate alone (Seralini *et al*. 2013; Gasnier *et al.* 2009; Peluso *et al*. 1998; Walsh *et al*. 2000). These adjuvants also have serious consequences to the health of humans and rats in acute exposures (Bradberry *et al.* 2004; Adam *et al.* 1997).

Adjuvants in pesticides are generally declared as inerts, and for this reason they are not tested in long-term regulatory experiments. It is thus very surprising that they amplify up to 1000 times the toxicity of their active principles in 100% of the cases where they are indicated to be present by the manufacturer. In fact, the differential toxicity between formulations of pesticides and their active principles now appears to be a general feature of pesticides toxicology. As we have seen, the role of adjuvants is to increase AP solubility and to protect it from degradation, increasing its half-life, helping cell penetration, and thus enhancing its pesticidal activity (Marutani and Edirveerasingam 2006) and consequently side effects. They can even add their own toxicity (Mesnage 2013). The definition of adjuvants as “inerts” is thus nonsense; even if the US Environmental Protection Agency has recently changed the appellation for “other ingredients” pesticide adjuvants should be considered as toxic “active” compounds.

Government initiatives

The “Monitoring of Pesticide Residues at National Level” scheme has been initiated for monitoring and analysis of pesticide residues in agricultural commodities in different agro-ecological regions of the country. During the last five years, the incidence of residues in various commodities has shown an increase from 1.2 to 2.6% (GOI 2016).

In 2005, the Joint Parliamentary Committee (JPC) set out a clear agenda for governments to ensure the safe use of pesticides (Bhushan *et al.* 2013). The committee recommended to make mandatory the setting of maximum residue limits (MRL) for pesticides before registering it, setting MRLs for deemed registered pesticides, reviewing the set MRLs for compliance with the Acceptable Daily Intake (ADI) of pesticides and monitoring pesticide residues regularly. In their paper, (Bhushan *et al.* 2013) reviewed the state of pesticide regulations in India from a food safety perspective in the light of the recommendations made by the JPC. Pesticide use in India is regulated by the Central Insecticides Board and Registration Committee (CIBRC) and the Food Safety and Standards Authority of India (FSSAI). The CIBRC registers pesticides for crops while the FSSAI sets the maximum residue limits of pesticides for the crops it has been registered for. It was reported that recommendations of JPC have not been followed properly. Of the 234 pesticides registered in the country, the FSSAI has not set MRLs for 59 pesticides. A review of MRL status of 20 commonly used and recommended pesticides showed that the MRLs set for 18 pesticides are not complete. MRLs have not been set for all the crops these pesticides have been registered for. A few MRLs have been set for crops for which the corresponding pesticide is not registered. MRLs have been set for broad groups like fruits, vegetables and food grains rather than specific crops while the pesticides have been registered for specific crops. In the paper, the Theoretical Maximum Daily Intakes (TMDI) for 20 pesticides was calculated to check the compliance of these pesticides with ADI. The TMDIs of seven pesticides was above the corresponding ADIs for adults while TMDIs for nine pesticides was higher than ADI for children. The comparison of TMDIs with reference doses (RfD), US EPA equivalent of ADI, showed that they were higher than corresponding RfDs for six and eight pesticides for adults and children, respectively. A review of 11 important crops in India was done—wheat, paddy, apple, mango, potato, cauliflower, black pepper, cardamom, tea, sugarcane and cotton. The paper shows that the pesticide recommendations made by state agriculture universities, agriculture departments and other boards for a crop do not adhere to the pesticides that the CIBRC has registered for those crops. The agriculture universities, departments and boards have recommended many pesticides that have not been registered for some crops. Recommendations of waiting periods for pesticides are not complete. An analysis of 10 common pesticides showed that waiting periods for many of their registered uses (crop-pest/weed/disease combination) have not been recommended. The farmers were found to be unaware of the registered pesticides. They mostly followed the pesticides as the dealers recommended them. The outreach of state agriculture universities and departments to the farmers was minimal.

The DAC&FW have taken a number of measures to ensure that chemical pesticides are employed as a last resort to pest management. The department has revised 68 Integrated Pest Management (IPM) Packages of Practices for major crops giving impetus to ecological and cultural techniques of pest management (GOI 2016). Capacity building and training programmes are held annually to sensitize stakeholders (farmers, extension officers, pesticides dealers, *etc*) about various facets of pest management. “Grow Safe Food” campaign has been launched to create awareness among the stakeholders regarding judicious use of Plant Protection chemicals. Efforts are in the pipeline to explore usage of Information Technology (IT) in pest management to ensure that pest assessment report and advisories thereon are disseminated on real time basis. In India, the Bureau of Indian Standards (BIS) adopted the ‘Requirements for Good Agricultural Practices’ in 2010. It recommends practices for every stage of farming from land preparation to post harvest supply chain (Bureau of Indian Standards 2010).

Conclusion

Pesticides are inevitable to prevent losses in agriculture. The number of pests attacking crops has increased from 1940s. The demand of pesticides especially herbicides is increasing due to shortage of labour in agriculture. Based on active principle herbicides as a category are less hazardous than the insecticides but it is intended not to give clear chit to herbicides; after all the ultimate toxicity depends on the formulation. Therefore, residual limits need to be set based on formulations. The recommendations made for pesticides in India are unsatisfactory at multiple levels. There is lack of uniformity in the recommendations. Therefore, it is difficult to either set the MRLs of a pesticide for appropriate food commodities or to monitor pesticide residues. The State Agricultural Universities do not consider the recommendations of Central Insecticide Board and Registration Committee (CIBRC) while recommending pesticides. They have their own research mechanism that they follow. This leads to the difference between recommendations and makes it difficult to monitor the pesticides residues in crops. The MRLs need to be completed for all pesticides and for all crops the pesticides have been recommended for. The MRLs for some commodities like fruits and vegetables need to be revised and brought down to a level at which the TMDIs do not exceed ADIs.

REFERENCES

Adam A, Marzuki A, Rahman HA and Aziz MA. 1997. The oral and intratracheal toxicities of ROUNDUP and its components to rats. *Veterinary and Human Toxicology* **39**(3): 147–151.

Adamski Z, Machalska K, Chorostkowska K, Niewadzi M, Ziemnicki K and Hirsch HVB. 2009. Effects of sublethal concentrations of fenitrothion on beet armyworm (Lepidoptera: Noctuidae) development and reproduction. *Pesticide Biochemistry and Physiology* **94**(2-3): 73–78.

Bhushan C, Bhardwaj A and Misra SS. 2013. *State of Pesticide Regulations in India*, Centre for Science and Environment, New Delhi.

Boatman ND, Brickle NW, Hart JD, Milsom TP, Morris AJ, Murray AWA, Murray KA and Robertson PA. 2004. Evidence for the indirect effects of pesticides on farmland birds. *Ibis* **146**: 131–143.

Bradberry SM, Proudfoot AT and Vale J. A. 2004. Glyphosate poisoning. *Toxicological Reviews* **23**(3): 159–167.

Bright JA, Morris AJ and Winspear R. 2008. A review of Indirect effects of pesticides on birds and mitigating land-management practices. *Research Report 28*, Royal Society for the Protection of Birds, UK.

Brittain CA, Vighi M, Bommarco R, Settele J and Potts SG. 2010. Impacts of a pesticide on pollinator species richness at different spatial scales. *Basic and Applied Ecology* 11(2): 106–115.

Bureau of Indian Standards 2010. *Requirements for Good Agricultural Practices* – India GAP.

Carson Rachel. *Silent Spring*. Boston: Houghton Mifflin, 1962.

Chatrath R, Mishra B and Shoran. 2006. Yield potential survey-India, In: *International Symposium on Wheat Yield Potential: Challenges to International Wheat Breeding*, (eds. Reynolds MP, Pietragalla J and Bran HJ). CIMMYT, El Batan, Mexico.

Chiocchio V, Venedikian N, Martinez AE, Menendez A, Ocampo JA and Godeas A. 2000. Effect of the fungicide benomyl on spore germination and hyphal length of the arbuscular mycorrhizal fungus Glomus mosseae. *International Microbiology* **3**: 173–175.

De Jong FMW, de Snoo GR and van de Zande JC. 2008. Estimated nationwide effects of pesticide spray drift on terrestrial habitats in the Netherlands. *Journal of Environmental Management* **86**(4): 721–730.

Evans S, Shaw E and Rypstra A. 2010. Exposure to a glyphosate-based herbicide affects agrobiont predatory arthropod behaviour and long-term survival. *Ecotoxicology*, pp 1-9.

Ferencz L and Balog A. 2010. A pesticide survey in soil, water and foodstuffs from central Romania. *Carpathian Journal of Earth and Environmental Sciences* **5**(1): 111–118.

FICCI 2015. Ushering in the 2nd *Green Revolution: Role of Crop Protection Chemicals, a Report on Indian Chemical Industries*, November 2015, Federation of Indian Chambers of Commerce and Industry. 51p.

Frabotta D. 2011. India herbicide market to propel to double-digit growth in crop protection value. Farm Chem, Int. **47**: 2209–2218.

Gasnier C, Dumont C, Benachour N, Clair E, Chagnon M and Seralini G. 2009. Glyphosate-based herbicides are toxic and endocrine disruptors in human cell lines. *Toxicology* **262** (3): 184–191.

Geiger F, Bengtsson J, Berendse F, Weisser WW, Emmerson M, Morales MB, Ceryngier P, Liira J, Tscharntke T, Winqvist C, Eggers S, Bommarco R, Pärt T, Bretagnolle V, Plantegenest M, Clement LW, Dennis C, Palmer C, Oñate JJ, Guerrero I, Hawro V, Aavik T, Thies C, Flohre A, Hänke S, Fischer C, Goedhart PW and Inchausti P. 2010. Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic and Applied Ecology* **11**(2): 97–105.

Gigliotti C and Allievi L. 2001. Differential effects of the herbicides Bensulphuron and Cinosulphuron on soil microorganisms. *Journal of Environmental Science and Health, Part B: Pesticides, Food Contaminants, and Agricultural Wastes* **36**(6): 775–782.

GOI 2016. *State of Indian Agriculture 2015-16*. Government of India, Ministry of Agriculture & Farmers Welfare; Department of Agriculture, Cooperation & Farmers Welfare; Directorate of Economics and Statistics, New Delhi.

Hildebrandt A, Lacorte S, Barceló D. 2009. Occurrence and Fate of Organochlorinated Pesticides and PAH in agricultural soils from the Ebro River Basin. *Archives of Environmental Contamination and Toxicology* **57**(2): 247–255.

Hossain MM. 2015. Recent perspective of herbicide: Review of demand and adoption in world agriculture. *Journal of the Bangladesh Agricultural University* **13**(1): 19–30.

http://ficci.in/study-page.asp?spid=20541&sectorid=7.

http://www.careratings.com/upload/NewsFiles/SplAnalysis/Outlook%20of%20Indian%20Pesticide%20Industry.pdf

http://www.newsagropages.com/News/NewsDetail—10649.htm.

http://www.tsmg.com/download/reports/Indian_Agrochemicals_Industry_2013.pdf.

Jiang YF, Wang XT, Jia Y, Wang F, Wu MH, Sheng GY, Fu JM. 2009. Occurrence, distribution and possible sources of organochlorine pesticides in agricultural soil of Shanghai, China. *Journal of Hazardous Materials* b(2-3): 989–997.

Koleva NG and Schneider UA. 2010. The impact of climate change on aquatic risk from agricultural pesticides in the US, *International Journal of Environmental Studies* **67**(5): 677–704.

Kreutz LC, Leonardo Jose Gil BarcellosII Tális Oliveira Silva,Deniz AnzilieroI Daiana MartinsI Monique LorensonI Ariane Marteninghe, Leonardo Bolognese da Silva 2008. Acute toxicity test of agricultural pesticides on silver catfish (*Rhamdia quelen*) fingerlings. *Ciência Rural, Santa Maria* **38**(4): 1050–1055.

Li XH, Wang W, Wang J, Cao Xl, Wang Xf, Liu JC, Liu XF, Xu XB and Jiang XN. 2008. Contamination of soils with organochlorine pesticides in urban parks in Beijing, China. *Chemosphere* **70**(9): 1660–1668.

Liebich J, Schäffer A and Burauel P. 2003. Structural and functional approach to studying pesticide side-effects on specific soil functions. *Environmental Toxicology and Chemistry* **22**(4): 784–790.

Longley M and Sotherton NW. 1997. Factors determining the effects of pesticides upon butterflies inhabiting arable farmland. *Agriculture, Ecosystems & Environment* **61**(1): 1–12.

Marutani M and Edirveerasingam V. 2006. Influence of irrigation methods and an adjuvant on the persistence of carbaryl on pakchoi. *Journal of Environmental Quality* **35**(6): 1994–1998.

Menendez A, Martínez A, Chiocchio V, Venedikian N, Ocampo JA and Godeas A. 1999. Influence of the insecticide dimethoate on arbuscular mycorrhizal colonization and growth in soybean plants. *International Microbiology* **2**: 43–45.

Mesnage R, Bernay B and Seralini GE. 2013. Ethoxylated adjuvants of glyphosate-based herbicides are active principles of human cell toxicity. *Toxicology* **313**(2-3): 122–128.

Mesnage R, Nicolas D, Joel SdV, and Gilles ES. 2014. Major Pesticides Are More Toxic to Human Cells Than Their Declared Active Principles. *BioMed Research International Volume 2014*, Article ID 179691, 8 pages (http://dx.doi.org/10.1155/2014/179691).

Moreby SJ and Southway SE. 1999. Influence of autumn applied herbicides on summer and autumn food available to birds in winter wheat fields in southern England. *Agriculture, Ecosystems & Environment* **72**(3): 285–297.

OPCI. 2014.*Outlook of Pesticide Consumption in India*.

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.

Pandey P, Khillare PS and Kumar K. 2011. Assessment of organochlorine pesticide residues in the surface sediments of river Yamuna in Delhi, India, *Journal of Environmental Protection* **2**: 511–524.

Peluso M, Munnia A, Bolognesi C and Parodi S. 1998. 32P-postlabeling detection of DNA adducts in mice treated with the herbicide Roundup. *Environmental and Molecular Mutagenesis* **31**(1): 55–59.

Philips McDougall. 2013. [Online]. Available: http://phillipsmcdougall.co.

Prasad RHR, Sreeramappa KE and Dinesha MV. 2016. Trends and growth rate of pesticide use in Indian agriculture- An economic analysis. *International Journal of Applied Research* **2**(8): 643–647.

Relyea RA. 2003. Predator cues and pesticides: a double dose of danger for amphibians. *Ecological Applications* **13**(6): 1515–1521.

Relyea RA. 2005: The lethal impact of Roundup on aquatic and terrestrial amhibians. *Ecological Applications* **15**(4): 1118–1124.

Seralini GE, Mesnage R and Defarge N. 2013. Answers to critics: why there is a long term toxicity due to NK603 Roundup tolerant genetically modified maize and to a Roundup herbicide. *Food and Chemical Toxicology* **53**: 461–468.

Shegunova P, Klanova J and Holoubek I. 2007: Residues of organochlorinated pesticides in soils from the Czech Republic. *Environmental Pollution* **146**(1): 257–261.

Sorgob MAY and Vilanova E. 2002. Enzymes involved in the detoxification of organophosphorus, carbamate and pyrethroid insecticides through hydrolysis. *Toxicology Letters* **128**: 215–228.

Stuart M, Lapworth D, Crane E and Hart A. 2012. Review of risk from potential emerging contaminants in UK groundwater, *Science of the Total Environment* **416**: 1–21.

Taylor RL, Maxwell BD and Boik RJ. 2006. Indirect effects of herbicides on bird food resources and beneficial arthropods. *Agriculture, Ecosystems & Environment* **116**(3&4): 157–164.

Toan V, Thao V, Walder J, Schmutz HR and Ha C. 2007. Contamination by Selected Organochlorine Pesticides (OCPs) in Surface Soils in Hanoi, Vietnam. *Bulletin of Environmental Contamination and Toxicology* **78**(3): 195–200.

Waliszewski S, Bermudez ME and Infanzon R. 2002. Niveles de DDT en tejido adiposo materno, suero sanguineo y leche de madres residentes en Veracruz, Mexico. *Revista Internacional de Contaminacion Ambiental* **18**: 17–25.

Waliszewski S, Meza V, Infanzon R, Trujillo PY and Morales GI. 2003. Niveles de plaguicidas organoclorados persistentes en mujeres con carcinoma mamario en Veracruz. *Revista Internacional de Contaminacion Ambiental* **19**: 59–65.

Waliszewski SM, Gomez-Arroyo S, Infanzon RM, Carvajal O, Villalobos- Pietrini R, Trujillo PY and Maxwell HM. 2004. Persistent organochlorine pesticide levels in bovine fat from México. Food Addit. Contam. **21**: 774–780.

Waliszewski SM, Gomez-Arroyo S, Infanzon RM, Villalobos-Pietrini RY and Maxwell HM 2003. Comparison of organochlorine pesticide levels between abdominal and breast adipose tissue. *Bulletin of Environmental Contamination and Toxicology* **71**: 156–162.

Walsh LP, McCormick C, Martin C and Stocco DM. 2000. Roundup inhibits steroidogenesis by disrupting steroidogenic acute regulatory (StAR) protein expression. *Environmental Health Perspectives* **108**(8): 769–776.

WAP (World Agricultural Pesticides). 2014. Industry Market Research for Business Leaders, Strategists, Decision Makers. pp 399–411.

White PJ and Kerr JT. 2007. Human impacts on environment–diversity relationships: evidence for biotic homogenization from butterfly species richness patterns. *Global Ecology and Biogeography* **16**(3): 290–299.

WHO. 2010. *The WHO Recommended Classification of Pesticides by Hazard and Guidelines to Classification 2009.* 78p.

Zhao YY and Pei YS. 2012. Risk evaluation of groundwater pollution by pesticides in China: a short review, *Procedia Environmental Sciences* **13**: 1739–1747.

Indian Journal of Weed Science **50**(3): 250–256, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Dissipation and fate of ready mix combination of pyrazosulfuron-ethyl and pretilachlor in rice field

V. Ezhilarasi, P. Janaki*, P. Murali Arthanari and C. Chinnusamy

Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641003

**Department of Soil Science and Agricultural Chemistry, Anbil Dharamalingam Agricultural College and Research Institute, Tamil Nadu Agricultural University, Trichy 620009*

**Email: janakibalamurugan@rediffmail.com*

Article information

DOI: 10.5958/0974-8164.2018.00054.0

Type of article: Research article

Received : 21 June 2018
Revised : 18 August 2018
Accepted : 7 September 2018

Key words

HPLC

GC

Persistence

Pretilachlor

Pyrazosulfuron-ethyl

Rice

ABSTRACT

Application of ready-mix herbicides containing two active ingredients in rice to manage broad group of weeds is in practice currently. Among different ready mix formulations, one comprising pyrazosulfuron-ethyl and pretilachlor have been recently registered in India. Though, the persistence of each herbicide in soil under rice as single formulation was reported, the information on persistence of herbicides from ready-mix formulations is not reported under semi-arid tropical conditions of India. Hence, an experiment was conducted to study the dissipation and fate of these ready-mix formulation herbicides in rice soil, water and in rice grain. Pyrazosulfuron-ethyl and pretilachlor residues were determined using high performance liquid chromatograph (HPLC) and gas chromatograph (GC), respectively. The average recoveries of pyrazosulfuron-ethyl and pretilachlor from matrix ranged from 80.3-103.3% with less than 10% standard deviation and sensitivity up to 0.001 µg/g. Both herbicides showed rapid dissipation in rice field water than soil and the degradation followed first order reaction kinetics. While pyrazosulfuron-ethyl dissipated with a half-life of 2.17-5.45 and 0.77-0.79 days respectively in rice field soil and water, pretilachlor dissipated with a half-life of 5.18–6.68 days in soil and 2.59–3.00 days in field water. Pyrazosulfuron-ethyl has shorter half-life than pretilachlor and both the active ingredients dissipated rapidly in rice field soil than water. At harvest, the residues of both the herbicides in rice grain and straw were below the MRLs set by FSSAI.

INTRODUCTION

Rice (*Oryza sativa* L.) is the major food crop for one-third of world's population. About 90% of its production and consumption is contributed from Asia. India accounts for 19.3 to 22.9% of its global production (Mukherjee 2006, Janaki and Chinnusamy 2012). Weed infestation is the major cause for yield reduction in rice by competing crops with nutrients, moisture, light, air, space and other micro-environment factors (Chinnusamy *et al.* 2012). Consequently, providing timely control of weeds is vital to have productive use of growth factors. Weed management by mechanical and traditional methods is not a viable option owing to non-availability of weeders and scarcity of labour during crucial periods of requirement (Janaki *et al.* 2009). Hence, weed control through chemical methods using herbicides becomes inevitable to the farmers.

Pyrazosulfuron-ethyl {ethyl 5-[(4,6-dimethoxy-pyrimidin-2-ylcarbamoyl)-sulfamoyl]-1-methyl-pyrazole-4-carboxylate} is a systemic herbicide belongs to sulfonylurea group. It can be applied as pre- or early post-emergence and has outstanding activity against a broad spectrum of annual and perennial weeds. Fate and persistence of sulfonylurea herbicides in soil are widely affected by the soil acidity, temperature, moisture content, soil microbial diversity and biochemical activity (Wang *et al.* 2013).It was almost unstable under acidic environment and hydrolysis of sulfonamide linkages the prime degradation path of pyrazosulfuron-ethyl in water (Singh and Singh 2013). It dissipates rapidly from puddled rice soil with ahalf-life1.9 days in field water and 11 days in soil (Ishii *et al.* 2004).

Pretilachlor [2-chloro-2',6'-diethyl-N-(2-propoxyethyl) acetanilide] is a pre-emergence herbicide applied to control sedges and broadleaf weeds in rice fields (WSSA 2008). It quickly degrades with a half-life of 7 to 10 days in rice soil and 3.0 to 3.6 in field water (Fajardo *et al.* 2009) by following first order dissipation kinetics. Pretilachlor degradation in soil environment was chiefly depending on soil physico-chemistry, management practices and climatic conditions (Kaur *et al.* 2015). Pretilachlor might be toxic to aquatic organisms if the residues in crops, soil and water were above the maximum residue level (Sadeghi and Imanpoor 2013; Maryam *et al.* 2013).

In recent years a number of ready mix formulations having different herbicide combinations are registered in India due to their high efficiency at low application rate. To our knowledge, little work has been published on the dissipation behavior of herbicides in ready mix formulations. A range of herbicides including ready mix combinations are available for weed control in rice. Therefore, the present research was carried out with the objectives to assess to behavior and fate of ready mix formulation of pretilachlor and pyrozosulfuron-ethyl in rice soil, water, straw and grain.

MATERIALS AND METHODS

Field experiment

Field experiment with rice as test crop was conducted during *Rabi* season at Tamil Nadu Agricultural University farm, Coimbatore, India in a randomized block design. Soil of the experimental field was clay loam in texture and has alkaline pH (8.18) and low EC (0.32dS/m) with CEC of 23.8 Cmol (p+)/kg soil. The field soil has low available N (168 kg/ha), medium available P (18.5 kg/ha), high available K (503 kg/ha) and medium organic carbon (0.53%). The granular herbicides formulation containing pyrazosulfuron-ethyl 0.15% plus pretilachlor 6.0% was applied to the rice field as pre-emergence at three doses, *viz.* 10.0, 12.5, and 20.0 kg/ha along with control plot (without herbicide application). Each treatment was replicated thrice. Sides of the each plot were protected by bunds elevated to a level of 50 cm high and 30 cm width. Herbicide was applied by knapsack sprayer with a flat fan nozzle using the water spray volume of 500 l/ha and the control plots were sprayed with water alone. Weather variables prevailed over rice experimental period was documented (**Figure 1**).

The surface soil samples of 0-15 cm were taken at random from rice experimental field on 0 (2 hrs), 1, 3, 5, 7, 15, 30 and 45 days after herbicide application and at harvest. From each treatment plot, the soil samples were taken at 5-6 spots in net plot avoiding outer 30 cm from border using auger. The collected soils from each plot were pooled and stored at -10p C prior to analysis. The water samples were collected in plastic bottles at same interval as followed for soil sampling and stored at -4p ^{0}C for analysis. The rice grain and straw samples were taken at harvest from ready-mix herbicides formulation treated and untreated plots. The rice grains were powdered by blender and straw was sliced into tiny pieces prior to residue analysis.

Chemicals, reagents and soil

The certified standards of pyrazosulfuron-ethyl and pretilachlor (purity 98%) were purchased from Sigma-Aldrich and the test granular formulation of herbicide containing pyrazosulfuron-ethyl (0.15%) and pretilachlor (6%) was obtained from M/s United

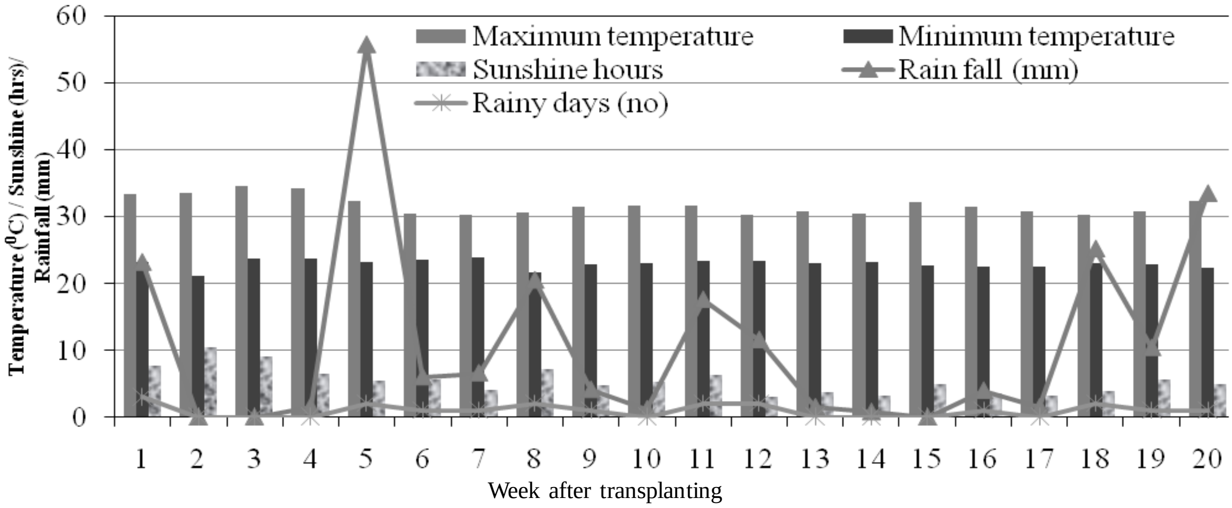

Figure 1. Weather conditions recorded during sampling period (May to September)

Phosphorus Limited, Mumbai. Analytical grade solvents and chemicals were purchased from S.D. fine chemicals, Mumbai were used for residue analysis. HPLC-grade acetonitrile, hexane and 0.2 µm filtered Milli-Q water was used for residue determination in HPLC / GC.

Instruments and operating conditions

For pyrazosulfuron-ethyl residue analysis, 1200 series liquid chromatography (Agilent Technologies, USA) equipped with diode array detector (DAD), binary pump and auto sampler was used. The computer enabled software EZChrom was used to record the chromatograms. The compound separation was achieved by Eclipse XDB – C 18 RP column with 5 µm, 4.6 x 150 mm dimension at the temperature of 30°C. The mobile phase of acetonitrile: water with 0.1% H_3PO_4 (70:30 v/v) in binary mode was used at a flow rate of 0.5 ml/min. The sample of 10 µl volume was injected and detection was performed at 236 nm.

For quantitatively analyzing the pretilachlor residue, Thermo (Chemito model GC8610) Gas Chromatograph equipped with ECD (^{63}Ni) and Computer enabled IRIS 32 software was used. The pretilachlor separation was performed using mega pore capillary column of 0.5 µm, 30 m × 0.5 mm at nitrogen gas flow rate of 10 ml/min. GC was operated in split-less mode with the sample injection volume of 0.5 µl. Temperature conditions of 210°C, 240°C and 260°C, respectively were maintained at oven, injector and detector.

Herbicides extraction

Homogenized rice grain, straw and soil samples were extracted separately for pyrazosulfuron-ethyl and pretilachlor by methanol and water (Singh *et al.* 2011; Janaki *et al.* 2012) using horizontal shaker for 1 hr. The supernatant was filtered through a Buchner funnel allowing the soil sediment to settle down. The process was repeated twice and the filtrate was combined to the same flask for partitioning and cleans up of each herbicide. The pyrazosulfuron-ethyl was partitioned using 10% NaCl and dichloromethane thrice and the pretilachlor was partitioned using 10% sodium chloride and hexane twice. The organic phase of each herbicide was dehydrated using anhydrous Na_2SO_4 and evaporated in a rotovap. The dried residues of pyrazosulfuron-ethyl and pretilachlor were re-dissolved in HPLC grade acetonitrile and hexane, respectively for chromatographic analysis.

Method validation and detection limits

Before proceeding to the main residue study, the extraction method was validated by fortifying control samples of rice grain, straw, husk and soil with known concentrations (1.00, 0.50, 0.10, 0.05 and 0.01 µg/g) of pyrazosulfuron-ethyl and pretilachlor separately as described by Singh *et al.* (2011) and Kaur *et al.* (2015). The extraction and cleanup of each herbicide was made as described in the methodology. The validated method was followed for the residue estimation in samples.

The instrument detection limit (IDL) or limit of detection (LOD) for each herbicide was assessed by repeated injections of a standard solution containing 0.005 to 1.0 µg/ml of working standards seven times. The IDL is calculated by 3:1 signal/noise ratio and replicate standard deviation. The method detection limit (MDL) or quantification limit (LOQ) was established at the signal/noise ratio of 10:1 using the fortified recovery studies.

Statistical analysis

The dissipation of both the herbicides in soil, were studied using the first-order kinetic equation

$$C = C_0^{e-kt}$$

Where, C is the amount of herbicide recovered from soil at time t, C_0 is the amount of herbicide recovered at t = 0 interval, k is the degradation constant and t is the time in days.

The time taken by molecule for 50% dissipation (DT_{50}) from its initial concentration was calculated by the formula DT_{50} = ln 2D k.

RESULTS AND DISCUSSION

LOD, recovery and LOQ

Under the standardized HPLC and GC conditions, the pyrazosulfuron-ethyl and pretilachlor was detected at 3.4 and 4.6 min respectively. The calibration curve of working standards of each herbicide was linear from 0.01 to 1.0 ìg/ml and with correlation coefficient of>0.99. The LOD was 0.001 and 0.005 µg/ml for pyrazosulfuron-ethyl and pretilachlor, respectively. The per cent mean recovery of pyrazosulfuron-ethyl from fortified rice grain, straw, water and soil respectively varied from 82.1-88.3, 80.2-89.8 and 91.0-96.1and for pretilachlor these were 83.2-85.1% and 84.5-88.8, 82.8-85.5, 86.4-97.5 and 82.5-91.6% respectively (**Table 1**). The LOQ for pyrazosulfuron-ethyl was established to

Table 1. Average recoveries of pyrazosulfuron-ethyl and pretilachlor from fortified rice grain, straw and soil

Matrix	Mean recovery (%)*±% S.D. Concentration of herbicides fortified (µg/g)				LOQ (µg/g or µg/ml)
	0.01	0.05	0.10	0.50	
Pyrazosulfuron-ethyl					
Field soil	85.13± 1.32	83.19± 1.64	83.94± 1.27	84.80± 2.29	0.05
Field water	96.14± 1.70	94.04± 1.51	95.35± 1.07	91.05± 1.16	0.001
Rice straw	81.69± 3.98	80.21± 1.09	88.66± 1.13	89.75± 1.21	0.05
Rice grain	88.32± 3.92	82.12± 1.01	82.82± 2.85	82.50± 3.93	0.05
Pretilachlor					
Field soil	83.81± 1.90	82.48± 2.01	85.93± 1.76	91.57± 2.17	0.01
Field water	86.61± 1.28	89.35± 1.32	92.81± 1.86	97.50± 2.06	0.001
Rice straw	82.82± 1.03	85.49± 1.01	83.54± 2.98	85.45± 1.86	0.03
Rice grain	88.35± 2.52	85.42± 1.91	88.81± 2.79	84.50± 3.75	0.03

*Average of three replicates; ± S.D. – Standard deviation

be 0.05 µg/g for soil, rice grain and straw and 0.001 µg/ml for water. The LOQ for pretilachlor was found to be 0.001 µg/ml for water, 0.01 µg/g for soil and 0.03 µg/g for rice grain and straw.

Dissipation of pyrazosulfuron-ethyl in rice field soil and water

The ready-mix formulation consisting pyrazosulfuron-ethyl and pretilachlor were applied to transplanted rice as pre-emergence on 3rd day after transplanting at three rates, *viz*.10, 12.5 and 20 kg/ha. Residues in rice soil were examined up to harvest after its application. Initial concentration of pyrazosulfuron-ethyl on 0th day (2 hr) was0.134, 0.173 and 0.187 µg/g of soil at 10, 12.5 and 20 kg/ha, respectively (**Table 2**). Pyrazosulfuron-ethyl residues dissipated in soil within 7 days, and were below detectable level of 0.05 µg/g after 7 days at each applied rate. On day 1, pyrazosulfuron-ethyl dissipated rapidly from soil with the rate of 40.8, 34.3 and 21.8% at the applied doses of 10, 12.5 and 20 kg/ha. On day 5, dissipation of 85.4, 78.5 and 78.8% was observed at the application rates of 10, 12.5 and 20 kg/ha. Residues of pyrazosulfuron-ethyl were below the quantification limit in soil at harvest. In rice field water, initial concentration of pyrazosulfuron-ethyl on day 0 (2 hrs) was ranged from 0.0027 to 0.0656 µg/ml across different rates of application.

Table 2. Pyrazosulfuron-ethyl persistence and dissipation in rice soil and water under different application doses of ready-mix formulation

Days after herbicide application	Rice field soil (µg/g)			Rice field water (µg/ml)		
	10.0 kg/ha	12.5 kg/ha	20.0 kg/ha	10.0 kg/ha	12.5 kg/ha	20.0 kg/ha
0 (2 hr)	0.134	0.173	0.187	0.003	0.012	0.066
1	0.111 (40.8)	0.114 (34.3)	0.146 (21.8)	0.001 (59.3)	0.005 (59.4)	0.027 (58.5)
3	0.058 (68.9)	0.093 (46.0)	0.071 (61.7)	0.001 (70.4)	0.001 (92.8)	0.015 (76.4)
5	0.027 (85.4)	0.037 (78.5)	0.039 (78.8)	<LOQ	<LOQ	0.003 (94.8)
7	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
15	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

* Average of three replicates; SD: standard deviation; figures in parentheses indicate % dissipation

More than 50 and 90% of the initial pyrazosulfuron-ethyl residue dissipated from water on day 1 and 3, respectively. The rate of disappearance of pyrazosulfuron-ethyl in water was fast at lower dose of 10 kg/ha. On day 5, residue becomes below 0.01 µg/ml at all doses of application.

The pyrazosulfuon-ethyl persistence in both soil and water follows first order reaction kinetics and accordingly the disappearance factors, *viz*. the degradation constant (k) and half-life ($T_{1/2}$) were

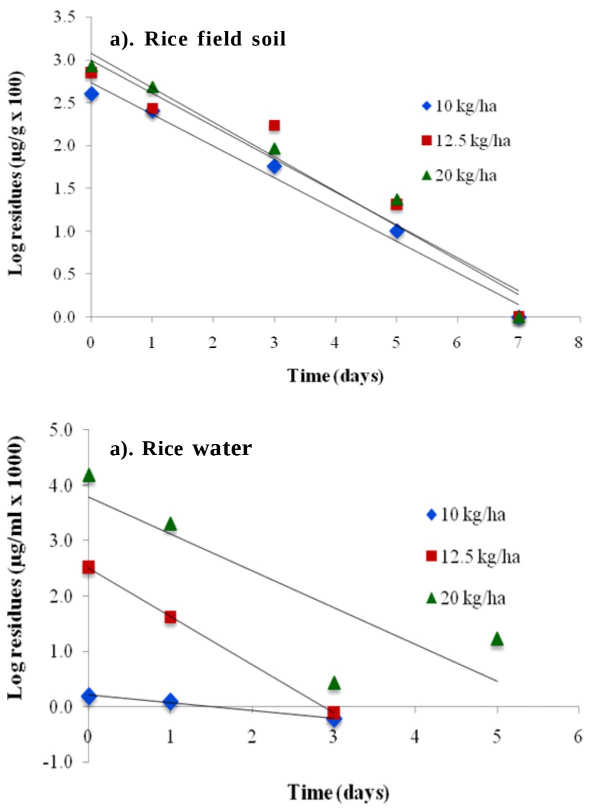

Figure 2. Linear plots of pyrazosulfuron-ethyl dissipation kinetics in rice field soil and water

calculated. The logarithmic concentration of pyrazosulfuron-ethyl against time showed good linearity in both rice field soil and water and signifying first order rate of dissipation (**Figure 2**). The calculated DT_{50} of pyrazosulfuron-ethyl in rice field soil and water ranged between 2.17-5.45 and 0.77-0.79 days, respectively (**Table 3**).

The present study revealed that the pyrazosulfuron-ethyl dissipation was fast and the observed half-life in rice soil and water was in accordance with the range reported by Singh *et al.* (2011) who reported a half-life of 0.9 and 5.4 days, respectively for water and soil in rice fields. The present findings are differing to the Ishii *et al.* (2004) who observed half-lives of 11.0 days in soil and 1.9 days in water while applied as formulation of 0.3% pyrazosulfuron-ethyl and 10% mefenacet. This could be attributed to the properties of the soil and herbicides or formulation used in the present study and climatic conditions. Higher rainfall received during the first week of herbicide application (**Figure 1**) might have augmented its hydrolysis and dissipation from soil and field water. It dissipated fast in the present study from field water with the mean half-life of 0.70 days since pH of the field water sample was above 8.0. Zheng *et al.* (2008) found that the pyrazosulfuron-ethyl hydrolysis was faster in acidic and basic aqueous solution than in neutral solution. Similarly, shorter half-life in soil could be attributed to the high soil pH (8.25) and low organic carbon (0.56%) of the experimental field.

Dissipation of pretilachlor in rice field soil and water

The dissipation behaviour of pretilachlor from ready-mix formulation in rice grown soil at all three different application doses was studied. The mean pretilachlor recovered from the rice soil and water is presented in **Table 4**. The quantity of pretilachlor residue detected on 0th day (2 hrs after application) was ranged from 0.104 – 0.247 µg/g in rice soil and 0.0122-0.0130 µg/ml in rice water at different doses of ready-mix application. The pretilachlor residue concentration at different time intervals was influenced by the doses and increased with increase in application dose. More than 50% of the initial pretilachlor concentration recovered on day 0, degraded from the water and soil, respectively on 3rd and 5th days irrespective of applied doses. This showed that the pretilachlor dissipation was fast in rice water than soil. The dissipation rate was slow at higher rate of 20 kg/ha specifically during the later period (on day 15 for soil and 5 for field water) in field water and *vice versa* in soil. On day 30 after application of ready-mix formulation, more than 90% of the initial concentration of pretilachlor dissipated from soil and degraded to below quantification limit on 45th day. However in field water, 68.5 to 73.8% of pretilachlor residue dissipation occurred on 5th day across different doses of application and then degraded to below quantification limit of 0.001µg/g. The pretilachlor dissipation rate in rice soil and water followed first order degradation kinetics at all doses of application and observed a good linear fit of pretilachlor concentration at different intervals against time (**Figure 3**). The first order degradation rate constant, coefficient of determination (R^2) and half-lives of pretilachlor in rice field soil and field water at three rates of ready-mix application are given in **Table 4**. Similar way it degraded from the field water and observed a significant correlation coefficient of 0.968 to 0.972 across the three doses of application (**Table 3**). The half-lives of pretilachlor calculated using linear equations was ranged from 5.18-6.68 days in soil and 2.59-3.00 days in field water. Similar first order kinetics for pretilachlor in rice soil was reported by Kaur *et al.* (2015) who stated that the soil physico-chemistry, management practices and climatic conditions largely influenced the pretilachlor dissipation in rice soil and water.

Table 3. Regression equation, correlation coefficient (R^2) and half-life ($t_{1/2}$) of herbicides in rice soil and water different application doses of ready-mix formulation

Dose (commercial formulation)	Rice field soil			Rice field water		
	Regression equation	R^2	Half-life (days)	Regression equation	R^2	Half-life (days)
Pyrazosulfuron-ethyl						
10.0 kg/ha	y = 2.737 - 0.370x	0.984	2.17	y =0.780 - 0.370x	0.801	0.77
12.5 kg/ha	y = 2.990 - 0.382x	0.903	2.26	y = 2.507 - 0.875x	0.999	0.77
20.0 kg/ha	y = 3.074 - 0.401x	0.964	5.45	y = 4.101 - 0.550x	0.963	0.79
Pretilachlor						
10.0 kg/ha	y = 2.257 - 0.129x	0.994	5.18	y = 2.522 - 0.284x	0.972	2.59
12.5 kg/ha	y = 2.582 - 0.099x	0.936	6.42	y = 2.565 - 0.250x	0.968	2.91
20.0 kg/ha	y = 2.888 - 0.091x	0.818	6.68	y = 2.544 - 0.237x	0.985	3.00

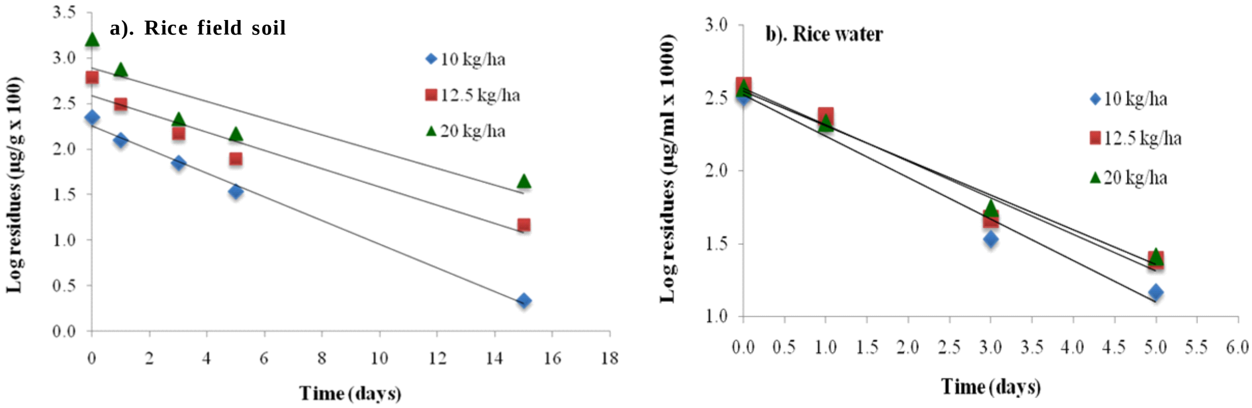

Figure 3. Linear plots of pretilachlor dissipation kinetics in rice field soil and water

Table 4. Pretilachlor persistence and dissipation in ricesoil and water under different application of doses of ready-mix formulation

Days after herbicide application	Rice field soil (µg/g)			Rice field water (µg/ml)		
	10.0 kg/ha	12.5 kg/ha	20.0 kg/ha	10.0 kg/ha	12.5 kg/ha	20.0 kg/ha
0 (2 hrs)	0.104	0.163	0.247	0.0122	0.0131	0.0130
1	0.082 (21.9)	0.121(25.8)	0.178(27.7)	0.0103 (15.5)	0.0107 (18.1)	0.0102 (21.3)
3	0.064 (39.1)	0.088(46.2)	0.103 (58.1)	0.0046 (62.2)	0.0053 (59.6)	0.0057 (56.2)
5	0.047 (55.3)	0.067(59.1)	0.088(64.5)	0.0032 (73.8)	0.0040 (69.5)	0.0041 (68.5)
15	0.015 (86.6)	0.032(80.2)	0.052 (78.9)	<LOQ	<LOQ	<LOQ
30	0.007 (93.6)	0.009(94.8)	0.010(96.1)	<LOQ	<LOQ	<LOQ
45	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ

The half-lives of pretilachlor calculated in rice soil (5.18-5.45 days) and water (2.59-3.00 days) were in line with the findings of Fajardo *et al.* (2009); Dharumarajan *et al.* (2011) and Kaur *et al.* (2015). The longer persistence of pretilachlor in soil and water than pyrazosulfuron-ethyl could be attributed to its higher sorption to soil clay particles and dissolved organic matter (Braschi *et al.* 2003). Pretilachlor half-lives obtained in the present study were lower than that recorded by Vidotto *et al.* (2004). This could be ascribed to photo-decomposition and enhanced soil microbial degradation by favorable day temperature (30.3 to 34.6 ^{0}C) and soil pH during the cropping period.

Harvest residue studies in soil, rice grain and straw

The pyrazosulfuron-ethyl and pretilachlor residues in soil at crop harvest (110 days after transplanting) was analyzed and found the concentration was below detection limit of 0.001 and 0.005 µg/g, respectively. The high temperature, clayey soil texture and high rainfall and its even distribution during the crop growing period (**Figure 3**) might have enhanced the chemical and microbial degradation of pretilachlor to below 0.005 µg/g. Similar results were reported by Kaur *et al.* (2015) for pretilachlor where the residue was below 0.01 mg/kg in rice grain. This could be due to the formation of inactive pretilachlor derivative in rice plant by its conjugation with reduced glutathione accomplished by glutathione-S-transferase enzymes (Scarponi *et al.* 2003). The maximum residue limits (MRL) of both pyrazosulfuorn-ethyl and pretilachlor residues in rice grain have not been set by European Union (EU), USDA, WHO/FAO, FFCR, Japan and PMRA, Canada, however the MRL of 0.01 and 0.05 mg/kg respectively in rice grain was set by FSSAI (2017). The detection of pyrazosulfuron-ethyl residues below MRL set by FSSAI showed that, it doesn't transported to the rice plant significantly. Rapid metabolic inactivation of the parent pyrazosulfuron-ethyl through demethylation, hydroxylation, cleavage of sulfonamide linkage etc., may have contributed to low residue level below the detection limit (Zheng *et al.* 2008). Singh and Singh (2011) studied the translocation of pyrazosulfuron-ethyl to rice aerial portions through ^{14}C activity and found that its concentration never exceeds 1% of the initial activity over a period of 25 days. Since the residue of both the herbicides in the rice grain was below MRLs set by FSSAI, ready-mix formulation containing pyrazosulfuron-ethyl and pretilachlor is considered to be non-toxic to rice crop and environment. However the indiscriminate and continuous use of these herbicides formulation in rice growing environment needs to be monitored to avoid bioaccumulation.

ACKNOWLEDGEMENTS

Authors are grateful to the Department of Agronomy, Tamil Nadu Agricultural University, India and AICRP-WM, DWR-ICAR for providing infrastructural facilities to accomplish the study.

REFERENCES

Braschi I, Pusino A and Gessa C. 2003. Adsorption-desorption of pretilachlor and cinosulfuron on rice field sediment. pp. 161–167. In: *Proceedings of the XII Symposium Pesticide Chemistry* Piacenza, Italy.

Chinnusamy C, Janaki P, Muthukrishnan P and Jeyaraman S. 2012. Long term herbicidal weed management integrated with nitrogen nutrient in transplanted rice-rice cropping system of Tamil Nadu, India. *Pakistan Journal of Weed Science Research* **18**: 95–103.

Dharumarajan S, Sankar R and Arun S. 2011. Persistence and dissipation of pretilachlor in soil, plant and water of coastal rice ecosystem. *Indian Journal of Weed Science* **43**(3&4): 199–202.

Fajardo FF, Takagi K, Ishizaka M and Usui K. 2009. Pattern and rate of dissipation of pretilachlor and mefenacet in plow layer and rice water under lowland field conditions: a three-year study. *Journal of Pesticide Science* **25**: 94–100.

FSSAI. 2017. Food safety and standards (contaminants, toxins and residues) regulations. http://www.fssai.gov.in/ Portals/ 0/Pdf/Food%20safety%20and%20standards%20 (contaminats,%20toxins%20and%20residues) %20regulation,%202011.pdf Version II (18.8.2017). Accessed July, 2018.

Ishii Y, Inao K and Kobara Y. 2004. Dissipation of some herbicides in a flooded rice field and increase of water-holding times after application of herbicides. *Bulletin of the National Institute of Agro-Environmental Sciences* **23**: 15–25.

Janaki P, Chinnusamy C and Nalini K. 2012. Adsorption and desorption behaviour of alachlor in different soils of Tamil Nadu. *Journal of the Indian Society of Soil Science* **60**(3): 230–232.

Janaki P and Chinnusamy C. 2012. Determination of metamifop residues in soil under direct-seeded rice. *Toxicological and Environmental Chemistry* **94**: 1043–1052.

Janaki P, Meena S and Chinnusamy C. 2009. Persistence and degradation of herbicides in rice, maize and soybean grown vertisols of Tamil Nadu, Southern India. In: *Proceedings of the 2nd International Conference on "Novel and Sustainable Weed Management in Arid and Semi-Arid agro Ecosystem"* held between 7th September and 10th September, 2009 at Santorini, Athens, Greece. Retrieved in http:// slideplayer.com/slide/3843757

Kaur P, Kaur P and Bhullar MS. 2015. Persistence behaviour of pretilachlor in puddled rice fields under sub-tropical humid climate. *Environmental Monitoring and Assessment* **187**: 524, DOI 10.1007/s10661-015-4756.

Maryam P, Mehdi M, Morteza S, Masood F, Abbasali Z and Firouz A. 2013. Determination of the acute toxicity of pretilachlor on liver and gill issues as well as glucose and cortisol levels in fingerling grass carps (*Ctenopharyngodon idella*). *Journal of Fisheries and Aquatic Science* **8**(6): 721-726.

Mukherjee D. 2006. Weed management strategy in rice - A review. *Agricultural Reviews* **27**(4): 247–257.

Roberts TR and Hutson DH. 1998. Metabolic Pathway of Agrochemicals: Herbicides and Plant Growth Regulators. Royal Society of Chemistry, Cambridge, UK. pp. 543–545.

Sadeghi A and Imanpoor MR. 2013. Effect of pretilachlor on the mortality of fish Gambusia. *World Journal of Zoology* **8**(3): 336–339.

Scarponi L, Buono D and Vischetti C. 2003. Persistence and detoxification of pretilachlor and fenclorim in rice (*Oryza sativa*). *Agronomie, EDP Sciences* **23**(2): 47–151.

Singh N and Singh SB. 2011. Translocation and degradation of pyrazosulfuron-ethyl in rice soil. *Pest Management Science* **67**(11): 1451–1456.

Singh N and Singh SB. 2013. Degradation behaviour of pyrazosulfuron-ethyl in water as affected by pH. *Journal of Environmental Science and Health Part B* **48**(4): 266–271.

Singh SB, Sharma R and Singh N. 2011. Persistence of pyrazosulfuron in rice-field and laboratory soil under Indian tropical conditions. *Pest Management Science* **68**: 828–833.

Vidotto F, Ferrero A, Bertoia O, Gennari M and Cignetti A. 2004. Dissipation of pretilachlor in rice water and sediment. *Agronomie* **24**(8): 473–479.

Wang Y, Du L and Bai L. 2013. Photochemical degradation of pyrazosulfuron ethyl in aqueous solution. *Journal of the Brazilian Chemical Society* **24**(1): 26–31.

WSSA.2008. Herbicide Handbook, Edited by Vencill WK, 8th Edition. Published by Weed Science Society of America, Lawrence, U.S.A. ISBN 1-891276–33–6.

Zheng W, Yates SR and Sharon KP. 2008. Transformation kinetics and mechanism of the sulfonylurea herbicides pyrazosulfuron ethyl and halosulfuron methyl in aqueous solutions. *Journal of Agricultural and Food Chemistry* **56**: 7367–7372.

Indian Journal of Weed Science 50(3): 257–261, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Pretilachlor + pyrazosulfuron-ethyl (ready-mix) against complex weed flora in transplanted rice and its residual effects

Dharam Bir Yadav*, Ashok Yadav, S.S. Punia, Narender Singh and Anil Duhan

CCS Haryana Agricultural University, Hisar, Haryana, 125 004

**Email: dbyadav@gmail.com*

Article information

DOI: 10.5958/0974-8164.2018.00055.2

Type of article: Research article

Received : 02 August 2018
Revised : 18 September 2018
Accepted : 21 September 2018

Key words

Herbicides

Pretilachlor + pyrazosulfuron

Ready-mix

Residues

Transplanted rice

Weeds

ABSTRACT

A field experiment was conducted at CCS HAU, Regional Research Station, Karnal during *Kharif* 2010 to 2014 to evaluate the bio-efficacy of pretilachlor 6.0% + pyrazosulfuron-ethyl 0.15% GR (ready-mix) against complex weed flora in transplanted rice and also to study its residual effects. Results from on-station experiment (2010 and 2011) revealed that the optimum dose of pretilachlor + pyrazosulfuron-ethyl was 615 g/ha which provided effective control (91-96%) of complex weed flora in transplanted rice, with higher grain yield (5.98-6.05 t/ha) and B-C ratio (2.19-2.28). In general, it was comparable to its higher doses, bensulfuron-methyl + pretilachlor 660 g/ha, pretilachlor 1000 g/ha, butachlor 1500 g/ha, bispyribac-sodium 25 g/ha and weed free check in terms of weed control, grain yield of rice and benefit-cost ratio. In comparison to weedy check, there was 54-57% increase in grain yield of transplanted rice under pretilachlor + pyrazosulfuron-ethyl 615 g/ha. On an average of 19 adaptive/farmers-participatory trials, pretilachlor + pyrazosulfuron-ethyl 615 g/ha proved superior to commonly used herbicides butachlor 1500 g/ha in 2013 and pretilachlor 1000 g/ha in 2014 in terms of weed control and grain yield of rice. There was no phyto-toxicity of pretilachlor + pyrazosulfuron-ethyl on transplanted rice up to 1230 g/ha (2x dose) and it was also safe to the succeeding chickpea and wheat (2011-12, 2012-13 and 2012-13) crops in rotation.

INTRODUCTION

Rice is grown over an area of about 44 mha in India with the total production of 105 m tones, amounting to 40% of the total food grain in the country (Economic Survey 2015-16). Rice-wheat is the most important cropping system covering 10.5 mha area in India and supporting 600 million people. Infestation of weeds in transplanted rice is a major problem resulting into yield reductions of 27-68% (Singh *et al.* 2003, Yadav *et al.* 2009, Manhas *et al.* 2012, Duary *et al.* 2015). Pre-emergence herbicides like butachlor, pretilachlor, anilofos and oxadiargyl are most commonly used for the control of weeds in transplanted rice. Bispyribac-sodium is also being recently used for post-emergence control of weeds in transplanted rice (Yadav *et al.* 2009). But single application of one herbicide is not that effective against complex weed flora throughout the crop season. Moreover, some of the broad-leaf weeds and sedges are not effectively controlled by alone application of these herbicides. To achieve satisfactory control of complex weed flora, farmers resort to use 2,4-D, metsulfuron + chlorimuron or ethoxysulfuron as sequential post-emergence herbicides. However, this adds to the cost of weed management. Being easy to apply, farmers' preference otherwise also remains mostly in favour of pre-emergence herbicides to achieve effective weed management at an early stage. Under such situations, more suitable option would be single shot application of ready-mix or tank-mix combination of herbicides as pre-emergence. Keeping this in view, an investigation was conducted to evaluate the performance of pretilachlor + pyrazosulfuron (ready-mix) as pre-emergence against complex weed flora in transplanted rice and also its residual effects.

MATERIALS AND METHODS

Bio-efficacy studies

A field experiment was conducted at CCS HAU Regional Research Station, Karnal during *Kharif* 2010 and 2011 to evaluate the bio-efficacy of pretilachlor 6.0% + pyrazosulfuron-ethyl 0.15% GR (Eros 6.15% GR) against complex weed flora in transplanted rice. The soil of the experimental field was low in organic carbon, medium in available phosphorus, and potassium with slightly alkaline in reaction (pH 8.2).

The treatments included pretilachlor + pyrazosulfuron-ethyl 461, 615, 769, 922 g/ha at 0-5 days after transplanting (DAT); bensulfuron-methyl + pretilachlor 660 g/ha at 0-5 DAT, pyrazosulfuron-ethyl 15 g/ha at 3-7 DAT, pretilachlor 600 g/ha at 0-5 DAT, pretilachlor 50%EC 1000 g/ha at 0-3 DAT, butachlor 1500 g/ha at 0-3 DAT, bispyribac sodium 25 g/ha, along with weed free and weedy checks. Pretilachlor + pyrazosulfuron-ethyl 1230 g/ha at 0-5 DAT was kept as an additional treatment for phyto-toxicity studies. The experiment was laid out in randomized complete block design with three replicates. HKR47 cultivar of rice was transplanted at a spacing of 20 × 15 cm on 4 July 2010 and 22 July 2011 with plot size of 5.7 × 2.4 m in 2010 and 4.7 × 2.4 m in 2011. Density and dry weight of weeds was recorded at 75 DAT. Phyto-toxicity of different herbicides on 0-10 scale was recorded at 3, 7, 15 and 30 days after application (DAA). Grain yield and yield attributes were recorded at maturity of the crop. Crop was harvested on 13 October 2010 and 27 October 2011. Benefit-cost ratio was computed as gross returns over variable cost.

Another field experiment was conducted for residual phyto-toxicity studies during 2010-11 to 2012-13, with three treatments, *viz*. pretilachlor + pyrazosulfuron-ethyl 615 g/ha, 1230 g/ha and untreated check laid out with three replications and plot size of 5.7 × 2.4 m. The herbicides were applied at 5 DAT in rice (Var. '*HKR 47*') transplanted on 4 July 2010, 22 July 2011 and 15 July 2012 with a spacing of 20 × 15 cm. After harvest of rice in October, chickpea (var. '*HC5*') and wheat (*'DPW 621-50'*) were sown on 19 November 2010, 19 November 2011, 20 November 2012 during succeeding *Rabi* seasons, using the seed rate of 40 kg/ha (row spacing 30 cm) and 100 kg/ha (row spacing 20 cm), respectively. Visual phyto-toxicity on chickpea and wheat was recorded on 0-10 scale at 15, 30, 45, 60 and 75 days after sowing (DAS).

Harvest residue studies

For harvest residue studies, three treatments, *viz*. pretilachlor + pyrazosulfuron-ethyl 615 g/ha, 1230 g/ha and untreated check were laid out with three replications with plot size of 17.5 × 12.5 m during *Kharif* 2014. Transplanting of rice cultivar '*HKR47*' was done at a spacing of 20 × 15 cm on 19 July 2014. Crop was raised as per the recommendations of the University and harvested on 3 November 2014. Soil, rice grain and straw samples were taken from the treated plots at crop harvest and were analyzed for residues in Residue Lab, Department of Agronomy, CCS HAU, Hisar.

Adaptive/farmers-participatory trials

The adaptive/farmers-participatory trials were conducted in different districts of Haryana at 19 locations each during *Kharif* 2013 and 2014. Under these adaptive trials, pretilachlor + pyrazosulfuron-ethyl 615 g/ha was compared with recommended herbicides butachlor 1500 g/ha in 2013 and pretilachlor 1000 g/ha in 2014.

Statistical analysis

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

RESULTS AND DISCUSSION

Bio-efficacy studies

Weed flora of the experimental field: The weed flora of the experimental field consisted of *Echinochloa crus-galli* (grassy), *Ammannia baccifera* broad-leaf weed (BLW), and *Cyperus difformis* and *Fimbristylis miliaceae* among sedges during *Kharif* 2010. During *Kharif* 2011, the weed flora of the experimental field consisted of *Echinochloa crus-galli, Leptochloa chinensis, Eragrostis tenella* among grasses, *Ammannia baccifera* BLW, and *Cyperus rotundus, Cyperus difformis* and *Fimbristylis miliaceae* among sedges.

Effect on weeds

Density of weeds: The density of grassy weed *Echinochloa crus-galli* at 75 DAT decreased with increase in dose of pretilachlor + pyrazosulfuron-ethyl (ready-mix) during both the years (**Table 1**). Density of *Echinochloa crus-galli* under pretilachlor + pyrazosulfuron-ethyl 615 g/ha was lower than its lower dose of 461 g/ha but at par with its higher doses, hence 615 g/ha was realized to be the optimum dose. Pretilachlor + pyrazosulfuron-ethyl 615 g/ha was superior to pyrazosulfuron-ethyl 15 g/ha, pretilachlor 600 g/ha during 2010 but at par with bensulfuron-methyl + pretilachlor (ready-mix) 660 g/ha, pretilachlor 1000 g/ha, butachlor 1500 g/ha, bispyribac-sodium 25 g/ha and weed free check in respect of density of *Echinochloa crus-galli* during both the years.

The density of BLW *Ammannia baccifera* decreased with increase in dose of pretilachlor + pyrazosulfuron-ethyl during both the years (**Table 1**). During 2010, density of *Ammannia baccifera* under pretilachlor + pyrazosulfuron-ethyl 615 g/ha was lower than its lower dose but at par with its higher doses, hence it was realized to be the optimum dose. Pretilachlor + pyrazosulfuron-ethyl 615 g/ha was superior to pretilachlor 600 g/ha, bispyribac-sodium 25 g/ha and weedy check but at par with bensulfuron-methyl + pretilachlor 660 g/ha, pretilachlor 100 g/ha, butachlor 1500 g/ha and weed free check in respect of density of *Ammannia baccifera*. During 2011, density of BLW at 75 DAT under pretilachlor + pyrazosulfuron-ethyl 615 g/ha was lower than its lower dose (461 g/ha), pretilachlor 600 g/ha and weedy check but at par with all other herbicidal treatments.

The density of sedges decreased with increase in dose of pretilachlor + pyrazosulfuron-ethyl. The density of sedges under pretilachlor + pyrazosulfuron-ethyl 615 g/ha was at par with all other herbicidal treatments and weed free check (**Table 1**). Pretilachlor 750 g/ha + pyrazosulfuron-ethyl 25 g/ha as tank-mix application at 3 DAT has already been reported very effective in reducing density of complex weed flora in transplanted rice elsewhere (Teja *et al.* 2016).

Dry weight of weeds: The dry weight of grassy weeds decreased with increase in dose of pretilachlor + pyrazosulfuron-ethyl during both the years (**Table 2**). All the doses of pretilachlor + pyrazosulfuron-ethyl were at par with each other. During 2010, pretilachlor + pyrazosulfuron-ethyl 615 g/ha was superior to pyrazosulfuron-ethyl 15 g/ha, pretilachlor 600 g/ha and weedy check but at par with bensulfuron-methyl + pretilachlor 660 g/ha, pretilachlor 1000 g/ha, butachlor 1500 g/ha, bispyribac sodium 25 g/ha and weed free check in respect of dry weight of grassy weeds. During 2011, dry weight of *E. crus-galli* under pretilachlor + pyrazosulfuron-ethyl 615 g/ha was at par with all other herbicidal treatments except being superior to pyrazosulfuron-ethyl 15 g/ha. Dry weight of other grassy weeds (*Leptochloa chinensis, Eragrostis tenella*) was similar under all the treatments during 2011.

The dry weight of BLW decreased with increase in dose of pretilachlor + pyrazosulfuron-ethyl during both the years (**Table 2**). During 2010, dry weight of BLW under pretilachlor + pyrazosulfuron-ethyl 615 g/ ha was lower than its lower dose (461 g/ha), but at par with its higher doses, hence it was realized to be the optimum dose (**Table 2**). Pretilachlor + pyrazosulfuron-ethyl 615 g/ha was superior to pretilachlor 600 g/ha and weedy check but at par with bensulfuron-methyl + pretilachlor 660 g/ha, pretilachlor 1000 g/ha, butachlor 1500 g/ha, bispyribac-sodium 25 g/ha and weed free check in respect of dry weight of BLW. However, during 2011, dry weight of BLW under pretilachlor + pyrazosulfuron-ethyl 615 g/ha was at par with all herbicidal treatments except being lower than pretilachlor 600 g/ha and bispyribac-sodium 25 g/ha, and also weedy check.

The dry weight of sedges decreased with increase in dose of pretilachlor + pyrazosulfuron-ethyl during both the years (**Table 2**). Pretilachlor + pyrazosulfuron-ethyl 615 g/ha was at par with all other treatments except being superior to pretilachlor 600 g/ha and weedy check.

Based on two years data, the optimum dose of pretilachlor + pyrazosulfuron-ethyl was realized to be

Table 1. Effect of pretilachlor + pyrazosulfuron-ethyl on density of weeds (no./m^2) in transplanted rice (2010 and 2011)

Treatment	Dose (g/ha)	*Echinochloa crus-galli*		Other grass weeds	Broad-leaf weeds		Total sedges	
		2010	2011	2011	2010	2011	2010	2011
Pretilachlor + pyrazosulfuron-ethyl	461	2.63(6.0)	2.58(6.0)	1.41(1.3)	8.36 (70.0)	6.37(40.0)	1.00 (0.0)	3.83(15.3)
Pretilachlor + pyrazosulfuron-ethyl	615	1.41(1.3)	1.66(2.0)	1.00(0.0)	5.73 (32.7)	4.79(22.0)	1.00 (0.0)	2.19(6.7)
Pretilachlor + pyrazosulfuron-ethyl	769	1.00(0.0)	1.41(1.3)	1.00(0.0)	5.35 (30.0)	4.65(20.7)	1.00 (0.0)	2.27(7.3)
Pretilachlor + pyrazosulfuron-ethyl	922	1.00(0.0)	1.00(0.0)	1.00(0.0)	4.73 (22.0)	4.59(21.3)	1.00 (0.0)	1.00(0.0)
Bensulfuron-methyl + pretilachlor	660	1.90(2.7)	1.82(2.7)	1.41(1.3)	6.19 (37.3)	4.79(22.0)	1.00 (0.0)	2.56(6.0)
Pyrazosulfuron-ethyl	15	3.93(14.7)	3.95(14.7)	1.24(0.7)	5.10 (26.7)	4.16(16.7)	1.00 (0.0)	1.00(0.0)
Pretilachlor	600	2.75(6.7)	2.07(3.3)	1.00(0.0)	8.06 (64.0)	6.68(44.0)	1.67 (2.7)	3.88(14.7)
Pretilachlor	1000	1.41(1.3)	1.82(2.7)	1.00(0.0)	6.79 (46.0)	4.65(20.7)	1.00 (0.0)	2.18(4.7)
Butachlor	1500	1.49(1.3)	1.49(1.3)	1.00(0.0)	7.20 (51.3)	4.91(23.3)	1.00 (0.0)	1.00(0.0)
Bispyribac-sodium	25	1.00(0.0)	1.41(1.3)	3.28(10.0)	6.51 (42.0)	6.18(37.3)	1.00 (0.0)	1.00(0.0)
Weed free	-	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00 (0.0)	1.00(0.0)	1.00 (0.0)	1.00(0.0)
Weedy check	-	5.39(28.0)	5.31(28.7)	3.50(11.3)	12.31 (151.3)	10.31(105.3)	3.65 (13.3)	4.51(19.3)
LSD (p=0.05)		0.68	1.17	0.64	1.92	1.04	0.78	1.78

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

615 g/ha with weed control efficacy of 91-96%. In general, it was comparable to its higher doses, bensulfuron-methyl + pretilachlor 660 g/ha, pretilachlor 1000 g/ha, butachlor 1500 g/ha, bispyribac-sodium 25 g/ha and weed free check. Pretilachlor 750 g/ha + pyrazosulfuron-ethyl 25 g/ha as tank-mix application at 3 DAT has already been reported very effective in reducing biomass of complex weed flora in transplanted rice elsewhere (Teja *et al*. 2016). Pre-emergence application of herbicides in combination has been reported very effective against complex weed flora in transplanted rice earlier also (Manhas *et al*. 2012, Kumar *et al*. 2014, Duary *et al*. 2015, Teja *et al*. 2015).

Effect on crop

Number of effective tillers/mrl under pretilachlor + pyrazosulfuron-ethyl 615 g/ha was at par with all other treatments except being superior to pyrazosulfuron-ethyl 15 g/ha and weedy check during both the years (**Table 3**). Grain yield of rice under pretilachlor + pyrazosulfuron-ethyl 615 g/ha was higher than its lower dose (461 g/ha) but at par with its higher doses (769 and 922 g/ha), indicating it to be the optimum dose. Pretilachlor + pyrazo-sulfuron-ethyl 615 g/ha (5.97-6.05 t/ha) provided grain yield of rice at par with bensulfuron-methyl + pretilachlor 660 g/ha, pretilachlor 1000 g/ha, butachlor 1500 g/ha, bispyribac-sodium 25 g/ha and weed free check (5.87-6.27 t/ha). Pretilachlor + pyrazosulfuron-ethyl 615 g/ha resulted in grain yield of rice higher than pyrazosulfuron-ethyl 15 g/ha and weedy check during both the years and pretilachlor 600 g/ha during 2010.

In comparison to weedy check, there was 54-57% increase in grain yield of transplanted rice under pretilachlor + pyrazosulfuron-ethyl 615 g/ha, 53-54% at 769 g/ha and 52-57% at 922 g/ha, 54% under bensulfuron-methyl + pretilachlor 660 g/ha, 44-45% under pretilachlor 600 g/ha, 54-56% under pretilachlor 1000 g/ha, 54-55% under butachlor 1500 g/ha, 51-57% under bispyribac-sodium 25 g/ha,16-25% under pyrazosulfuron-ethyl 15 g/ha and 60-64% under weed free check during both the years. Teja *et al.* (2016) have also reported grain yield of transplanted rice in pretilachlor 750 g/ha + pyrazosulfuron 25 g/ha treated plots (3 DAT) similar to weed free/two hand weeding. Effective management of complex weeds consequently resulting into higher yields of transplanted rice due to combined application of herbicides has been realized earlier also (Kumar *et al*. 2014, Duary *et al*. 2015, Teja *et al*. 2015).

Economics: Pretilachlor + pyrazosulfuron-ethyl 615 g/ha provided B: C ratio (benefit:cost ratio) (2.19 in 2010 and 2.28 in 2011) better than its other doses of 461 g/ha and 922 g/ha, pyrazosulfuron-ethyl 15 g/ha, pretilachlor 600 g/ha, weed free and weedy checks (**Table 3**). Pretilachlor + pyrazosulfuron-ethyl 615 g/ha provided B:C ratio similar to its higher dose of 769 g/ha, pretilachlor 1000 g/ha, butachlor 1500 g/ha, bispyribac-sodium 25 g/ha and bensulfuron + pretilachlor 660 g/ha during both years.

Crop phyto-toxicity and residue

There was no phyto-toxicity at 3, 7, 15 and 30 days after application of pretilachlor + pyrazo-sulfuron-ethyl at any of its doses up to 1230 g/ha on transplanted rice crop during both the years (data not given). Similarly, there was no crop phyto-toxicity due to any of other herbicidal treatments.

Residual phyto-toxicity on succeeding crop and Harvest residues: There was no residual phyto-toxicity of pretilachlor + pyrazosulfuron-ethyl at 615 and 1230 g/ha at 15, 30, 45, 60 and 75 DAS on the succeeding chickpea and wheat crops (2010-11, 2011-12 and 2012-13) at any stage indicating its safety even at 2X dose to these crops in rotation (data not given). No harvest residues of pretilachlor and

Table 2. Effect of pretilachlor + pyrazosulfuron-ethyl on dry weight of weeds (g/m^2) in transplanted rice (2010 and 2011)

Treatment	Dose (g/ha)	*Echinochloa crus-galli*		Other grass weeds	BLW		Sedges	
		2010	2011	2011	2010	2011	2010	2011
Pretilachlor + pyrazosulfuron-ethyl	461	27.3	45.3	3.5	5.5	2.4	0.0	1.2
Pretilachlor + pyrazosulfuron-ethyl	615	15.2	30.5	0.0	2.8	1.3	0.0	0.5
Pretilachlor + pyrazosulfuron-ethyl	769	0.0	18.8	0.0	2.1	1.5	0.0	0.4
Pretilachlor + pyrazosulfuron-ethyl	922	0.0	0.0	0.0	2.2	0.7	0.0	0.0
Bensulfuron-methyl + pretilachlor	660	23.1	30.0	0.2	3.1	1.4	0.0	0.6
Pyrazosulfuron-ethyl	15	262.1	203.0	3.9	2.1	0.5	0.0	0.0
Pretilachlor	600	65.7	42.1	0.0	5.0	2.9	1.3	1.3
Pretilachlor	1000	14.1	15.8	0.0	3.6	0.9	0.0	0.5
Butachlor	1500	14.7	19.2	0.0	3.0	1.3	0.0	0.0
Bispyribac-sodium	25	0.0	0.9	3.4	3.3	2.9	0.0	0.0
Weed free	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weedy check	-	392.5	337.9	5.3	8.9	5.7	4.4	3.6
LSD (p=0.05)		26.7	41.0	NS	0.9	1.5	1.2	0.8

Table 3. Effect of pretilachlor + pyrazosulfuron-ethyl on yield and yield attributes of transplanted rice (*Kharif* 2010 and 2011)

Treatment	Dose (g/ha)	Effective tillers/ mrl		Grain yield (t/ha)		B-C ratio	
		2010	2011	2010	2011	2010	2011
Pretilachlor + pyrazosulfuron-ethyl	461	53.5	52.0	5.43	5.30	2.01	1.98
Pretilachlor + pyrazosulfuron-ethyl	615	58.8	57.7	5.98	6.05	2.19	2.28
Pretilachlor + pyrazosulfuron-ethyl	769	59.2	56.8	5.99	6.06	2.18	2.27
Pretilachlor + pyrazosulfuron-ethyl	922	59.3	57.8	6.00	5.96	2.16	2.21
Bensulfuron-methyl + pretilachlor	660	58.8	57.8	5.87	5.99	2.15	2.26
Pyrazosulfuron-ethyl	15	43.8	44.7	4.43	4.87	1.66	1.87
Pretilachlor	600	53.0	53.2	5.49	5.67	2.05	2.17
Pretilachlor	1000	59.5	59.5	5.95	6.04	2.19	2.29
Butachlor	1500	58.0	59.7	5.91	6.03	2.20	2.31
Bispyribac-sodium	25	58.0	60.2	6.00	5.93	2.15	2.19
Weed free	-	63.2	61.3	6.25	6.27	1.91	1.89
Weedy check	-	39.3	37.8	3.81	3.92	1.46	1.53
LSD (p=0.05)		6.10	6.20	0.43	0.53		

Table 4. Performance of pretilachlor + pyrazosulfuron-ethyl against weeds in transplanted rice under adaptive/ farmer-participatory trials (average of 19 locations each in *Kharif* 2013 and 2014)

Treatment	Weed control (%)		Grain yield (t/ha)	
	2013	2014	2013	2014
Pretilachlor + pyrazosulfuron-ethyl 615 g/ha	78(94)	77(94)	6.51	5.37
Butachlor 1500 g/ha	68(85)	-	6.34	-
Pretilachlor 1000 g/ha	-	69(87)	-	5.05
LSD (p=0.05)	4.6	1.3	0.06	0.08

*Original figures in parenthesis were subjected to angular transformation before statistical analysis.

Locations in 2013 (19): 2 (Gabipur and Barwala), 5 (Pirthala), 3(2-Dhani Lehranwali and Kala Grewal), 3 (2-Batta and Teek), 3 (2-Barhi and Sukhrahon), 1 (Chanarthal) and 2 (Khanpur and Sagga) in Hisar, Fatehabad, Sirsa, Jind, Kaithal, Ambala, Kurukshetra and Karnal districts of Haryana, respectively.

Locations in 2014 (19): 1 (Bithmada), 2 (Nangla), 3 (Dhani Kahan Singh and 2-Rania), 2 (Danoda), 4 (Kingan, Bhagal, Teek and Kheri Raiwali), 2 (Thana and Chanarthal), 2 (Danoura and Landa), 1 (Saidu Pur) and 2 (Majri Jattan) in Hisar, Fatehbad, Sirsa, Jind, Kaithal, Kurukshetra, Ambala, Yamuna Nagar and Punchkula districts of Haryana, respectively.

pyrazosulfuron-ethyl were detected in rice grain, straw and soil samples drawn from plots treated with pretilachlor + pyrazosulfuron-ethyl 615 and 1230 g/ha, indicating its safety up to 2X dose.

Adaptive trials

Based on average of 19 locations, pretilachlor + pyrazosulfuron-ethyl 615 g/ha provided better control of complex weed flora (93.9% in 2013 and 94.2% in 2014) and higher gain yield (6.50 t/ha in 2013 and 5.37 t/ha in 2014) in transplanted rice than the already recommended herbicides butachlor 1500 g/ha (85%, 6.34 t/ha in 2013) and pretilachlor 1000 g/ha (87%, 5.05 t/ha in 2014) (**Table 4**).

It may be concluded that pretilachlor + pyrazosulfuron (RM) 615 g/ha at 0-5 DAT could safely be used for control of complex weed flora in transplanted rice.

REFERENCES

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

Economic Survey. 2015-16. Ministry of Finance, Govt. of India. http://indiabudget.nic.in/budget2016-17/es2014-15/echapter-vol2.pdf (accessed 17.12.2017), Vol-II, pp. 100.

Kumar N, Nandal DP and Punia SS. 2014. Efficacy of post-emergence herbicides for weed control in transplanted rice. *Indian Journal of Weed Science* **46**(4): 380–382.

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

Sheoran OP, Tonk DS, Kaushik LS, Hasija RC and Pannu RS. 1998. Statistical Software Package for Agricultural Research Workers. pp 139–143. In: *Recent Advances in Information Theory, Statistics & Computer Applications* (Eds. DS Hooda & RC Hasija). CCS HAU, Hisar.

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

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

Teja KC, Duary B, Kumar M and Bhowmick MK. 2015. Effect of bensulfuron-methyl + pretilachlor and other herbicides on mixed weed flora of wet season transplanted rice. *International Journal of Agriculture, Environment and Biotechnology* **8**(2): 323–329.

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

Indian Journal of Weed Science **50**(3): 262–268, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Impact of crop intensification and establishment techniques on weed dynamics under different cropping systems

Indu Bala Sethi*, Rohitashav Singh, V.K. Singh, Sumit Chaturvedi, Ajit Pratap Singh, Dushyant Prabhakar and Jodh Pal Singh

G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand 263 145

Email: indubalasethia2012@gmail.com

Article information

DOI: 10.5958/0974-8164.2018.00056.4

Type of article: Research article

Received : 21 April 2018
Revised : 16 June 2018
Accepted : 7 August 2018

Key words

Crop establishment

Intensification

Land configurations

Rice-wheat system

Weed dynamics

ABSTRACT

The field experiments were conducted during 2015-16 and 2016-17 at Norman E. Borlaug Crop Research Center, Pantnagar G.B Pant University of Agriculture & Technology, Pantnagar, U.S. Nagar (Uttarakhand) India, to study the crop intensification and establishment techniques influence on weed dynamics under irrigated rice-wheat system**.** In *Kharif* season, density of total weeds as well as grasses, broad-leaved weeds and sedges was observed lowest in rice – wheat cropping system. Transplanted rice-vegatable pea- groundnut cropping sequence proved superior over those cropping systems where upland direct-seeded rice was included as one of the crop with respect to control of *Kharif* season weeds. In *Rabi* season, maize (B) (cob + fodder) + cowpea (B) + Sesbania (F)-2:1:2 - vegetable pea (B) + toria (F)-3:1 – groundnut (B) + mentha (F)-3:1(BBF 105 x 30 cm)] proved to be the most prominent cropping system for controlling broad-leaved weeds and sedges. All the cropping systems proved superior for the control of grassy weeds (*Phalaris minor* and *Avena fatua*) in which there was inclusion of either legumes or oilseed crops in place of wheat. During summer season, soybean (B) + rice (DSR) (F)-2:1 – wheat (B) + mentha (F) (3:1) - continue (NBS 60 x 30 cm) cropping system was found better for the control of complex weed flora

INTRODUCTION

Weed dynamics is severely affected by cropping system and establishment techniques. Continues cultivation of same crop year after year the weed population will be same. Crop rotations affect seed banks because weed control measures change with successive crops (Ball 1992). Weeds that survive and produce seeds in one crop contribute to the seed bank from which weed seedlings are recruited in successive crops. Because of greater variability in the type and timing of soil, crop, and weed management practices, there are more opportunities for weed mortality events in rotations than in monoculture (Martin and Felton 1993). However, this variability may also provide more chances for successful weed emergence, establishment, and seed production in rotations than in monoculture (Dorado *et al.* 1999). Manipulation of cropping systems for the purpose of improving integrated weed management requires a good understanding of weed dynamics and influences of crop- and soil-related factors on weed life cycles (Davis and Liebman 2003). Weed flora have changed over the past century, with either increasing or decreasing species abundance depending on the management (Bagmet 2000, Marshall *et al.* 2003, Stoate *et al.* 2002). Changes in crop rotation and herbicide use could change the weed seed banks in arable soils (Squire *et al.* 2000). Rotations comprised of two cool-season crops followed by two warm-season crops are the most disruptive of weed population growth. The impact of rotation design on weed community density is enhanced by no-till. Crop tolerance to weeds is improved by systems of cultural tactics. The tolerance is greatest when three tactics are combined together (Anderson 2007). Replacing spring cereals with winter cereals resulted in a 25% reduction in weed density and species diversity (Hald 1999). Considering plants with allelopathic effects such as rye and triticale permits sustainable weed management while, reducing the impact of agriculture on the environment (Tabaglio *et al.* 2008). Crop intensification and establishment techniques important to influence the weed dynamics. Keeping the above aspects in view, the present investigation

"Impact of crop intensification and establishment techniques on weed dynamics under different cropping systems" has been planned with the objective to study impact of crop intensification and establishment techniques on weed dynamics and reduce the weed dynamics by increase cop intensification and using establishment techniques.

MATERIALS AND METHODS

A field experiment was conducted during 2015-16 and 2016-17 at Norman E. Borlaug Crop Research Center, G.B Pant University of Agriculture & Technology, Pantnagar, U.S. Nagar (Uttarakhand) India, situated 29^0 1' N latitude, 79^0 29' E longitudes and an altitude of 243.83 m above mean sea level, which lies in the Tarai belt of Shivalik range of Himalayan foot hills to study crop intensification and establishment techniques to enhance productivity under irrigated rice-wheat system. The soil of experimental field was loam in texture, high in organic carbon (0.80), low in available nitrogen (260.4 kg/ha), high in phosphorus (29.6 kg/ha) and medium in potassium (203.9 kg/ha) with neutral in pH (7.33).

The experiment was laid out in a randomized block design with nine treatments, *viz.*, [rice (transplanted -TPR) – wheat], [rice (TPR) - vegetable pea – groundnut], [rice (direct seeded rice-DSR) - vegetable pea - maize (grain)], [rice (DSR) - potato -cowpea (vegetable + fodder)], [rice (DSR) - vegetable pea - maize (cob + fodder)], [rice (DSR) - yellow sarson – cowpea], [rice (DSR) (bed) + sesbania (furrow)- 2:1 -vegetable pea (bed) + toria (furrow)-2:1 - maize (bed (B)) (cob + fodder) + mentha (furrow (F))1:1, (furrow irrigated raised bed (FIRB), 45cm x 30 cm)], [soybean (bed) + rice (DSR) (furrow)-2:1 - wheat + mentha (3:1) - continue (narrow bed system (NBS), 60 x 30 cm)], [maize (bed) (cob + fodder) + cowpea (vegetable) (bed) + Sesbania (furrow)-2:1:2 - vegetable pea + toria-3:1 - groundnut + mentha-3:1(broad bed furrow (BBF) 105 x 30 cm)] and replicated thrice. The crops were sown as per the package of practices recommended for different crops. The nine cropping sequence were evaluated for productivity. '*HKR-47*' variety of rice, '*UP-2572*' variety of wheat, '*Kashi kanchan*' variety of cowpea, '*Suvarna*' variety of maize (cob + fodder), '*Arkle*' variety of vegetable pea, '*Uttara*' variety of toria, '*Kufri Bahar (3797)*' variety of potato, '*PS-1024*' variety of soybean, '*PPS-1* 'variety of yellow mustard, '*ICGS-11*' variety of groundnut and '*Kosi*' variety of mentha were used in experimentation.

Weed dynamics was observed in terms of weed density recorded species wise just before the execution of first hand weeding or before the application of post - emergence herbicides during both years by using a quadrate of size 0.5 x 0.5 m (0.25 m^2). Weed count was expressed as number per meter square.

RESULTS AND DISCUSSION

Weed flora of experimental field were collected, identified, and classified as grasses, sedges and broad-leaved weeds. There were 19 weed species (grassy 7, broad-leaved weeds 10, and sedges 2) in experimental field (**Table 1**).

Weed density

Density of individual weed was recorded before the execution of first hand weeding or application of post - emergence herbicide in crops. Large variations were observed in weed density under different cropping systems.

Grassy weeds

The data related to density of grassy weeds in *Kharif, Rabi and* summer season are given (**Table 2**). This was significantly influenced by crop intensification and establishment techniques. In *Kharif* season, among the grasses, the lowest value of density of *Echinochloa colona*, *Eleusine indica*, *Leptochloa chinensis*, *Digitaria sanguinalis* and *Echinochloa cru-galli* were recorded in treatment rice – wheat cropping system during 2015 and 2016. This was at par with treatment of rice - vegetable pea-groundnut cropping system during both years.

It might be due to rice raised through transplanting method because puddling of soil required for rice transplanting caused churning of weed flora present in the field, therefore population of weeds get minimized. Results confirmed with the findings of Bhurer *et al.* (2013) who reported that puddling benefits rice by reducing water percolation losses, controlling weeds, facilitating easy seedling establishment and creating anaerobic conditions to enhance nutrient availability. Aerobic systems are subjected to much higher weed pressure than conventional puddled transplanting system (Rao *et al.* 2007) in which weeds are suppressed by standing water and by transplanted rice seedlings, which have a "head start" over germinating weed seedlings (Moody 1983). The grasses were the most damaging weeds in the rice-pea-rice system, even more than in the rice-wheat system (Singh and Singh 2004).

Table 1. Weed flora of experimental field during 2015-16 and 2016-17

Scientific name	Family	English name	Local name
Grassy weeds			
Avena fatua	Poaceae	Wild oat	Jangli jai
Digitaria sanguinalis	Poaceae	Crab grass	Jhernia grass/Seur
Echinochloa colona	Poaceae	Jungle rice	Sai / Chhoti sai
Echinochloa cru-galli	Poaceae	Barn yard grass	Sanwa /Daura/Sawan/kodon
Eleusine indica	Poaceae	Goose grass	Jangli mandua/Mandla/ Balrara
Leptochloa chinensis	Poaceae	Red sprangle top	-
Phalaris minor	Poaceae	Little seed canary grass	Gulli danda/ Gehu ka mama
Broad-leaved weeds			
Alternanthera sessilis	Amaranthaceae	Alligator weed	Gadani
Anagallis arvensis	Primulaceae	Pimper -nel, scarlet	Krishna neel
Celosia argentia	Amaranthaceae	Cocks comb	Safed murga
Chenopodium album	Chenopodiaceae	Lambs quarter	Bathua/Bathu
Coronopus didymus	Brassicaceae	Swine cress	Jangli balu/jangli taratez
Melilotus species	Febaceae	Clover	Senji
Rumex dentatus	Polygonaceae	Sour dock	Jangli palak
Solanum nigrum	Solanaceae	Black night shade	Makoy/kakmoch
Trianthema monogyna	Aizoaceae	Giant pig weed, Horse purslane	Patherchatta /Santhi
Vicia sativa	Febaceae	Vetch	Ankari
Sedges			
Cyperus rotundus	Cyperaceae	Purple nut sedge	Motha
Cyperus iria	Cyperaceae	Yellow sedge/Flat sedge	Dachab/Gal motha

Table 2. Effect of crop intensification and establishment techniques on grassy weed density

Treatment	Grassy weeds (no./m^2)															
	Kharif										*Rabi*				Summer	
	E. colona		*E. indica*		*L. chinensis*		*D. sanguinalis*		*E. crus-galli*		*P. minor*		*A. fatua*		*D. sanguinalis*	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015-16	2016-17	2015-16	2016-17	2015	2016
Rice (TPR) – Wheat	2.41 (5.3)	2.67 (6.7)	1.34 (1.3)	1.74 (2.7)	1.34 (1.3)	1.76 (2.7)	1.34 (1.3)	1.76 (2.7)	1.34 (1.3)	1.72 (2.7)	4.52 (20.0)	4.67 (21.3)	4.06 (16.0)	4.22 (17.3)	-	-
Rice (TPR) - Vegetable pea – Groundnut	2.91 (8.0)	3.13 (9.3)	1.74 (2.7)	2.11 (4.0)	1.77 (2.7)	2.11 (4.0)	2.12 (4.0)	2.41 (5.3)	1.74 (2.7)	2.11 (4.0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	10.29 (105.3)	10.48 (109.3)
Rice (DSR) –Vegetable pea – Maize grain	7.43 (54.7)	7.6 (57.3)	3.33 (8.0)	2.91 (10.7)	3.13 (9.3)	3.33 (10.7)	4.94 (24.0)	5.20 (26.7)	3.33 (10.7)	3.70 (13.3)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	10.66 (113.3)	10.82 (117.3)
Rice (DSR) - Potato -Cowpea (vegetable)	7.24 (52.0)	7.52 (56.0)	2.67 (6.7)	2.91 (8.0)	3.13 (8.0)	2.88 (9.3)	4.79 (22.7)	5.07 (25.3)	3.13 (9.3)	3.34 (10.7)	1.34 (1.3)	0.71 (0)	0.71 (0)	0.71 (0)	10.54 (110.7)	10.98 (120.0)
Rice (DSR) - Vegetable pea - Maize (cob + fodder)	7.86 (61.3)	8.11 (65.3)	2.89 (8.0)	3.10 (9.3)	2.91 (8.0)	3.53 (12.0)	4.95 (24.0)	5.21 (26.7)	3.34 (10.7)	3.53 (12.0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	10.66 (113.3)	11.21 (125.3)
Rice (DSR) - Yellow Sarson – cowpea(vegetable + green manure)	7.41 (54.7)	7.69 (58.7)	2.67 (6.7)	2.92 (8.0)	3.34 (9.3)	3.13 (10.7)	4.81 (22.7)	4.95 (24.0)	3.13 (9.3)	3.53 (12.0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	10.61 (112.0)	11.03 (121.3)
Rice (DSR) (B) + *Sesbania* (F)- 2:1 (FIRBS 45cm * 30 cm) -Vegetable pea (B) + Toria (F)-2:1 (FIRBS) - Maize (B) (cob + fodder) + Mentha (F)1:1(FIRBS)	6.57 (42.7)	6.86 (46.7)	2.40 (5.3)	2.66 (6.7)	2.41 (5.3)	2.41 (5.3)	3.34 (10.7)	3.53 (12.0)	2.41 (5.3)	2.68 (6.7)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	9.62 (92.0)	10.07 (101.3)
Soybean (B) + Rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - Wheat + Mentha (3:1) (NBS 60 x 30 cm) - Continue (NBS 60 x 30 cm	6.84 (46.7)	7.43 (54.7)	2.67 (6.7)	2.67 (6.7)	2.68 (6.7)	2.91 (8.0)	3.34 (10.7)	3.53 (12.0)	2.68 (6.7)	2.91 (8.0)	4.05 (16.0)	4.22 (17.3)	2.9 (8.0)	2.91 (8.0)	0.71 (0)	0.71 (0)
Maize (B) (cob + fodder) + Cowpea (B) + *Sesbania* (F)-2:1:1 (BBF 105 x 30 cm) - Vegetable pea + Toria-3:1 (BBF) - Groundnut + Mentha-3:1(BBF)	6.47 (41.3)	6.76 (45.3)	2.08 (4.0)	2.60 (6.3)	2.11 (4.0)	2.41 (5.3)	3.12 (9.3)	3.34 (10.7)	2.40 (5.3)	2.66 (6.7)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	8.75 (76.0)	9.30 (86.7)
LSD (p=0.05)	0.54	0.48	0.64	0.59	0.27	0.49	0.49	0.47	0.42	0.43	0.32	0.19	0.22	0.10	0.37	0.98

Original values given in parentheses was subjected to square root $(\sqrt{x+1})$ransformation before analysis; B - bed; F - furrow; NBS - narrow bed system; BBF - broad bed furrow; FIRB - furrow irrigated raised bed

In *Rabi* season, among the grasses, the density of *Phalaris minor* was recorded significantly higher in puddled transplanted Rice (TPR) – wheat treatment, which might be due to dominance of *P. minor* in wheat crop over the other species. Similarly, Walia *et al*. (1997) also reported that grassy weeds like *P. minor* were maintaining its dominance in wheat crop since last three decades *i.e.* from the era of introduction of Mexican wheat crop. The density of this weed was lower in all other treatments. Density of *A. fatua* was also recorded significantly higher in TPR – wheat treatment during both the years, which might be due to inclusion of wheat crop of same nature which provides favourable environment to this weed. The other treatments recorded significantly lower weed density of *A. fatua* than TPR – wheat were soybean (bed) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm. Similarly, it could be due to growth of wheat associated weed *A. fatua,* which was raised on bed, which might had helped to reduce the weeds (Das 2008).

Among the grasses, in summer season density of *Digitaria sanguinalis* was recorded significantly higher in rice (DSR) - vegetable pea - maize (cob + fodder) during 2015 and 2016. However, it was found to be at par with rice (TPR) - vegetable pea – groundnut, rice (DSR) –vegetable pea – maize grain, rice (DSR) - potato -cowpea (vegetable) and rice (DSR) - yellow sarson – cowpea (vegetable + green manure) during both the years. It might be due to direct seeding of rice. The lowest density was recorded in soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm treatment. It could be due to effect of mentha crop in cropping sequence in furrow and wheat was already raised on bed; therefore weed density reduced.

Broad-leaved weeds (BLWs)

The data pertaining to density of BLWs in *Kharif, Rabi and* summer are given in **Table 3**. Density of broad-leaved weeds was significantly influenced by crop intensification and establishment techniques.

In *Kharif*, among the broad-leaved weeds, rice – wheat cropping sequence recorded the least values of density of *Trianthema monogyna, Alternanthera*

Table 3. Effect of crop intensification and establishment techniques on broad-leaved weed density

Treatment				T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	LSD (p=0.05)
Broad-leaved weeds (no./m^2)	*Kharif*	*T. monogyna*	2015-16	2.9(8.0)	3.3(10.7)	5.3(28.0)	4.9(24.0)	5.2(25.3)	4.9(24.0)	3.7(13.3)	3.7(13.3)	3.5(12.0)	0.40
			2016-17	3.1(9.3)	3.9(14.7)	5.6(30.7)	5.3(28.0)	5.1(26.7)	5.6(30.7)	3.9(14.7)	3.9(14.7)	4.0(15.7)	0.53
		A. sessilis	2015-16	1.3(1.3)	1.7(2.7)	3.3(10.7)	2.9(8.0)	3.1(9.3)	3.5(10.7)	2.1(4.0)	2.4(5.3)	2.7(6.7)	0.36
			2016-17	1.8(2.7)	2.1(4.0)	3.5(12.0)	3.1(9.3)	3.3(10.7)	3.3(12.0)	2.7(6.7)	2.9(8.0)	2.9(8.0)	0.61
		Celosia argentea	2015-16	2.1(4.0)	2.9(8.0)	7.9(62.7)	7.5(56.0)	7.9(58.7)	7.3(53.3)	7.1(49.3)	7.2(52.0)	6.9(46.7)	0.48
			2016-17	2.4(5.3)	3.1(9.3)	8.2(66.7)	8.1(65.3)	7.7(62.7)	7.8(61.3)	7.4(54.7)	7.7(58.7)	6.8(45.3)	0.56
	Rabi	*S. nigrum*	2015-16	3.3(10.7)	3.3(10.7)	3.5(12.0)	3.7(13.3)	3.1(9.3)	3.3(10.7)	2.9(8.0)	2.7(6.7)	2.4(5.3)	0.30
			2016-17	3.5(12.0)	3.3(10.7)	3.9(14.7)	3.9(14.7)	3.3(10.3)	3.7(13.3)	3.3(10.7)	2.9(8.0)	2.7(6.7)	0.47
		C. didymus	2015-16	3.3(10.7)	3.13(9.3)	3.7(13.3)	3.5(12.0)	3.9(14.7)	2.9(8.0)	2.4(5.3)	2.9(8.0)	2.7(6.7)	0.36
			2016-17	3.5(12.0)	3.3(10.7)	3.9(13.3)	3.9(13.3)	3.3(16.0)	3.7(9.3)	3.3(8.0)	2.9(9.3)	2.7(8.0)	0.47
		Melilotus. species	2015-16	3.5(12.0)	4.1(16.0)	5.3(28.0)	5.7(28.0)	5.3(28.0)	4.5(20.0)	2.7(6.7)	2.4(5.3)	2.1(4.0)	0.37
			2016-17	3.7(13.3)	4.2(17.3)	5.5(29.3)	5.3(32.0)	5.5(29.3)	4.7(21.3)	2.9(8.0)	2.4(5.3)	2.1(4.0)	0.39
		C. album	2015-16	4.1(16.0)	4.9(24.0)	5.3(28.0)	4.1(17.3)	4.9(24.0)	4.1(16.0)	2.7(6.7)	3.5(12.0)	2.4(5.3)	0.70
			2016-17	4.2(17.3)	5.1(25.3)	5.5(29.3)	4.4(18.7)	5.1(25.3)	4.2(17.3)	2.9(8.0)	3.7(13.3)	2.7(6.7)	0.30
		C. arvense	2015-16	2.9(8.0)	3.5(12.0)	3.5(12.0)	5.3(28.0)	4.5(20.0)	3.5(12.0)	2.4(5.3)	2.1(4.0)	2.7(6.7)	0.39
			2016-17	2.9(8.0)	3.7(13.3)	3.7(13.3)	5.6(30.7)	4.7(21.3)	3.7(13.3)	2.7(6.7)	2.1(4.0)	2.9(8.0)	0.43
		T. monogyna	2015-16	2.9(8.0)	0.7(0.0)	2.9(8.0)	2.1(4.0)	2.9(8.0)	0.7(0.0)	1.3(1.3)	0.7(0)	2.7(6.7)	0.33
			2016-17	3.1(9.3)	0.7(0)	3.1(9.3)	2.1(4.0)	2.9(8.0)	0.7(0.0)	1.8(2.7)	0.7(0.0)	2.9(8.0)	0.27
		R. dentatus	2015-16	3.5(12.0)	0.7(0)	0.7(0)	1.3(1.3)	0.7(0)	0.7(0)	0.7(0)	3.3(10.7)	0.7(0)	0.19
			2016-17	3.7(13.3)	0.7(0)	0.7(0)	1.8(2.7)	0.7(0)	0.7(0)	0.7(0)	3.3(10.7)	0.7(0.0)	0.29
		V. sativa	2015-16	3.5(12.0)	4.5(20.0)	5.3(28.0)	0.7(0.0)	4.1(16.0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.18
			2016-17	3.7(13.3)	4.7(21.3)	5.5(29.3)	0.7(0)	4.2(17.3)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.21
		A. arvensis	2015-16	3.5(12.0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	2.9(8.0)	0.7(0)	0.20
			2016-17	3.7(13.3)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	0.7(0)	3.1(9.33)	0.7(0)	0.17
		M. alba	2015-16	4.1(16.0)	0.7(0)	2.9(8.0)	4.5(20.0)	0.7(0)	0.7(0)	0.7(0)	2.9(8.0)	0.7(0)	0.24
			2016-17	4.4(18.7)	0.7(0.0)	3.1(9.3)	4.7(21.3)	0.7(0)	0.7(0)	0.7(0)	3.1(9.3)	0.7(0)	0.20
	Summer	*T. monogyna*	2015	-	9.7(95)	10.0(99)	8.7(75)	10.3(107)	10.0(100)	9.0(80.0)	0.7(0.0)	8.0(64)	0.44
			2016	-	10.1(101)	10.1(103)	9.3(87)	10.8(117)	10.5(109)	9.5(90.7)	0.7(0)	8.5(72)	0.79

Treatment = T_1 - Rice (TPR) – Wheat; T_2- Rice (TPR) – Wheat; T_3 - Rice (TPR) - Vegetable pea – Groundnut; T_4 - Rice (DSR) – Vegetable pea – Maize grain; T_5 - Rice (DSR) - Potato -Cowpea (vegetable); T_6 - Rice (DSR) - Vegetable pea - Maize (cob + fodder); T_7 - Rice (DSR) – Yellow Sarson – cowpea (vegetable + green manure); T7 - Rice (DSR) (B) + Sesbania (F)- 2:1 (FIRBS 45cm * 30 cm) -Vegetable pea (B) + Toria (F)-2:1 (FIRBS) - Maize (B) (cob + fodder) + Mentha (F)1:1(FIRBS); T_8 - Soybean (B) + Rice (DSR) (F)-2:1 (NBS 60cm * 30 cm) - Wheat + Mentha (3:1) (NBS 60cm * 30 cm) - Continue (NBS 60cm * 30 cm; T_9 - Maize (B) (cob + fodder) + Cowpea (B) + Sesbania (F)-2:1:1 (BBF 105cm * 30 cm) - Vegetable pea + Toria-3:1 (BBF) - Groundnut + Mentha-3:1 (BBF)

Original values given in parentheses was subjected to square root $(\sqrt{x+1})$ransformation before analysis; B - bed; F - furrow; NBS - narrow bed system; BBF - broad bed furrow; FIRB - furrow irrigated raised bed *sessilis* and *Celosia argentia* during both the years, which might be due to puddling operation performed in transplanted rice. The density of all these weeds was significantly more when rice raised through direct seeding or in other cropping sequences.

In *Rabi* season, among the broad leaved weeds, significantly lower weed density of *Solanum nigrum*, *Coronopus didymus*, *Melilotus* sp. and *Chenopodium album* was recorded in maize (B) (cob + fodder) + cowpea (B) + *Sesbania* (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) - groundnut + mentha-3:1 (BBF) treatment during both the years except during 2015-16 where density of *C. didymus* was significantly lower in rice (DSR) (B) + sesbania (F)- 2:1 (FIRBS 45 x 30 cm) -vegetable pea (B) + toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + mentha (F)1:1(FIRBS) treatment. Significantly higher density of these weeds was found rice (DSR) – vegetable pea – maize grain and rice (DSR) - potato - cowpea (vegetable) treatment where rice was raised through direct seeding in upland condition. No infestation of *T. monogyna* was reported in rice (TPR) - vegetable pea – groundnut, rice (DSR) - yellow sarson – cowpea (vegetable + green manure) and soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm during both years, whereas the highest density of this weed was recorded in rice (DSR) –vegetable pea – maize grain treatment which was at par with rice (DSR) - vegetable pea - maize (cob + fodder) and maize (B) (cob + fodder) + cowpea (B) + *Sesbania* (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) - groundnut + mentha-3:1(BBF) treatment during 2015-16 while rice (TPR) – wheat treatment recorded the highest being at par with rice (DSR) – vegetable pea – maize grain, rice (DSR) - vegetable pea - maize (cob + fodder) and maize (B) (cob + fodder) + cowpea (B) + *Sesbania* (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) - groundnut + mentha-3:1(BBF) during 2016-17. No density of *Rumex dentatus* was recorded in rice (TPR) - vegetable pea – groundnut, rice (DSR) – vegetable pea – maize grain, rice (DSR) - vegetable pea - maize (cob + fodder), rice (DSR) - yellow sarson – cowpea (vegetable + green manure), rice (DSR) (B) + sesbania (F)- 2:1 (FIRBS 45 x 30 cm) -vegetable pea (B) + toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + mentha (F)1:1(FIRBS), maize (B) (cob + fodder) + cowpea (B) + Sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) - groundnut + mentha-3:1(BBF) treatments during both the years, while the highest density of this weed of was recorded in rice (TPR) – Wheat treatment during both the years.

No population of *Vicia sativa* was recorded in rice (DSR) - yellow sarson – cowpea (vegetable + green manure), rice (DSR) (B) + sesbania (F)- 2:1 (FIRBS 45 x 30 cm) -vegetable pea (B) + toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + mentha (F)1:1(FIRBS), soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm, maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) - groundnut + mentha-3:1(BBF) treatment, while the highest density of this weed was found in rice (DSR) –vegetable pea – maize grain treatment during both years.

No population of *Anagallis arvensis* was recorded in rice (DSR) - potato -cowpea (vegetable), rice (DSR) - vegetable pea - maize (cob + fodder), rice (DSR) - yellow sarson – cowpea (vegetable + green manure), rice (DSR) (B) + *Sesbania* (F)- 2:1 (FIRBS 45 x 30 cm) -vegetable pea (B) + toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + mentha (F)1:1(FIRBS), maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) - groundnut + mentha-3:1(BBF) treatments, while the highest density of this weed was recorded in rice (TPR) – wheat treatment during both the years.

No population of *Melilotus alba* was recorded in rice (DSR) - vegetable pea - maize (cob + fodder), rice (DSR) - yellow sarson – cowpea (vegetable + green manure), rice (DSR) (B) + *Sesbania* (F)- 2:1 (FIRBS 45 x 30 cm) -vegetable pea (B) + toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + mentha (F)1:1(FIRBS), rice (DSR) (B) + *Sesbania* (F)- 2:1 (FIRBS 45 x 30 cm) -vegetable pea (B) + toria (F)-2:1 (FIRBS) - maize (B) (cob + fodder) + mentha (F)1:1(FIRBS) treatments, while the highest density of this weed was found in rice (DSR) - potato - cowpea (vegetable) treatment during both the years.

In summer season, among the broad-leaved weeds, no population of *T. monogyna* was recorded in soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm) treatment which might be due to sowing spreading type crop like mentha, while the highest density of this weed was recorded in rice (DSR) - vegetable pea - maize (cob + fodder) treatment during both the years. Teasdale (1996) reported that cover crop control the weeds and control increased with greater amounts of crop residue biomass; however, weed suppression was species specific in terms of both the cover crop and weed. A more recent review stated that those

Table 4. Effect of crop intensification and establishment techniques on density of sedges

Treatment	Sedges (no./m^2)							
	Kharif				*Rabi*		Summer	
	C. rotundus		*C. iria*		*C. rotundus*		*C. rotundus*	
	2015	2016	2015	2016	2015-16	2016-17	2015	2016
Rice (TPR) – Wheat	9.9(97)	10.1(101)	1.34(1.3)	1.74(2.7)	7.15(50.7)	7.43(54.7)	-	-
Rice (TPR) - Vegetable pea – Groundnut	10.0(100)	10.1(101)	1.77(2.7)	2.10(4.0)	6.67(44.0)	6.77(45.3)	8.75(76)	9.30(87)
Rice (DSR) –Vegetable pea – Maize grain	11.3(128)	11.6(133)	2.39(5.3)	2.86(8.0)	6.24(38.7)	6.52(42.0)	11.69(140)	12.0(144)
Rice (DSR) - Potato -Cowpea (vegetable)	11.2(124)	11.3(128)	2.41(5.3)	2.66(6.7)	6.04(36.0)	6.14(37.3)	10.42(108)	11.0(121)
Rice (DSR) - Vegetable pea - Maize (cob + fodder)	11.1(121)	11.0(125)	2.68(6.7)	2.91(8.0)	6.14(37.3)	6.25(38.7)	12.24(149)	12.4(155)
Rice (DSR) - Yellow Sarson – cowpea(vegetable + green manure)	11.2(121)	11.0(123)	2.91(8.0)	3.13(9.3)	5.33(28.0)	5.69(32.0)	11.16(124)	11.4(129)
Rice (DSR) (B) + Sesbania (F)- 2:1 (FIRBS 45cm * 30 cm) -Vegetable pea (B) + Toria (F)-2:1 (FIRBS) - Maize (B) (cob + fodder) + Mentha (F)1:1(FIRBS)	10.4(108)	10.5(111)	2.65(6.7)	2.90(8.0)	4.67(21.3)	5.20(26.7)	8.75(76)	9.23(85)
Soybean (B) + Rice (DSR) (F)-2:1 (NBS 60 cm * 30 cm) - Wheat + Mentha (3:1) (NBS 60cm * 30 cm) - Continue (NBS 60cm * 30 cm	10.3(105)	10.7(115)	2.67(6.7)	3.12(9.3)	4.95(24.0)	5.08(25.3)	0.71(0)	0.71(0)
Maize (B) (cob + fodder) + Cowpea (B) + Sesbania (F)-2:1:1 (BBF 105cm * 30 cm) - Vegetable pea + Toria-3:1 (BBF) - Groundnut + Mentha-3:1(BBF)	10.1(101)	10.3(105)	2.40(5.3)	2.91(8.0)	4.38(18.7)	4.52(20.0)	6.04(36)	6.45(41)
LSD (p=0.05)	0.63	0.62	0.53	0.64	0.62	0.55	1.41	0.82

Original values given in parentheses was subjected to square root ($\sqrt{x+1}$)ransformation before analysis; B - bed; F - furrow; NBS - narrow bed system; BBF - broad bed furrow; FIRB - furrow irrigated raised bed

alternative methods such as the use of allelopathy, cover crops, and living mulches are low cost, effective and eco-friendly practices for sustainable weed management in cropping systems (Mohammadi 2013).

Sedges

The data regarding to density of sedges is given in **Table 4**. Density of sedges was significantly affected by crop intensification and establishment techniques before the post-emergence application of herbicides during both the years.

In *Kharif*, among the sedges, significantly lower density of *Cyperus rotundus* and *C. iria* was recorded in rice-wheat cropping system being at par with rice-vegetable pea- groundnut cropping system during both the years which might be due to puddling operation in transplanted rice, while the highest density of *C. rotundus* and *C. iria* was recorded in rice (DSR) –vegetable pea – maize grain and rice (DSR) - yellow sarson – cowpea (vegetable + green manure) treatments during both the years. It might be due to direct seeding of rice similar to as reported by Singh and Singh (2004) that in rice –wheat system weed density was the highest for sedges (>60%) followed by grasses and broadleaved weeds, but in biomass, grasses had a >60% share, followed by sedges and non-grasses. In *Rabi*, among the sedges, density of *C. rotundus* was recorded significantly lower in maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:1 (BBF 105 x 30 cm) - vegetable pea + toria-3:1 (BBF) - groundnut + mentha-3:1(BBF) treatment while the highest density was recorded in rice (TPR) – wheat treatment during both the years. It could be due to inclusion of cereals crops like wheat in *Rabi* season which don't cause smothering effect on weeds therefore weed density resulted the highest.

In summer, among the sedges, no density of *C. rotundus* was recorded in soybean (B) + rice (DSR) (F)-2:1 (NBS 60 x 30 cm) - wheat + mentha (3:1) (NBS 60 x 30 cm) - continue (NBS 60 x 30 cm treatment while the highest density was recorded in rice (DSR) - vegetable pea - maize (cob + fodder) treatment during both the years.

In *Kharif* season density of total weeds as well as grasses, broad-leaved weeds and sedges was observed the lowest in rice – wheat cropping system. In *Rabi* season, [maize (B) (cob + fodder) + cowpea (B) + sesbania (F)-2:1:2 - vegetable pea (B) + toria (F)-3:1 – groundnut (B) + mentha (F)-3:1(BBF 105 x 30 cm)] proved to be the most prominent cropping system for controlling total weeds likewise broad leaved weeds and sedges. All the cropping systems proved superior for the control of grassy weeds (*Phalaris minor* and *Avena fatua*) in this season in which there was inclusion of either legumes or oilseed crops over those cropping systems in which wheat was raised. During summer season, soybean (B) + rice (DSR) (F)-2:1 – wheat (B) + mentha (F) (3:1) - continue (NBS 60 x 30 cm) cropping system was found better for the control of complex weed flora

REFERENCES

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

Anderson RL. 2007. Managing weeds with a dualistic approach of prevention and control A review. *Agronomy for Sustainable Development* **27**: 13–18.

Bagmet L. 2000. Dynamic of the segetal element of weed flora in the Lower-Volga region, *Z. Pflanzenk. Pflanzen.* **17**: 85–90.

Ball DA. 1992. Weed seed bank response to tillage, herbicides, and crop rotation sequence. *Weed Science* **40**: 654–659.

Bhurer KP, Yadav DN, Ladha JK, Thapa RB and Pandey K. 2013. Integrated weed management practices on performanceof dry direct seeded rice (*Oryza sativa* L.). *Agronomy Journal of Nepal* **3**: 53–63.

Das TK. 2008. *Weed Science: Basics and Application*. Jain Brothers Pub, New Delhi, First edition, 901 p.

Davis AS and Liebman M. 2003. Cropping system effects on giant foxtail (*Setaria faberi*) demography: I. Green manure and Tillage timing, *Weed Science* **51**: 919–929.

Dorado J, Del Monte JP and Lopez-Fando C. 1999. Weed seed bank response to crop rotation and tillage in semiarid agroecosystems. *Weed Science* **47**: 67–73.

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

Hald AB. 1999. Weed vegetation (wild flora) of long established organic versus conventional cereal fields in Denmark, *Annals of Applied Biology* **134**: 307–314.

Kewat ML. 2014. Improved weed management in *Rabi* crops. pp. 22-25. In: *National Training on Advances in Weed Management,* held at DWSR, Jabalpur, India.

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

Martin RJ and WL Felton. 1993. Effect of crop rotation, tillage practice, and herbicides on the population dynamics of wild oats in wheat. *Australian Journal Experimental Agriculture* **33**: 159–165.

Mohammadi GR. 2013. *Alternative Weed Control Methods: A Review, Weed and Pest Control - Conventional and New Challenges*, (Ed. Sonia Soloneski), ISBN: 978-953-51-0984-6, InTech, doi: 10.5772/54164.

Moody K. 1983. The status of weed control in Asia.*FAO Plant Protection Bulletin* **30**: 119–120.

Oerke EC. 2006. Crop losses to pests. *The Journal of Agricultural Science* **144**: 31–43.

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

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

Sharma AR. 2014. Weed management in conservation agriculture systems- problems and prospects. pp. 1-9. In: *National Training on Advances in Weed Management,* held at DWSR, Jabalpur, India on 14-23 January.

Singh R and Singh B. 2004. Effect of irrigation time and weed management practices on weeds and wheat yield. *Indian Journal of Weed Science* **36**: 25–27.

Squire GR, Rodgers S and Wright G. 2000. Community-scale seed bank response to less intense rotation and reduced herbicide input at three sites.*Annals of Applied Biology* **136**: 47–57.

Stoate C, Boatman D, Borralho RJ, Carvalho CR, Desnoo GR and Eden P. 2002. Ecological impacts of arable intensification in Europe, *Journal of Environmental Manage* **63**: 337–365.

Tabaglio V, Gavazzi1 C, Schulz M and Marocco A. 2008. Alternative weed control using the allelopathic effect of natural benzoxazinoids from rye mulch. *Agronomy for Sustainable Development* **28**: 397–401.

Teasdale JR. 1996. Contribution of cover crops to weed management in sustainable agricultural systems. *Journal Production Agriculture* **9**: 475–479.

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

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

Indian Journal of Weed Science **50**(3): 269–272, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Weed seed bank in soil as affected by different weed management practices in spring sweet corn

Prithwiraj Dey*, Tej Pratap, Sudershan Mishra, Pramit Pandit

G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand 263 145

**Email: mailprithwi@gmail.com*

Article information

DOI: 10.5958/0974-8164.2018.00057.6

Type of article: Research article

Received : 30 June 2018
Revised : 15 September 2018
Accepted : 18 September 2018

Key words

Atrazine
Sweet Corn
Tembotrione
Weed seed bank

ABSTRACT

A field study was conducted in spring season of 2016 and 2017 on sweet corn to evaluate the effect of different weed management practices upon the weed seed bank dynamics in the soil. In the sample from seed bank studied, the per cent contribution of *Cleome viscosa* was highest among all the weed species before sowing and harvest stage of the crop and was followed by *Dactyloctenium aegypticum,* in both the stages and years. Depth wise weed seed distribution indicated highest weed seed in 10-15 cm depth before sowing and in 0-5 cm depth at harvest stage of the crop. Effect of all the weed control treatments upon previous season's dormant seeds was non-significant. Twice hand weeding was effective to reduce seed bank in deeper layer. Atrazine 1000 g/ha followed by tembotrione 120 g/ha and tembotrione alone 120 g/ha had caused a significant reduction in weed seed number in 0-5 and 0-10 cm layer but weed seed number at 10-15 cm layer remained unchanged.

INTRODUCTION

Weeds generally depends on its seed bank in the soil for the persistence in agricultural systems (Buhler *et al.* 1997). It is very likely that if all the weeds in a particular land germinate at once, there is very possibility that we will get rid of weeds permanently. But unfortunately, weeds persists and the major cause behind the weed persistence is the maintenance of the weed seed bank in the soil (Borgy *et al.* 2015). So, it is necessary to understand the weed seed bank dynamics as affected by the different weed management strategies because only controlling the weeds in short term is not desirable. Weed management options that manage the seed bank of weeds also controls the weeds for the future instances. Weed seed bank dynamics is a potent inference of the reproductive biology of the weed species and must be considered while devising a functional weed management strategy (Bhowmik 1997, Hossain and Begum 2015). In the present experiment, the nature of weed seed bank present in the studied cropping system and the effect of different weed management strategies upon weed seed bank in terms of species wise and layer wise net seed addition or reduction of viable seed reserve, were studied. The study aims to find out the best management practice to manage the weeds and their seed bank for formulating a sustainable weed management system.

MATERIALS AND METHODS

The current experiment was conducted during spring seasons of 2016 and 2017 in N. E Borlaug Crop Research Centre of G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India (29ÚN, 79.3ÚE). The soil on the experimental site was sandy loam, neutral in pH (7.3) with high organic carbon (0.79%), medium available nitrogen (314.3 kg/ha), phosphorus (19.8 kg/ha) and potassium (220.3 kg/ha). Sweet corn variety *'Sugar 75'* was used for the experiment. The experiment was laid out in a randomized block design with three replications and seven treatments *viz.* pre-emergence application (PE) of atrazine at 1000 g/ha, post-emergence application (POST) of tembotrione at 120 g/ha, atrazine at 1000 g/ha PE *fb* tembotrione PoE at 120 g/ha, atrazine at 1000 g/ha PRE *fb* one hand weeding at 40 DAS, hand weeding twice at 20 and 40 DAS, weed free and weedy check.

Soil samples were taken before sowing of the crop after final land preparation and at harvest stage of the crop in a zigzag manner from three places at soil depths of 0-5, 5-10 and 10-15 cm in three replications (Smutný and Køen 2002). The samples were drawn with the help of 'khurpi' and 'spade' using a 0.0625 m^2 (0.25 × 0.25) quadrate for sampling. Each of the collected soil was washed using 0.2 mm brass sieve and seeds were collected. All the other propagules and crop seeds were discarded and only weed seeds were considered for this study. The seeds were then graded visually and identified. Unidentified seeds were germinated in a seed germinator at 25°C, 90% RH in paper-tower method using an artificial fluorescent illumination for 8 hrs. per day (Chalam *et al.* 1967). Seedlings were identified after 14 days (Konstantinovich 2012).

Data from both the years were pooled for analysis as no significant time to treatment interaction was found (Elsami and Afgani 2009). General species wise contributions in terms of seeds/square meter were expressed as pooled mean value ± standard deviation. The weed seeds count from the samples were transformed using square root transformation ($\sqrt{x+1}$) for the purpose of treatment comparison using ANOVA. Effect of the treatments was compared statistically by Fisher's least significant difference method at 5% level of significance (Gomez and Gomez, 1984). All statistical analysis were made using IBM SPSS 24.0 software package developed by IBM Corp. (2016).

RESULTS AND DISCUSSION

The weed seeds identified in both the years were *Ageratum conyzoides* (3.27%), *Amaranthus retroflexus* (5.72%), *Brachiaraia mutica* (7.16%), *Celosia argentea* (6.56%), *Chenopudium album* (5.86%), *Cleome viscosa* (16.07%), *Dactyloctenium aegypticum* (10.60%), *Digera arvensis* (10.33%), *Digitaria sanguinallis* (10.10%), *Echinochloa colona* (3.98%), *Parthenium hysterophorus* (6.08%), *Physalis minima* (1.69%), *Polygonum aviculare* (4.29%) and *Trianthema portulacastrum* (7.17%). Some weed seeds were left unidentified as they failed to germinate in controlled condition in spite of being alive in tetrazolium test. They are classified and analyzed as 'other seeds'. Other seeds contributed 0.90%, on an average, in total seeds found initially in weedy check.

The per cent contribution was highest for *Cleome viscosa* among all the weed species, which was followed by *Dactyloctenium aegypticum* in both the sampling stages. Depth wise contribution was found highest in 10-15 cm depth before sowing and in 0-5 cm depth at harvest stage of the crop in both the years (**Table 1**). This may be due to the inversion in soil due to tillage at the final land preparation, which may have caused deep burial of the weed seeds that were present on upper surface at the end of previous crop. As there was no soil disturbance at the time of sampling on the completion of sweet corn season, more number of seeds were found on the shallow depth up to 5 cm (Clements *et al.* 1996).

Weeds of preceding crop were mostly present on the deeper soil layer (10-15 cm depth) and the current season weed seeds were mostly found on surface and only up to medium depth due to lack of soil disturbance. The weed seeds of previous season were mainly of *Amaranthus retroflexus*, *Brachiaria*

Table 1. Soil depth wise and species wise weed seed number and their contribution to weed seed bank in weedy check (pooled data of 2016 and 2017)

Weed species	Depth (0-5 cm) (no. of seeds/m^2 soil)		Depth (5-10 cm) (no. of seeds/m^2 soil)		Depth (10-15 cm) (no. of seeds/m^2 soil)		Contribution (%)	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Ageratum conyzoides	53.5±7.9	98.8±14.6	17.8±2.6	26.7±4.0	0.0±0.0	1.8±0.3	3.27±0.5	4.43±0.7
Amaranthus retroflexus	15.6±2.0	22.0±2.8	43.4±5.4	62.5±7.8	65.6±8.2	66.2±8.3	5.72±0.7	5.24±0.7
Brachiaraia mutica	23.4±2.2	29.6±2.8	36.3±3.4	52.3±4.9	96.1±8.9	100.9±9.4	7.16±0.7	6.35±0.6
Celosia argentea	77.4±10.2	138.0±18.3	31.2±4.1	46.9±6.2	34.3±4.5	34.1±4.5	6.56±0.9	7.61±1.0
Chenopudium album	49.7±8.2	94.2±15.5	33.9±5.6	51.0±8.4	44.0±7.2	45.4±7.5	5.86±1.0	6.63±1.1
Cleome viscosa	70.0±9.9	92.6±13.1	82.6±11.7	112.9±16.0	197.2±28.0	202.6±28.7	16.07±2.3	14.19±2.0
Dactyloctenium aegypticum	49.4±6.4	58.8±7.6	74.7±9.7	107.2±13.9	106.6±13.9	111.9±14.5	10.60±1.4	9.66±1.3
Digera arvensis	34.8±4.6	37.9±5.0	50.8±6.7	74.5±9.9	139.3±18.4	136.5±18.1	10.33±1.4	8.65±1.1
Digitaria sanguinallis	36.8±4.5	46.5±5.7	76.2±9.3	110.8±13.5	111.8±13.6	108.1±13.2	10.10±1.2	9.23±1.1
Echinochloa colona	68.6±7.2	142.1±14.8	18.0±1.9	27.1±2.8	0.0±0.0	0.0±0.0	3.98±0.4	5.88±0.6
Parthenium hysterophorus	53.8±7.1	99.5±13.2	34.9±4.6	48.4±6.4	43.6±5.8	39.8±5.3	6.08±0.8	6.52±0.9
Physalis minima	27.3±4.5	70.7±11.6	9.6±1.6	3.8±0.6	0.0±0.0	0.0±0.0	1.69±0.3	2.59±0.4
Polygonum aviculare	93.3±13.9	147.7±22.1	0.0±0.0	0.0±0.0	0.0±0.0	6.5±1.0	4.29±0.6	5.36±0.8
Trianthema portulacastrum	14.5±1.8	26.8±3.3	33.7±4.1	50.5±6.2	107.9±13.3	110.1±13.5	7.17±0.9	6.51±0.8
Other	7.3±1.1	16.5±2.4	7.6±1.1	11.2±1.7	4.6±0.7	5.3±0.8	0.90±0.1	1.15±0.2
% Contribution:	31.02±4.0	38.99±4.4	25.30±3.1	27.32±3.0	43.68±5.8	33.69±4.2	-	-

*Pooled mean values ± Standard deviation

Table 2. Effect of different treatments on the initial and final weed seed number of different weed species number (pooled data of 2016 and 2017)

Treatment	Previous season weed seeds (no. of seeds/m^2 soil)							Current season weed seeds (no. of seeds/m^2 soil)						
	Amaranthus sp.	*Brachiaria* sp.	*Cleome* sp.	*Dactyloctenium* sp.	*Digera* sp.	*Digitaria* sp.	*Trianthema* sp.	*Celosia* sp.	*Echinochloa* sp.	*Parthenium* sp.	*Physalis* sp.	*Polygonum* sp.	*Ageratum* sp.	*Chenopodium* sp.
Atrazine 1000 g/ha	11.2 (124.7)	12.7 (159.4)	18.5 (341.1)	15.4 (237.2)	14.7 (215.0)	14.8 (218.7)	12.6 (158.1)	12.0 (143.0)	9.3 (86.4)	11.3 (127.7)	5.4 (28.4)	9.7 (92.2)	8.5 (72.1)	11.5 (131.4)
Tembotrione 120 g/ha	11.2 (123.5)	12.0 (141.9)	17.4 (302.1)	14.7 (214.2)	13.9 (192.0)	13.9 (193.1)	11.9 (140.6)	8.6 (73.0)	5.8 (32.1)	9.3 (85.0)	3.6 (11.7)	4.6 (20.6)	5.9 (34.4)	9.0 (80.9)
Atrazine 1000 g *fb* tembotrione 120 g/ha	11.1 (123.3)	12.5 (156.5)	18.3 (332.2)	15.4 (235.6)	14.6 (212.2)	14.6 (213.5)	12.6 (156.7)	11.8 (137.1)	9.1 (81.5)	11.1 (123.3)	5.3 (26.6)	9.3 (85.9)	8.3 (68.2)	11.3 (127.2)
Atrazine 1000 g *fb* 1 HW at 40 DAS	10.7 (113.7)	12.9 (165.3)	18.9 (358.0)	15.2 (231.3)	15.2 (229.4)	14.8 (219.3)	13.5 (180.2)	9.1 (81.6)	5.5 (29.3)	8.8 (76.9)	4.3 (17.5)	4.9 (23.1)	6.1 (36.7)	9.2 (83.2)
2 Hand weeding at 20 and 40 DAS	10.6 (111.8)	11.8 (138.9)	17.4 (303.4)	14.0 (196.0)	14.0 (194.4)	13.7 (185.8)	12.3 (150.2)	8.6 (72.9)	5.2 (26.2)	8.3 (68.6)	4.1 (15.6)	4.6 (20.6)	5.8 (32.8)	8.7 (74.3)
Weed free	10.3 (106.1)	11.6 (134.3)	17.1 (293.1)	13.8 (190.6)	13.8 (189.4)	13.5 (181.8)	12.1 (146.0)	8.4 (70.1)	5.1 (25.3)	8.2 (66.0)	4.0 (15.1)	4.5 (19.7)	5.7 (32.0)	8.5 (71.8)
Weedy check	11.3 (126.6)	12.5 (154.6)	18.4 (338.4)	15.2 (229.3)	14.6 (210.8)	14.9 (220.8)	12.6 (157.0)	12.7 (159.7)	10.8 (114.9)	11.9 (141.1)	7.1 (49.1)	10.1 (101.8)	8.8 (76.6)	12.1 (145.0)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	1.04	0.91	0.99	0.56	0.91	0.72	0.32

mutica, *Cleome viscosa*, *Dactyloctenium aegypticum*, *Digera arvensis*, *Digitaria sanguinallis* and *Trianthema portulacastrum*. The weeds that appeared in the current season were *Celosia argentea*, *Echinochloa colona*, *Parthenium hysterophorus*, *Physalis minima*, *Polygonum aviculare*, *Ageratum conyzoides* and *Chenopudium album* (**Table 2**).

Different weed control treatments effect upon the number of previous season's dormant seeds was non-significant as herbicides have no control over the dormant seeds (Dyer 1995). Manual weeding may expose dormant seeds to desiccating sun but it had negligible effects on the previous season's seeds which were at 10-15 cm depth. On the contrary, all the weed control treatments had significant effect on the number of seeds of all weeds present at harvest stage of sweet corn. In all the weed species that have germinated in studied season (spring), weed free plots were recorded to have lowest seed count per square meter of soil which was at par with the twice hand weeding at 20 and 40 DAS, atrazine 1000 g/ha *fb* tembotrione 120 g/ha and alone application of tembotrione 120 g/ha in both the experimentation years. This result was in accordance with findings of Buhler (1999). The significant reduction in seed addition in the seed bank indicates the effective control of weeds by the weed control treatments. Before sowing of the crop, all the treatments were having similar seed counts on particular depth (**Figure 1**). Highest seed number before sowing of the crop was recorded at 10-15 cm depth. But at harvest stage, the difference in seed number at harvest stage from the initial values is a clear indication of net weed seed addition or reduction in the seed bank. The highest reduction in weed seed number in all the depths was recorded in hand weeded twice plots. The maximum effects of the treatments on the weed seed count at harvest was observed in the 0-5 cm soil depth with little change in 10-15 cm layer. Treatments having hand weeding as a component had reduced weed seed number in 10-15 cm soil depth due to certain soil disturbance due to hand weeding, which might have promoted weed seed germination from deeper soil layer and their subsequent removal or mortality.

Conclusion

It was concluded that weed seed placement depth has a role in weed seed bank strength and its persistence over time. Previous season's weeds, if not germinated in current season, are likely to be unaffected by the recommended chemical treatments. However, manual weeding may cause slight weed seed reduction in deeper layers too, due to soil disturbance. Hand weeding twice was effective to reduce deeper layer seed bank. Atrazine 1000 g/ha followed by tembotrione 120 g/ha and tembotrione alone 120 g/ha have caused significant reduction in weed seed bank of 0-5 and 5-10 cm layer, but weed seed number at 10-15 cm layer remained unchanged.

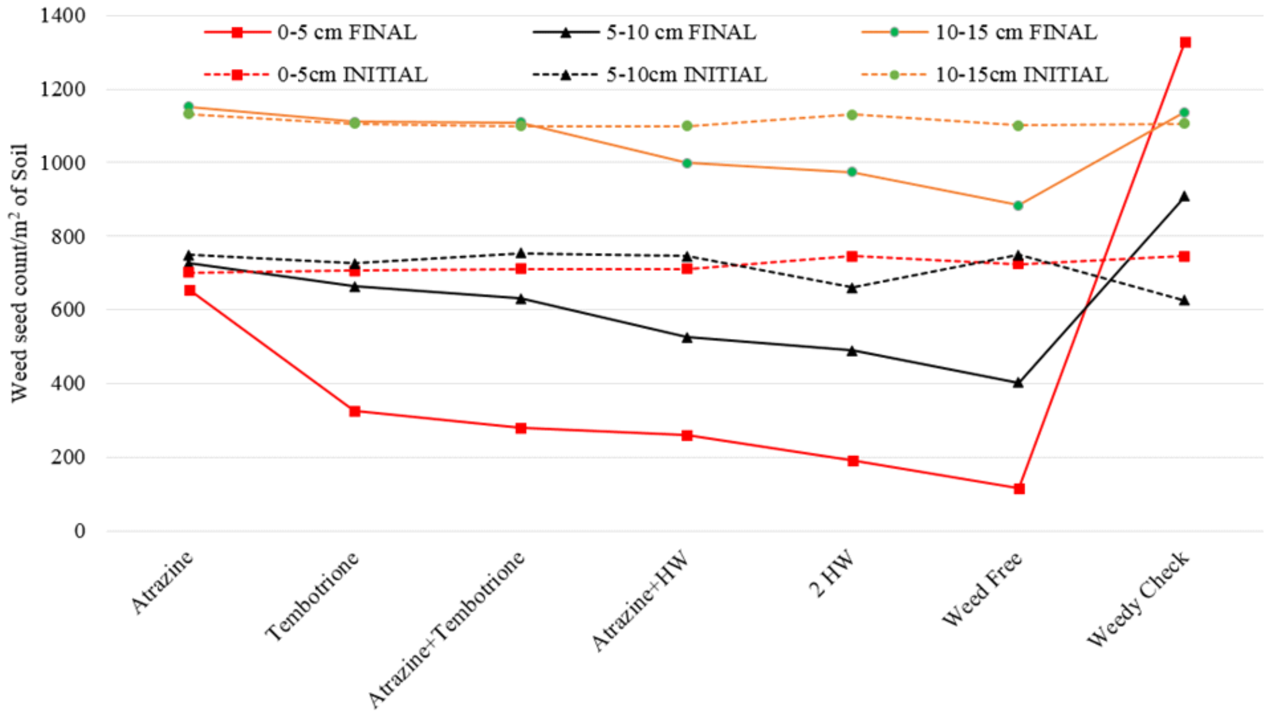

Figure 1. Effect of different weed control treatments on depth wise weed seed count per m² of soil before sowing (initial) and at harvest (final) (pooled data of 2016 and 2017)

ACKNOWLEDGEMENT

The data presented in this research paper are parts of academic thesis submitted by Prithwiraj Dey to G.B. Pant University of Agriculture and Technology, Pantnagar in the year 2018. The financial supports received from ICAR and GBPUA&T are also acknowledged.

REFERENCES

Bhowmik PC. 1997. Weed biology: importance to weed management. *Weed Science* **45**(3): 349–356.

Borgy B, Reboud X, Peyrard N, Sabbadin R and Gaba S. 2015. Dynamics of weeds in the soil seed bank: a hidden markov model to estimate life history traits from standing plant time series. *Plos One* **10**(10): 1–15.

Buhler DD. 1999. Weed population responses to weed control practices. I. Seed bank, weed populations, and crop yields. *Weed Science* **47**(4): 416–422.

Buhler DD, Hartzler RG and Forcella F. 1997. Weed seed bank dynamics. *Journal of Crop Production* **1**(1): 145–168.

Chalam GV, Douglas JE and Singh A. 1967. *Seed Testing Manual*. Indian Council of Agricultural Research and National Seeds Corporation, New Delhi.

Clements DR, Benott DL, Murphy SD and Swanton CJ. 1996. Tillage effects on weed seed return and seedbank composition. *Weed Science* **44**(2): 314–322.

Dyer WE. 1995. Exploiting weed seed dormancy and germination requirements through agronomic practices. *Weed Science* **43**(3): 498–503.

Elsami SV and Afgani F. 2009. Mouse barley germination environmental factors influencing germination of mouse barley (*Hordeum murinum* L.) in South Khorasan province, Iran. *Iranian Journal of Weed Science* **5**(1): 27–38.

Gomez KA and Gomez AA. 1984. *Statistical Procedures for Agricultural Research*. John wiley and sons, NewYork, 680 p.

Hossain MM and Begum M. 2015. Soil weed seed bank: importance and management for sustainable crop production- a review. *Journal of Bangladesh Agricultural University* **13**(2): 221–228.

IBM Corp. 2016. *IBM SPSS Statistics for Windows, Version 24.0*. Armonk, NY: IBM Corp.

Konstantinovich B, Meseldzija M and Korach M. 2012. Qualitative and quantitative content of soil weed seed bank in sunflower crop. *Bulgarian Journal of Agricultural Science* **18**(1): 348–353

Smutný V and Køen J. 2002. Improvement of an elutriation method for estimation of weed seed bank in the soil. *Rostlinna výroba* **48**: 271–278.

Indian Journal of Weed Science

Indian Journal of Weed Science **50**(3): 273–277, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Pre- and post-emergence application of atrazine in integration with hand weeding for weed management in pearl millet

H.M. Bhuva* and A.C. Detroja

Pearl Millet Research Station, Junagadh Agricultural University, Jamnagar, Gujarat 361 006

**Email: hasmukhbhuva@gmail.com*

Article information

DOI: 10.5958/0974-8164.2018.00058.8

Type of article: Research article

Received : 12 July 2018
Revised : 24 September 2018
Accepted : 27 September 2018

Key words

Atrazine, Nutrient removal, Pearl millet, Post-emergence, Pre-emergence, Weed control efficiency

ABSTRACT

A field experiment was conducted during the *Kharif* season of 2013 to 2015 at pearl millet Research Station, Jamnagar, Gujarat to study the effect of pre- and post-emergence application of atrazine integrated with manual weeding on weeds, crop productivity, nutrient removal and economics of pearl millet (*Pennisetum glaucum* L.). The experiment was laid out in a randomized block design comprising of eight weed control treatments with three replications. Lesser weed density (8.22 no./m^2 at 30 DAS and 11.89 no./m^2 at harvest) and weed-biomass (20.2 g/m^2), higher weed control efficiency (84.3%) and lower weed index (7.8%) were observed with post-emergence application of atrazine 0.40 kg/ha followed by (*fb*) hand weeding (HW) at 35 days after sowing (DAS). The pre-emergence application of atrazine 0.50 kg/ha + HW at 35 DAS was at par with post-emergence application of atrazine 0.40 kg/ha + HW at 35 DAS and recorded maximum net returns (` 40,087/ha) and benefit: cost ratio (2.97).

INTRODUCTION

Pearlmillet [*Pennisetum glaucum* (L.) R. Br. Emend.Stuntz] is a staple food grain crop of the arid and semi-arid regions of India. It is one of the important cereal crops globally after rice, wheat and maize. In India, pearl millet occupies an area of 7.32 million hectares producing 9.18 million tones with productivity of 1255 kg/ha. In Gujarat, it is cultivated over an area of 0.46 million hectares with a production and productivity of 0.77 million tones and 1677 kg/ha, respectively (DES 2016). Infestation of weeds is one of the most limiting factors of pearl millet production. Weeds compete with the crop plants for the essentials of growth, interfere with the utilization of land and water resources, and thus, adversely affect crop production. Weeds deplete 30-40% of applied nutrients from soil and compete with the crop plants for soil, moisture and sunlight too (Ram *et al.* 2004). Wider spacing and slow growing nature of the crop during the first 3-4 weeks provide enough opportunity for weeds to invade and offer severe competition resulting in 40-55% yield reduction (Sharma and Jain 2003, Banga *et al.* 2000). Keeping a crop weed-free throughout the crop season is a labour and cost-intensive affair. Hand-weeding is labourious, difficult to execute under frequent intermittent rains, cumbersome and time consuming besides being costly and economically not feasible in today's intensive agriculture (Sharma and Jain 2003).

Under scarcity of human labour, use of herbicide is the best option to reduce the weed menace during early stages of crop growth. Atrazine– a selective herbicide is well known and being extensively used in pearl millet grown during rainy season in the country (Das *et al.* 2013). Atrazine as pre-emergence is the most widely used herbicide for weed control in pearl millet. However, in case of continuous rainfall after sowing, spraying of pre-emergence herbicide may not be feasible. Furthermore, the efficacy of pre-emergence herbicides is moisture dependent. Too little or excessive moisture after herbicide application can result in poor weed control. Hence, there is a need to standardize the post-emergence dose of atrazine in pearl millet crop for safe and efficient weed control. The use of chemical along with manual weeding is best option for effective weed management (Girase *et al*. 2017) as neither herbicides nor mechanical cultivation are adequate for consistent and acceptable weed control. Keeping this in view, an attempt was made to find out the effect of integration of pre- and post-emergence application of atrazine with hand weeding on weeds, crop productivity, nutrient removal and economics of rainy season pearlmillet.

MATERIALS AND METHODS

A field experiment was conducted during the *Kharif* seasons of 2013 to 2015, at Pearl millet Research Station, Junagadh Agricultural University, Jamnagar (22º47' N, 70º07' E, 18.00 m above the mean sea level), Gujarat, to assess the effect of pre- and post-emergence atrazine integrated with manual weeding on weeds. The site is situated in the North Saurashtra agro-climatic region of Gujarat under Gujarat plains and hills zone of India. The climate of this region is semi-arid and sub-tropical with fairly dry and hot summer. The rainy season commences in the second fortnight of June and ends in September, with an average annual rainfall of 500 mm. July and August are the peak months of rainfall. December and January are the coldest months of winter with the mean minimum temperature ranging from 15 ºC to 17 ºC. The mean maximum and minimum temperature recorded 30.3 ºC and 21.2 ºC, respectively. The experimental soil was clayey (14.81% sand, 17.74% silt and 67.45% clay) in texture and slightly alkaline in reaction with pH 7.9 and EC 0.42 dS/m. It was moderately fertile being low in organic carbon (4.2 g/kg), medium in available nitrogen (202.3 kg/ha) and phosphorus (10.6 kg/ha) and high in available potassium (282.5 kg/ha). The initial DTPA extractable Fe and Zn were 7.0 and 0.68 mg/kg, respectively. The soil moisture content at field capacity and permanent wilting point in the upper 30 cm soil depth were 28.5 and 16.7%, respectively. Besides, initial bulk density and porosity of the 30 cm soil depth were 1.42 Mg/m^3 and 44.9%, respectively. Rainfall received during crop period of 2013-14, 2014-15 and 2015-16 were 1209, 261.5 and 294 mm with 40, 17 and 19 rainy days, respectively.

The experiment was laid out in a randomized block design with 8 treatments replicated 3 times. The treatments were: weedy check; weed free; atrazine 0.5 kg/ha as pre-emergence application (PE) + hand weeding (HW) at 35 days after seeding (DAS); atrazine 0.10 kg/ha as post-emergence application (PoE) + HW at 35 DAS; atrazine 0.20 kg/ha as PoE + HW at 35 DAS; atrazine 0.30 kg/ha as PoE + HW at 35 DAS; atrazine 0.40 kg/ha as PoE + HW at 35 DAS; and HW twice at 20 and 40 DAS. In weed free plot, hand weeding was done at 15, 30 and 45 DAS. The PE atrazine was sprayed after sowing on wet soil and PoE was applied at 20 DAS (3^{rd} leaf stage of weed) with the help of knapsack sprayer fitted with flood jet nozzle with discharge rate of 600 L water/ha. Pearl millet hybrid *'GHB 744'* was sown with 4.0 kg/ha seed by keeping 60 cm row spacing on 21 June 2013, 21 July 2014 and 21 June 2015 with onset of monsoon. The excess plants were thinned out at 20 DAS keeping within row distance at 10 cm to maintain uniform plant stand. The gross and net plot size was 5.0 × 3.6 m and 4.0 × 2.4 m, respectively. Pearl millet crop was fertilized with 80 kg N and 40 kg P/ha through urea and single super phosphate. At sowing 50% N along with full dose of P were applied and remaining 50% N was applied 30 DAS.

For measuring weed density, an area of 0.25 m^2 was selected randomly by throwing a metallic quadrate of size 0.5 × 0.5 m at 2 places at 30 DAS and at harvest and expressed on square meter basis (no./m^2). The weeds were dried in oven till a constant weight and then transformed into g/m^2 by using the appropriate formula. Weed density data showed variation and projected to square root transformation $\sqrt{x+0.5}$ to normalize their distribution. For nutrients removal study the weed samples collected were ground into fine powder and passed through a 40 mm mesh sieve and used for analysis of N, P and K concentration in weeds and the uptake of these nutrients. Nitrogen was estimated by Kjeldahl's method, P by Vanado-molybdo-phosphoric yellow colour method and K content was determined using flame photometry method. Growth, yield attributes and yield of pearl millet were recorded for 3 consecutive years. Due to yearly variation in price of pearl millet, the cost of cultivation and gross return were calculated by taking mean price of 3 years. Net returns were calculated by subtracting cost of cultivation from gross returns. All the data obtained were statistically analyzed using the F-test procedure given by Gomez and Gomez (1984). Least significant difference (LSD) values at p=0.05 were used for determine the significant of differences between means.

RESULTS AND DISCUSSION

Weed flora

The experimental field was infested with grassy weeds like, *Cynondon dactylon, Echinochloa colona, E. crus-galli*; broad-leaf weeds like, *Convolvulus arvensis, Digera arvensis, Commelina benghalensis, Amaranthus viridis, Trianthema portulacastrum, Eclipta alba* and sedges like, *Cyperus rotundus, C. esculentus* during all the years of experimentation.

Effect on weeds

All the weed management treatments were able to significantly reduced total weed density compared to weedy check at 30 DAS and harvesting stage (**Table 1**). The lowest density of total weeds was observed in weed-free plots and it was statistically significant over rest of the treatments during both the stages. The PoE application 0.40 kg/ha + HW at 35 DAS recorded significantly the lowest total weed density at 30 DAS (8.22 no./m^2) and at harvest (11.89 no./m^2) of the crop. Persistence of atrazine for longer period might have resulted in less weed population over weedy check treatment (Banga *et al.* 2000, Ram *et al.* 2005). The PoE application of atrazine 0.40 kg/ha + HW at 35 DAS, significantly reduced the broad-leaf weeds over hand weeding twice at 20 and 40 DAS, while grassy weeds and sedges remained statistically at par with it. The PE application of atrazine 0.50 kg/ha + HW at 35 DAS, significantly reduced the broad-leaf weeds over weedy check during 30 DAS and at harvest, while grassy weeds and sedges remained statistically at par with weedy check except grassy weeds at harvest. These are in conformity with the findings of Munde *et al.* (2012) and Mishra *et al.* (2017), who reported that broad-leaf weed controlled more efficiently than grassy weeds and sedges withthe application of atrazine.

Weed biomass at harvest significantly influenced by different weed management practices (**Table 2**). The highest weed biomass was recorded with weedy check, while the lowest with weed free condition. The PoE application of atrazine 0.40 kg/ha + HW at 35 DAS noted lowest weed biomass, which was at par with PE application of atrazine 0.50 kg/ha + HW

Table 1. Effect of weed management treatments on weeds density at two growth stages of pearl millet (pooled data of 3 years)

Treatment	Weed density (no./m^2) 30 DAS				At harvest			
	Grassy	Broad-leaf	Sedges	Total	Grassy	Broad-leaf	Sedges	Total
Atrazine 0.50 kg/ha as PE + HW	3.15 (9.4)	3.27 (10.2)	2.84 (7.5)	5.26 (27.2)	3.28 (10.2)	4.31(18.0)	3.60 (12.5)	6.42 (40.8)
Atrazine 0.10 kg/ha as PoE + HW	2.94 (8.1)	2.44 (5.5)	3.15 (9.4)	4.85 (23.0)	3.82 (14.1)	2.79 (7.3)	3.42 (11.2)	5.75 (32.6)
Atrazine 0.20 kg/ha as PoE + HW	2.74 (7.0)	1.65 (2.2)	2.93 (8.1)	4.22 (17.3)	3.39 (11.0)	2.09 (3.8)	3.09 (9.0)	4.94 (23.9)
Atrazine 0.30 kg/ha as PoE + HW	2.36 (5.0)	1.50 (1.7)	2.22 (4.4)	3.42 (11.2)	3.36 (10.8)	1.60 (2.1)	3.08 (9.0)	4.73 (21.9)
Atrazine 0.40 kg/ha as PoE + HW	2.29 (4.7)	1.12 (0.7)	1.79 (2.7)	2.95 (8.2)	2.37 (5.1)	1.39 (1.4)	2.42 (5.3)	3.52 (11.9)
Hand weeding twice at 20 and 40 DAS	2.12 (4.0)	2.71 (6.8)	1.92 (3.2)	3.81 (14.0)	2.66 (6.6)	2.75 (7.0)	2.43 (5.4)	4.42 (19.0)
Weedy check	3.73 (13.4)	6.15 (37.4)	3.22 (9.9)	7.82 (60.7)	4.47 (19.4)	7.21(51.5)	3.76 (13.6)	9.22 (84.6)
Weed free*	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	1.45 (1.6)	1.61 (2.1)	1.21 (1.0)	2.27 (4.7)
LSD (p=0.05)	0..67	0.96	0.64	1.01	0.75	0.98	0.68	1.05

Values are subjected to square root $\sqrt{x+0.5}$ transformation; figures in parentheses are original weed density/m^2**;** DAS: Days after sowing; HW: One hand weeding at 35 days after sowing; PE: Pre-emergence; PoE: Post-emergence; *Hand weeding at 15, 30 and 45 days after sowing (DAS)

Table 2. Effect of weed management treatments on weed biomass, weed control efficiency, weed index and pearl millet growth and yield attributes (pooled data of 3 years)

Treatment	Weed biomass (g/m^2)	Weed control efficiency (%)	Weed index (%)	Growth attributes: Plant height (cm)	Growth attributes: Total tillers/ plant	Yield attributes: Effective tillers/ plant	Yield attributes: Ear head length (cm)	Yield attributes: Ear head thickness (cm)	Yield attributes: 1,000 grain weight (g)
Atrazine 0.50 kg/ha as PE +HW	23.2	81.95	05.42	176.6	2.98	2.53	25.72	2.51	9.58
Atrazine 0.10 kg/ha as PoE + HW	67.2	47.71	23.48	169.5	2.69	2.24	24.11	2.35	9.39
Atrazine 0.20 kg/ha as PoE + HW	55.0	57.20	21.08	171.4	2.76	2.33	24.81	2.37	9.45
Atrazine 0.30 kg/ha as PoE + HW	36.3	71.75	17.28	172.7	2.84	2.40	25.03	2.42	9.53
Atrazine 0.40 kg/ha as PoE + HW	20.2	84.28	07.79	173.6	2.93	2.49	25.42	2.47	9.67
Hand weeding twice at 20 and 40 DAS	27.5	78.60	15.81	173.8	2.89	2.46	25.65	2.54	9.55
Weedy check	128.5	00.00	43.90	158.8	2.31	1.76	22.87	2.25	8.58
Weed free*	7.7	94.01	00.00	179.0	3.04	2.62	26.16	2.67	9.72
LSD (p=0.05)	14.8	10.54	6.97	5.7	0.17	0.16	1.32	0.23	0.30

DAS: Days after sowing; HW: One hand weeding at 35 days after sowing; PE: Pre-emergence; PoE: Post-emergence; *Hand weeding at 15, 30 and 45 days after sowing (DAS) at 35 DAS and hand weeding twice at 20 and 40 DAS. All the weed management treatments were able to significantly increase weed control efficiency (WCE) over weedy check and decrease weed index (WI) over weed free condition. Significantly the highest WCE noted with weed free (94.0%), which was at par with PoE application of atrazine 0.4 kg/ha + HW at 35 DAS (84.3%). Post-emergence application of atrazine 0.4 kg/ha + HW at 35 DAS, PE application of atrazine 0.5 kg/ha + HW at 35 DAS and hand weeding twice at 20 and 40 DAS recorded at par WCE with each other. Among all the weed control treatments, the lower WI was recorded with PE application of atrazine 0.5 kg/ha + HW at 35 DAS (5.4%), which was at par with PoE application of atrazine 0.4 kg/ha + HW at 35 DAS (7.8%). Weedy check recorded the maximum weed index (43.9%) due to maximum weed growth during entire crop growth period. The maximum WCE and minimum WI with PoE atrazine application was reported by Girase *et al.* (2017) in *Kharif* and Das *et al.* (2013) in summer season.

Effect on crop

All the weed control treatments significantly increased the growth and yield attributes and grain and stover yields of pearl millet compared with weedy check (**Table 2** and **3**). Different growth attributes, *viz*. plant height and total tillers/plant and yield attributes, *viz*. effective tillers/plant, ear head length, ear head thickness and 1,000 grain weight were recorded significantly the highest with weed free, which were at par with PE application of atrazine 0.50 kg/ha + HW at 35 DAS and post-emergence application of atrazine 0.40 kg/ha + HW at 35 DAS over weedy check. This might be owing to low weed density and biomass, which helped reduction in crop-weed competition and better crop growth and production of more effective tillers (Girase *et al*. 2017). The grain and stover yields (3.47 and 5.31 t/ha respectively) were significantly higher in weed free treatment and were at par with PE application of atrazine 0.50 kg/ha + HW at 35 DAS (3.28 and 5.10 t/ha, respectively) and PoE application of atrazine 0.40 kg/ha + HW at 35 DAS (3.20 and 4.93 t/ha, respectively). The efficient weed control measures reduced weed density and biomass resulting in improvement of yield related traits and ultimately crop yield (Mathukia *et al.* 2015, Ram *et al.* 2004). The lowest grain and stover yields were recorded with weedy check. This might be due to the fact that the luxuriant growth of many weed species with greater nutrient removal from the soil thus, reduced the crop yield considerably. These findings are in close conformity with those reported by Singh *et al.* (2017) and Kiroriwal *et al.* (2012).

Nutrient removal by weeds

Mean data of 3 years showed that all weed control treatments brought significant variation in nutrient removal by weeds in pearl millet (**Table 3**). The nutrient removal by weeds under unweeded situation was the maximum. The nutrient removal by weeds in all the weed control treatments was significantly lower compared with weedy check. The lowest NPK removal by weeds was recorded with weed free situation, which was statistically at par with PoE application of atrazine 0.4 kg/ha + HW at 35 DAS and PE application of atrazine 0.50 kg/ha + HW at 35 DAS. Similar reduction in nutrient removal by weeds under different weed management practices had also reported by Swapnil *et al.* (2017) in sorghum and Goswami *et al.* (2002) in pearl millet.

Economics

The choice of any weed control method ultimately depends on economics and efficiency in controlling weeds. The highest gross returns (` 56,508/ha) and net returns (` 41,733/ha) were observed in weed free treatment, which remained at par with PE application of atrazine 0.50 kg/ha + HW at 35 DAS and PoE application of atrazine 0.40 kg/ha + HW at 35 DAS. The maximum cost of cultivation was registered with weed free treatment due to higher cost of labour charges. Similar results were also reported by Mathukia *et al.* (2015) and Mishra *et al.* (2017). Significantly the highest benefit: cost ratio (BCR) was reported with PE application of atrazine 0.50 kg/ha + HW at 35 DAS (2.97) and remained at par with PoE application of atrazine 0.40 kg/ha + HW at 35 DAS (2.90) and weed free situation (2.82). Girase *et al.* (2017) also recorded the higher benefit: cost ratio with application of atrazine over weed free conditions. All the weed control treatments resulted in higher gross and net returns and BCR over weedy check.

Conclusion

Based on above results, it may be concluded that in case of labour scarcity, PE application of atrazine 0.50 kg/ha followed by hand weeding at 35 DAS or PoE application of atrazine 0.40 kg/ha at 3 leaf stage of weed followed by hand weeding at 35 DAS could be a best option for achieving higher yield, net returns, benefit: cost ratio as well as significant weed suppression in pearl millet.

Table 3. Effect of weed management treatments on pearl millet yield,nutrient removal by weeds and economics (pooled data of 3 years)

Treatment	Yield (t/ha)		Nutrient removal by weeds (kg/ha)			Economics			
	Grain	Stover	N	P	K	Gross returns (x10^3 `/ha)	Cost of cultivation (x10^3 `/ha)	Net returns (x10^3 `/ha)	Benefit: cost ratio
Atrazine 0.5 kg/ha as PE +HW	3.28	5.10	2.99	0.46	2.76	53.56	13.47	40.09	2.97
Atrazine 0.1 kg/ha as PoE + HW	2.65	4.42	8.80	1.38	8.20	43.77	13.07	30.70	2.35
Atrazine 0.2 kg/ha as PoE + HW	2.74	4.55	7.15	1.11	6.60	45.13	13.18	31.95	2.43
Atrazine 0.3 kg/ha as PoE + HW	2.86	4.69	4.72	0.73	4.36	47.18	13.27	33.91	2.55
Atrazine 0.4 kg/ha as PoE + HW	3.20	4.93	2.61	0.40	2.40	52.16	13.38	38.78	2.90
Hand weeding twice at 20 and 40 DAS	2.92	4.81	3.55	0.54	3.27	48.09	13.73	34.36	2.50
Weedy check	1.94	3.70	16.96	2.66	15.81	32.79	11.63	21.16	1.82
Weed free*	3.47	5.31	0.99	0.15	0.90	56.51	14.78	41.73	2.82
LSD (P=0.05)	0.28	0.38	2.27	0.32	2.08	4.89	-	3.41	0.27

DAS: Days after sowing;HW: One hand weeding at 35 days after sowing; PE: Pre-emergence; PoE: Post-emergence; *Hand weeding at 15,30 and 45 days after sowing (DAS)

REFERENCES

Banga RS, Yadav A, Malik RK, Pahwa SK and Malik RS. 2000. Evaluation of tank mixture of acetachlor and atrazine or 2, 4-D Na against weeds in pearl millet. *Indian Journal of Weed Science* **32**(2):194–198.

Das J, Patel BD, Patel VJ and Patel RB. 2013. Comparative efficacy of different herbicides in summer pearl millet. *Indian Journal of Weed Science* **45**(3): 217–18.

DES. 2016. *Agricultural Statistics at a Glance.*Directorate of economics and statistics, Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India, New Delhi. 102 p.

Girase PP, Suryawanshi RT, Pawar PP and Wadile SC. 2017. Integrated weed management in pearl millet. *Indian Journal of Weed Science* **49**(1): 41–43.

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

Goswami, VK, Kaushik SK and Gautam RC. 2002. Effect of intercropping and weed control on nutrient uptake and water-use efficiency of pearl millet (*Pennisetum glaucum*) under rainfed conditions. *Indian Journal of Agronomy* **47**(4): 504–508.

Kiroriwal A, Yadav RS and Kumawat A. 2012. Weed management in pearl millet based cropping system. *Indian Journal of Weed Science* **44**(3): 200–203.

Mathukia RK, Mathukia PR, Polara AM. 2015. Intercropping and weed management in pearl millet under *rainfed* condition. *Agricultural Science Digest* **35**(2): 138–141.

Mishra PS, Reddy R, Subramanyam D and Umamahesh V. 2017. Impact of integrated weed management practices on weed dynamics, growth and yield of pearl millet. *International Journal of Agriculture Sciences* **9**(3): 3677–79.

Munde SD, Aghav VD, Pagar RD and Patel JC. 2012. Effect of herbicides on weeds and yield of rainy season pearl millet.*Crop Research* **44**(3): 288–291.

Ram B, Chaudhary GR and Jat AS and Jat ML. 2005. Effect of integrated weed management and intercropping systems on growth and yield of pearl millet. *Indian Journal of Agronomy* **50**(3): 210–213.

Ram B, Chaudhary GR and Jat AS. 2004. Nutrient depletion by weeds, weed control efficiency and productivity of pearlmillet (*Pennisetum glaucum*) as influenced by intercropping systems and integrated weed management. *Indian Journal of Agricultural Sciences* **74**(10): 534–538.

Sharma OL and Jain NK. 2003. Integrated weed management in pearl millet (*Pennisetum glaucum*). *Indian Journal of Weed Science* **35**(1&2): 34–35.

Singh R, Kumar R, Kumar R, Kumar S, Kumar J, Pal LK, Kumar M, Kumar P and Sahu Y. 2017. Effect of weed management on growth, yield and yield attributes of pearl millet (*Pennisetum glaucum* L.) var. '*Manupur*' under rainfed condition. *Journal of Pharmacognosy and Phytochemistry* **6**(6): 1133–1135.

Swapnil, Deshmukh P and Usadadia VP. 2017. Weed management influence on crop-weed competition in sorghum under South Gujarat conditions. *Indian Journal of Weed Science* **49**(3): 272–275.

Indian Journal of Weed Science **50**(3): 278–281, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Nutrient uptake in maize under different weed and nutrient management options

Parvati Deewan*, S.L. Mundra, Jigyasa Trivedi, R.H. Meena and R. Verma

Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan 313 002

**Email: parvatideewan@gmail.com*

Article information

DOI: 10.5958/0974-8164.2018.00059.X

Type of article: Research article

Received : 3 August 2018
Revised : 24 September 2018
Accepted : 29 September 2018

Key words

Atrazine, Metribuzin, Oxyfluorfen, Quality protein maize, Weeds

ABSTRACT

Results of field experiment carried out during *Kharif* 2011 and 2012 at Instructional Farm, Rajasthan College of Agriculture, Udaipur, indicated various weed-management treatments significantly enhanced N and P uptake by maize (*Zea mays* L.) and reduced removal of nutrients by weeds as compared to weedy check. Maximum saving of 52.96% nitrogen and 51.87 % phosphorus was achieved with oxyfluorfen 0.15 kg/ha pre-emergence *fb* one hoeing 30 DAS. On pooled basis, this treatment gave 163.57% and 95.86%more grain and stover yield, respectively compared to weedy check, which was followed by metribuzin 0.25 kg/ha pre- emergence *fb* one hoeing 30 DAS. The yield as well as uptake of N and P by the crop was maximum with 150% RDF which were statistically at par with 125% RDF.

INTRODUCTION

Maize is an important cereal crop of Rajasthan during *Kharif* season. The state yield (1.78 t/ha) lagged way behind its potential yield. Maize is known to be very responsive to better management. However, weeds constitute a major problem in harnessing yield potential of maize. Reduction in yield of maize may be as high as 40-60% or even more depending upon the intensity and types of weed infestation (Thobatsi 2009). At present no herbicide is available which alone can provide desired degree of weed control in the maize crop. Moreover, the continuous use of single herbicide could be responsible for the evolution of herbicide resistance in various weed species and shift in weed flora (Pandey *et al.* 1999). Proper selection of herbicide along with proper dose and their integration with hoeing and weeding are the important considerations for lucrative returns in maize. Among the growth inputs mineral nutrition also plays a vital role in maize production. Nutrition losses caused by weeds can be effectively tackled either by effective weed management or through the use of higher fertilizer or combination of both. In view of these facts present investigation was therefore undertaken to study the extent of nutrient depletion by crop and weeds under various weed and nutrient management systems and to minimize these losses by controlling weeds.

MATERIALS AND METHODS

The experiment was conducted at Instructional Farm, Rajasthan College of Agriculture, Udaipur during *Kharif* season of 2011 and 2012. The experimental soil was clay loam, slightly alkaline, medium in available nitrogen and phosphorus and high in potassium. The experiment consisted of six weed-management treatments, *viz.* weedy check, atrazine 0.50 kg/ha pre-emergence *fb* one hoeing 30 DAS, metribuzin 0.25 kg/ha pre-emergence *fb* one hoeing 30 DAS, oxyfluorfen 0.15 kg/ha pre-emergence *fb* one hoeing 30 DAS, two hoeing 15 and 30 DAS, weed free in main plots and 4 nutrient management treatments *viz.* 75% RDF, 100% RDF, 125% RDF, 150% RDF in sub-plots. The experiment was laid out in split plot design with three replications. Maize variety "*HQPM-5*" was sown at 60 cm row spacing using 25 kg/ha seed on 7th and 8th July and harvested on 15 and 16 October in respective seasons. Application of 120 kg N and 40 kg P_2O_5/ha was done through Urea and DAP, respectively, as recommended dose of fertilizer. As per treatment whole dose of phosphorus and one–fourth dose of nitrogen was applied at the time of sowing and the remaining three-fourth dose of nitrogen was applied as top dressing in three equal splits each at 5-6 leaf stage, knee high and tasselling stage of crop growth. The size of the gross and net plot was 5.0 x 3.6 m and

4.0 x 2.4 m, respectively. Total rainfall in the respective seasons during crop period was 872.1 mm and 642.4 mm. As per treatment, herbicides (atrazine, metribuzin and oxyfluorfen) were sprayed one day after sowing as pre-emergence spray, when there was sufficient moisture in the soil. Inter-cultivation as per treatment was done at 30 DAS with hand-hoe (Kudali). Yield data on crops and dry weight of weeds were recorded at harvest. Crop was kept weed free up to 60 DAS. Observations on various parameters were taken following standard procedures.

RESULTS AND DISCUSSION

In two year field study, maize was infested with mixed flora of narrow and broad–leaved weeds. Important narrow-leaved weeds were *Cynodon dactylon*(L.), *Echinochloa colona* (L.), *Cyperus rotundus* (L.), *Brachiraria reptans* (L.) and *Dinebra arabica*(L.) while important broad-leaved weeds were *Amaranthus viridis, Commelina benghalensis* (L.), *Digera arvensis*(L.) and *Trianthema portulacastrum*. Out of these *Echinochloa colona* was the most dominating narrow leaved weed at the experimental site during both the years.

Dry matter

Pooled data **(Table 1)** revealed that all the weed-management treatments significantly reduced dry matter of narrow-leaved, broad-leaved and total dry matter of weeds compared to weedy check. Oxyfluorfen *fb* hand hoeing 30 DAS recorded the minimum total weed dry matter (139.08 g/m^2) after weed free treatment (26.80 g/m^2), however its effect was statistically at par with metribuzin *fb* hand hoeing 30 DAS (150.83g/m^2). Maximum total weed dry matter (644.37 g/m^2) was recorded in weedy check. Both of herbicidal treatments integrated with hand hoeing were found significantly superior to rest of the weed control treatments in reducing the total dry matter of weeds. The better weed control under these treatments was because of the reason that pre-emergence application of these herbicides curb the germination and growth of majority of weeds for longer period possibly due to its longer persistence in soil and whatever the weeds left uncontrolled were effectively tackled by hoeing operations done 30 DAS. The results corroborated with the findings of Nadiger *et al.* (2013) and Dutta *et al.* (2016) in maize. Amongst the various nutrient management treatments, significant increase in dry matter of both broad and narrow-leaved weeds as well as total weeds at harvest was recorded by raising the fertility levels upto 125% RDF. The maximum total weed dry matter of 248.36 g/m^2 was recorded under 150% RDF, which was statistically at par with 125% RDF (243.20 g/m^2) and minimum total weed dry matter was recorded under 75% RDF (207.29 g/m^2). Significant increase in weed dry matter with increase in fertility levels might be ascribed to the fact that increasing fertility provides greater amount of nutrients to weeds which perhaps might have resulted into better growth of weeds and reflected into more dry matter accumulation by them. The observed relationship corroborate with the findings of Venkata *et al.* (2016).

Table 1. Effect of weed and nutrient management on dry matter of weeds and nutrient removal at harvest (pooled data of 2 years)

Treatment	Weed dry matter (g/m^2)			Nutrient removal by weeds (kg/ha)					
				Nitrogen			Phosphorus		
	Narrow - leaved	Broad-leaved	Total	Narrow-leaved	Broad-leaved	Total	Narrow-leaved	Broad-leaved	Total
Weed management									
Weedy check	494.9	149.5	644.3	72.2	25.6	97.9	12.7	4.16	16.87
Atrazine 0.5 kg/ha *fb* HW 30 DAS	170.9	31.3	202.2	25.9	5.61	31.5	4.55	0.90	5.45
Metribuzin 0.25 kg/ha *fb* HW 30 DAS	123.8	27.0	150.8	19.1	4.99	24.1	3.33	0.80	4.13
Oxyfluorfen 0.15 kg/ha *fb* HW 30 DAS	116.0	23.1	139.1	18.0	4.36	22.3	3.16	0.69	3.85
HW 15 and 30 DAS	178.3	46.8	225.1	26.5	8.35	34.8	4.71	1.35	6.06
Weed free(Up to 60 DAS)	20.3	6.5	26.8	3.2	1.24	4.5	0.56	0.19	0.75
LSD (p=0.05)	14.0	4.2	17.9	1.6	0.86	1.8	0.36	0.15	0.28
Nutrient management									
75% RDF	166.5	40.8	207.3	24.4	7.13	31.5	4.31	1.15	5.46
100% RDF	179.7	47.0	226.8	26.8	8.28	35.1	4.71	1.33	6.04
125% RDF	193.0	50.2	243.2	29.0	8.89	37.9	5.11	1.43	6.54
150% RDF	196.9	51.5	248.4	29.7	9.17	38.9	5.23	1.47	6.70
LSD (p=0.05)	10.4	3.2	12.8	1.2	0.64	1.23	0.23	0.09	0.19

Grain, stover and biological yield

All the weed management treatments significantly increased grain, stover and biological yields compared to weedy check on pooled basis **(Table 2).** The pronounced effect of increased yield was observed with oxyfluorfen *fb* hand hoeing 30 DAS. This resulted into increase in grain, stover and biological yield by 163.57%, 95.86% and 115%, respectively compared to the weedy check treatments. The increase in yield under various weed management treatments might be attributed to significant reduction in weed dry matter **(Table1)** thereby reduction in crop-weed competition which provided congenial environment to the crop for better expression of vegetative and reproductive potential. Application of 150% recommended dose of fertilizer gave the highest grain (3.54 t/ha), stover (6.48 t/ha) and biological (10.01 t/ha) yields which were statistically at par with 125% RDF (grain 3.41 t/ha, stover 6.35 t/ha and biological yield 9.76 t/ha). The respective increase in grain, stover and biological yield under 150% RDF was 43.15, 22.41 and 29.01% compared to the lowest yield levels being recorded under 75% RDF. Higher fertility levels might have increased availability of nutrients in the soil which culminated into more absorption and higher uptake of nutrients by the crop thereby better plant growth. The favourable effect on yield could also be due to lesser competition for nutrient between crop and weeds under higher fertility levels. Results corroborate with the findings of Singh and Nepalia (2009).

Nutrient uptake by crop

All the weed management treatments significantly enhanced N and P uptake by grain, stover as well as total uptake of these nutrients by the crop over weedy check **(Table 2)**. The highest N and P uptake by the grain (68.4,13.7 kg/ha), stover (48.3,11.9 kg/ha) and total uptake (116.7,25.6 kg/ha) by the crop was recorded with oxyfluorfen *fb* hand hoeing 30 DAS after weed free treatment which was closely followed by metribuzin *fb* hand hoeing 30 DAS. It might be ascribed to lower weed dry matter due to higher weed control efficiency with these treatments resulting in more favorable environment for growth and development of crop plants. The results confirm the findings of Mahadevaiah and Karuna (2014). The highest total uptake of nitrogen (109.6 kg/ha) and phosphorus (23.7 kg/ha) were recorded under 150% RDF which was statistically at par with 125% RDF compared with lowest (73.1 and 16.3 kg/ha respectively) recorded under 75% RDF. The nutrient uptake by the crops is mainly the function of crop yield. Therefore, considerable increase in N and P uptake by crop was attributed to higher grain and stover yield at higher fertility levels. The results are in close conformity with the findings of Nath *et al.* (2009).

Nutrient removal by weeds

All the weed management treatments resulted into significant reduction of nutrient removal by narrow-leaved, broad-leaved and total uptake of these nutrients by the weeds compared to weedy check. The least drain of total N (22.35 kg/ha) and P (3.85 kg/ha) by weeds was recorded under oxyfluorfen *fb* hand hoeing 30 DAS treatment which was closely followed by metribuzin *fb* hand hoeing 30 DAS **(Table 1)**, while the maximum removal of nutrients

Table 2. Effect of weed and nutrient management on yield and nutrient removal by maize at harvest (pooled data of 2 years)

Treatment	Yield (t/ha)			Nutrient removal by crop (kg/ha)					
				Nitrogen			Phosphorus		
	Grain	Stover	Biological	Grain	Stover	Total	Grain	Stover	Total
Weed management									
Weedy check	1.40	3.55	4.96	23.7	20.21	43.91	4.25	4.86	9.11
Atrazine 0.5 kg/ha *fb* HW 30 DAS	3.09	5.94	9.03	53.2	37.11	90.31	10.29	9.03	19.32
Metribuzin0.25 kg/ha *fb* HW 30 DAS	3.55	6.59	10.15	62.73	44.31	107.0	12.68	10.95	23.63
Oxyfluorfen0.15 kg/ha *fb* HW 30 DAS	3.69	6.96	10.66	68.36	48.34	116.7	13.68	11.93	25.61
HW 15 and 30 DAS	2.94	5.76	8.70	50.39	35.65	86.04	9.75	8.71	18.46
Weed free(Up to 60 DAS)	3.85	7.22	11.07	71.4	51.96	123.4	14.65	12.64	27.29
LSD (p=0.05)	188	390	508	4.05	3.56	7.73	0.92	0.89	1.59
Nutrient management									
75% RDF	2.47	5.29	7.76	40.04	33.03	73.07	8.22	8.08	16.3
100% RDF	2.94	5.91	8.85	51.96	38.42	90.38	10.22	9.4	19.62
125% RDF	3.41	6.35	9.76	62.54	42.69	105.2	12.26	10.45	22.71
150% RDF	3.54	6.48	10.01	65.31	44.25	109.6	12.84	10.82	23.66
LSD (p=0.05)	127	267	348	2.79	2.46	4.53	0.6	0.58	1.22

(97.90 kg N and 16.87 kg P/ha) was recorded under weedy check. Significantly higher removal of N and P by narrow leaved, broad leaved and total uptake of these nutrient by the weeds were found under 100,125 and 150% RDF compared to 75% RDF. The uptake of N and P by weeds was estimated as 69.04% and 64.93%, respectively, of the total removal (weed + crop) in weedy check and only 16.07% and 13.07% in oxyfluorfen *fb* hand hoeing 30 DAS and18.36% and14.88% in metribuzin *fb* hand hoeing 30 DAS treatment. Thus saving of 52.96% N and 51.87% P could be obtained by the adoption of treatment oxyfluorfen *fb* hand hoeing 30 DAS while the respective saving of these nutrients under in metribuzin *fb* hand hoeing 30 DAS treatment was 50.67% and 50.06%. The uptake of N and P by the crop and weeds could be mainly attributed to their dry matter production. It is apparent from table 1 and 2 that whenever the removal of nutrients by weeds was more, corresponding uptake by the crop was less and vice-versa. Therefore, for efficient utilization of applied nutrients the weeds should be kept under control. On the basis of two years investigation on weed and nutrient management, it can be concluded that pre-emergence application of 0.15 kg oxyfluorfen / ha in conjugation with hoeing 30 DAS resulted in highest nutrient uptake by crop as well as the highest yield of quality protein maize. Under nutrient management treatments, 125% RDF (150 kg N and 50 kg P_2O_5) may be applied for maximization of nutrient uptake by crop and thereby yield.

REFERENCES

Dutta D, Thentu TL, Saha B and Duttamudi D. 2016. Effect of weed management practices on weed flora, soil micro-flora and yield of baby corn (*Zea mays*). *Indian Journal of Agronomy* **61**: 210–216.

Mahadevaiah K and Karuna SG. 2014. Effect of integrated weed management practices on yield, nutrient uptake and economics of baby corn. *Agricultural Science Digest* **34**: 303–306.

Nadiger S, Babu R and Kumar BNA. 2013. Bioefficacy of pre-emergence herbicides on weed management in maize. *Karnatka Journal of Agriculture Sciences* **2**: 17–19.

Nath K, Nepalia V and Singh D. 2009. Effect of integrated nutrient management on growth and yield of sweet corn (*Zea mays saccharata*). *Annals of Agricultural Research New series* **5**: 73–76.

Pandey A K, Singh P, Prakash V, Singh RD and Chuhan VS. 1999. Direct and residual effect of weed control measures in maize (*Zea mays* L.) and wheat (*Triticum aesitivum*) cropping system under mid-hill conditions of N-W Himalyas. *Indian Journal of Weed Sciences* **31**: 204–209.

Singh D and Nepalia V. 2009. Influence of integrated nutrient management on quality protein maize (*Zea mays*) productivity and soil of Southern Rajasthan. *Indian Journal of Agricultural Sciences* **79**: 1020–1022.

Thobatsi T. 2009 .*Growth and Yield Responses of Maize (Zea mays L.) and Cowpea (Vigna ungiculatea) in a Intercropping System*. M.Sc.Thesis, University of Pretoria. 149 p.

Venkata RP, Subbaiah G and Veeraraghavaiah R. 2016. Productivity and nutrient uptake of rice fallow maize (*Zea mays* L.) as influenced by plant density and fertilizers N under no till conditions. *International Journal of Current Microbiology Applied Sciences* **5**: 826–836.

Indian Journal of Weed Science **50**(3): 282–286, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Dynamics of microbial community and enzyme assay as influenced by green manuring and weed control measures in rice-groundnut cropping system

S.S. Pinjari*, S.B. Ganagawane, Y.R. Govekar, U.V. Mahadkar and N.A. Meshram

Department of Agronomy, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra 415 712

**Email: pinjari94222@gmail.com*

Article information

DOI: 10.5958/0974-8164.2018.00060.6

Type of article: Research article

Received : 2 June 2018
Revised : 29 July 2018
Accepted : 2 August 2018

Key words

Bacteria

Fungi

Free living nitrogen fixers

Microbial biomass carbon

Phosphate solubilizers

ABSTRACT

A long-term experiment was commenced (2011) and conducted at the Research Farm of Dapoli (Maharashtra) during *Kharif* and *Rabi* season in rice–groundnut cropping system, to evaluate the effect of green manuring and different weed control measures on the survival and growth of total bacteria, total fungi, total free living nitrogen fixers and total phosphate solubilizers in rhizospheric soil. Results emerged out from the conduct during 2011 to 2014 indicated that, green manuring (in-situ application of *Sesbania rostrata* 45 DAS) and without green manuring (control) as a main plot treatment and among the weed control measures and sub plot treatments comprising, comparative effects of hand weeding, fixed herbicide pretilachlor (pre-emergence) for rice crop and pendimethalin (pre-emergence) for groundnut crop, and different rotational herbicides (for rice crop, pyrazosulfuron 0.030 kg/ha at 8-10 DAT (1 year)**,** fenoxaprop -p-ethyl 0.056 kg/ha at 25-30 DAT (2 year)**,** oxadiargyl 0.100 kg/ha at 0-5 DAT (3 year), and for groundnut crop oxadiargyl 0.12 kg/ha at 0-2 DAS-1 year, butachlor 1.0 kg/ha at 0-3 DAS-2 year, alachlor1.5 kg/ha at 0-3 DAS-3 year) application to both the crops were significantly tested along with weedy check. The results concluded that the green manuring significantly increased in microbial populations than without green manuring. There were no adverse effects of herbicidal use on all the estimated microbial population at all the stages of both the crops. In contrast to use of fixed herbicide pretilachlor-S 0.75 kg/ha for rice and pendimethalin 1.00 kg/ha and different rotational herbicides had no long-term adverse effects on rhizosphere micro-flora of rice–groundnut cropping system.

INTRODUCTION

Soil micro-organisms and soil enzymes play a major role in soil fertility as these involve in the cycling of nutrients like carbon, nitrogen, phosphorus and sulphur, which are required for the plant growth. They are the sensitive biological indicators of soil quality evaluation because they can sensitively reflect minute changes in the soil environment. Soil microbial biomass is of great importance, because they play a crucial role in carbon flow, nutrient cycling and litter decomposition, which in turn affect soil fertility and plant growth (Bamboo *et al*. 2013). Healthy population of bacteria, fungi and actinomycetes can stabilize the ecosystem. Any change in the population and activity may indirectly affect the nutrient cycling, which in turn affects the productivity, fertility and other soil functions (Wang *et al*. 2008).Soil enzymes, the vital activators in life processes, are known to play a substantial role in maintaining the soil health and its environment. They are important in catalyzing several vital reactions necessary for the life processes of micro-organisms in soils and the stabilization of soil structure, the decomposition of organic wastes, organic matter formation and nutrient cycling (Dick, 1997).

Soil enzymes provide a unique integrative biological assessment of soil function, especially those that catalyze a wide range of soil biological processes, such as dehydrogenase, urease and phosphatase (Nannipieri *et al*. 2002). The dehydrogenase enzyme activity is commonly used as an indicator of biological activity in soils (Burns, 1978). Phosphatase catalyzes hydrolytic break down of phosphor monoesters, thereby showing a high correlation between the content of soil phosphorus and an indicator of soil fertility. Urease is the enzyme that catalyzes the hydrolysis of urea to CO_2 and NH_4^+ ions byacting on C-N non-peptide bonds in linear amides. It is an important enzyme in soil that mediates the conversion of organic nitrogen to inorganic nitrogen and has been widely used to evaluate the changes in soil fertility (Nazreen *et al.* 2012). Herbicide usage seems to be inevitable in transplanted rice, since weeds are the prime biological constraint due to the simultaneous emergence of rice and weed seedling, scarcity of labour and huge labour cost. A large numberof pre- and post-emergence herbicides are used by the farmers to control weeds in rice.

The pre- and post-emergence application of herbicides resulted in large proportion of herbicides reaching the soil and accumulating in top 0 to15 cm depth causing ecological damage (Latha and Gopal 2010). Preferred herbicides should not only have good efficacy, but also pose minimum adverse effects to crop, ecology and environment (Constenla *et al.* 1990). The continuous use of herbicides with similar mode of action might lead to the development of resistance in certain weeds to the herbicides and cause shift in weed flora. One of the recent advent ways to overcome this problem is the use of different herbicide. The impact of different herbicides on soil enzymatic activity and microbial population has not been studied so far. Hence, a study was conducted with an objective to find out the impact of herbicide on bacteria, fungi, nitrogen fixer, phosphate solubilizers, microbial biomass carbon and basal soil respiration in rice–groundnut cropping system

MATERIALS AND METHODS

The field experiment was started on 2011 and conducted for four years study at the Research Farm of All India Co-ordinated Research Project on Weed Management under Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli (Maharashtra) for rice-groundnut cropping system. The experiment was conducted on *Kharif* rice (Ratnagiri-24) and *Rabi* groundnut (KonkanTapora) cropping system, which included eight treatment combinations laid out in a split plot design (SPD) with three replications. The main plot treatments included green manuring, *viz.* green manuring with *Sesbania rostrata* (in-situ application after 45 DAS) and without green manuring (control) while the sub-plot treatments included weed control measures such as hand weeding at 20 and 40 DAS, fixed herbicide pretilachlor-S 0.75 kg/ha 3-7 days after transplanting (DAT) for rice crop and pendimethalin 1.0 kg/ha PE (pre-emergence) for groundnut crop and different rotational herbicides (for rice crop, pyrazosulfuron 0.030 kg/ha at 8-10 DAT(1 year)**,** fenoxaprop-p-ethyl 0.056 kg/ha at 25-30 DAT (2 year)**,** oxadiargyl 0.100 kg/ha at 0-5 DAT (3 year), and for groundnut crop oxadiargyl 0.12 kg/ha at 0-2 DAS-I year,butachlor 1.0 kg/ha at 0-3 DAS-2 year, alachlor1.5 kg/ha at 0-3 DAS-3 year), weedy check. Rhizospheric soils were collected at 30, 50 days after sowing (DAS) and at harvesting stage of both the crops by uprooting of four plants from each plot and keeping the soil around root system intact. After removing the bits of plant roots and other debris, the soil strongly adhered to the roots was immediately used without drying for determination of biological property of rhizospheric soils.

The total bacterial population, total fungal population, free living nitrogen fixers and total phosphate solubilizers of rhizosphere soil were determined. The colony forming units (CFU) of bacteria were enumerated on nutrient agar-agar media by serial dilution technique for bacterial populations, Martin's rose Bengal agar media used for total fungal population (Martins 1950), Noories N-free media used for total free living nitrogen fixers (Noories 1959) and Pikovskaya's agar medium used for total phosphate solubilizing microorganisms (Pikovskaya 1948). The relative equivalent yield (REY) was calculated by the mixture yields of a component crop expressed as a portion of its yields as a sole crop from the same replacement series is the relative yield of crop and sum of the relative yields of component crop. The experimental data were subjected to analysis of variances (ANOVA) and treatment means were compared, significant differences were tested at p=0.05 using split plot design (SPD) as given by Panse and Sukhatme (1985) using computer design DBSKKV_STAT.

RESULTS AND DISCUSSION

Effect of green manuring

The populations of all soil microbes were significantly influenced due to green manuring as compare to without green manuring (**Tables 1-4**). Significantly higher microbial population were found in green manuring treatment as compared to the without green manuring at 30 DAS, 50 DAS and at harvesting stage in *Kharif* rice as well as in *Rabi* groundnut. The increase in microbial population with the incorporation of green manuring (sesbania) in soil due to addition higher biomass reflects higher microbial diversity in soil (Tilak 2004). The green manures applied to the soils, it increases soil organic matter which helps to increased microbial populations, mineralization, enzymes assay and also maintain the soil C/N ratio (Tejada *et al.* 2008).

Effect of weed control measure

In rice crop, the treatment weed free check (2 HW) significantly influenced all soil microbes' population except fungi, which were found to be significantly superior over fixed herbicide, rotational herbicide and weedy check at 30 DAS, 50 DAS and at harvesting stage. The bacterial populations were also found significantly less in fixed herbicide and the rotational herbicide as compared to weedy check at 30 DAS, which were found to be at par with weedy check at 50 DAS and at harvest (**Table 1 and 2**). In respect of groundnut crop, the treatment of hand weeding twice caused significant increase in population of all soil microbes (*viz*. bacteria, nitrogen fixers, phosphate solubilizers, microbial biomass, basal soil respiration) except fungi population, which were noticed significantly superior than the both fixed and rotational herbicide and remain at par with weedy check at initial stage of 30 DAS, (**Table 3 and 4**). Microorganisms are able to degrade herbicides and utilize them as a source of biogenic elements for their own physiological processes. However, before degradation, herbicides have toxic effects on microorganisms, reducing their abundance, activity and consequently, the diversity of their communities (Adhikary *et al*. 2014). The toxic effects of herbicides are normally most severe immediately after application, when their concentrations in soil are the highest. Later on, microorganisms take part in a degradation process, and herbicide concentration and its toxic effect gradually decline up to half-life. Then the degraded organic herbicide provides the substrate with carbon, which leads to an increase of the soil microflora (Bera and Ghosh, 2013, Goveykar *et al*. 2014, Kumar 2015).The interaction effects of green manuring and weed control measures were found to be statistically non-significant.

Total relative equivalent yield of rice–groundnut cropping system

Effect of green manuring

The REY of rice-groundnut cropping system did not influence due to green manuring in whole pooled results. However, green manuring was recorded higher total REY of rice-groundnut cropping system than without green manuring (**Table 5**).

Table 1. Combined effects of green manuring and weed control measure on bacterial, fungal population and nitrogen fixers in rice–groundnut cropping system during *Kharif* season

Treatment	Bacteria (CFU x10^{-6}/g of soil)			Fungi (CFU x10^{-4}/g of soil)			Nitrogen fixers (CFU x10^{-3}/g of soil)		
	30 DAS	50 DAS	Harvest	30 DAS	50 DAS	Harvest	30 DAS	50 DAS	Harvest
Main plot treatment : Green manuring									
Green manuring	39.63	36.04	32.69	26.43	22.96	19.76	28.86	24.71	22.25
Without green manuring	31.85	31.49	26.67	17.32	17.10	12.97	21.23	20.34	17.16
LSD (p=0.05)	2.71	0.76	3.50	5.76	2.07	2.82	2.92	2.24	1.85
Sub plot: Weed control measures									
Fix herbicide – pendimethalin(PE)	33.62	31.82	27.03	20.39	19.03	15.99	22.85	20.54	17.33
Rotational herbicide – alachlor	33.80	31.63	27.17	20.07	18.35	15.17	22.62	20.45	17.65
Weed free check	38.98	37.72	34.38	24.92	22.64	18.27	28.94	26.64	24.15
Weedy check	36.56	33.88	30.12	22.10	20.09	16.03	25.75	22.47	19.70
LSD (p=0.05)	2.13	2.13	3.06	NS	NS	NS	2.02	2.95	4.10

Table 2. Combined effects of green manuring and weed control measure on phosphate solubilizers, microbial biomass carbon and basal soil respiration in rice – groundnut cropping system during *Kharif* season

Treatment	Phosphate solubilisers (CFU x10^3/g of soil)			Microbial biomass carbon (µg/g of soil)			Basal soil respiration (µg CO_2/100 g of soil)		
	30 DAS	50 DAS	Harvest	30 DAS	50 DAS	Harvest	30 DAS	50 DAS	Harvest
Main plot treatment : Green manuaring									
Green manuring	27.87	23.57	20.78	234.74	220.29	210.48	238.74	227.54	208.63
Without green manuring	19.38	18.74	15.55	199.32	204.70	192.71	209.22	205.51	194.78
LSD (p=0.05)	2.25	1.34	2.43	10.17	6.36	0.68	12.60	1.20	4.19
Sub plot: Weed control measures									
Fix herbicide - pendimethalin(PE)	21.37	19.11	16.28	210.42	206.71	197.21	215.03	209.50	196.22
Rotational herbicide – alachlor	21.29	19.29	16.45	208.67	204.63	195.03	216.06	209.37	196.46
Weed free check	28.14	26.11	22.54	230.49	225.96	213.08	238.36	231.36	212.05
Weedy check	23.71	20.12	17.41	218.54	212.68	201.08	226.46	215.89	202.09
LSD (p=0.05)	2.67	3.00	3.01	4.90	9.73	9.96	10.05	7.12	6.00

Note: Interaction between green manuring and weed control measures were non-significant during all the stages of observations

Table 3. Combined effects of green manuring and weed control measures on soil bacterial, fungal population and nitrogen fixers in rice-groundnut cropping system during *Rabi* season

Treatment	Bacteria (CFU × 10^{-6}/g of soil)			Fungi (CFU ×10^{-4}/g of soil)			Nitrogen fixers (CFU ×10^{-3}/g of soil)		
	30 DAS	50 DAS	Harvest	30 DAS	50 DAS	Harvest	30 DAS	50 DAS	Harvest
Main plot treatment : Green manuring									
Green manuring	44.72	48.49	43.57	29.10	32.18	28.84	28.01	30.99	26.57
Without green manuring	38.87	42.16	36.54	25.09	28.41	21.64	23.56	26.59	22.53
LSD (P=0.05)	1.50	1.53	1.44	2.80	1.53	2.49	2.51	3.35	2.08
Sub plot: Weed control measures									
Fix herbicide – pendimethalin(PE)	39.57	42.94	37.57	25.19	28.77	23.97	23.89	27.53	22.54
Rotational herbicide – alachlor	39.56	43.40	37.99	26.35	29.97	23.91	25.11	28.07	23.41
Weed free check	45.88	49.09	43.91	29.03	32.15	27.02	28.06	30.98	27.00
Weedy check	42.19	45.87	40.75	27.81	30.29	26.07	26.08	28.59	25.25
LSD (P=0.05)	3.67	NS	NS	NS	NS	NS	2.13	NS	NS

Note: Interaction between green manuring and weed control measures were non-significant during all the stages of observations

Table 4. Combined effects of green manuring and weed control measures on phosphate solubilizers, microbial biomass carbon and basal soil respiration in rice-groundnut cropping system during *Rabi* season

Treatment	Phosphate solubilisers (CFU × 10^{-3}/g of soil)			Microbial biomass carbon (µg/g soil)			Basal soil respiration (µg CO_2/100 g soil)		
	30 DAS	50 DAS	Harvest	30 DAS	50 DAS	Harvest	30 DAS	50 DAS	Harvest
Main plot: Green manuring									
Green manuring	27.91	29.94	26.58	245.37	265.05	244.67	236.55	259.43	238.84
Without green manuring	23.87	26.29	21.78	219.38	244.23	222.69	215.99	231.93	218.25
LSD (P=0.05)	1.23	2.69	2.24	14.56	12.12	17.54	5.49	18.37	13.95
Sub plot: Weed control measures									
Fix herbicide – pendimethalin(PE)	24.17	26.52	22.64	222.46	247.66	228.10	219.52	240.52	223.80
Rotational herbicide – alachlor	24.70	27.42	22.98	224.42	251.54	229.23	221.60	241.30	224.61
Weed free check	28.32	30.37	26.87	248.00	263.00	242.29	236.45	253.67	236.53
Weedy check	26.38	28.14	24.23	234.62	256.36	235.12	227.51	247.23	229.23
LSD (p=0.05)	2.66	NS	NS	8.65	NS	NS	7.74	NS	NS

Note: Interaction between green manuring and weed control measures were non-significant during all the stages of observations

Table 5. Effects of green manuring and weed control measures on relative equivalent yield of groundnut and total relative equivalent yield of rice-groundnut cropping system

Treatment	REY of Groundnut (t/ha)					Total REY of system (t/ha)				
	2011	2012	2013	2014	Pooled	2011	2012	2013	2014	Pooled
Main plot treatment : Green manuring										
Green manuring	16.72	15.08	14.10	13.65	13.47	20.87	20.68	17.67	17.81	17.84
Without green manuring	15.73	14.78	13.98	13.45	13.10	18.39	19.00	17.37	17.45	16.67
LSD (p=0.05)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Sub plot: Weed control measures										
Fixed. herbicide – pendimethalin(PE)	17.02	15.68	14.61	14.16	13.90	20.51	20.55	17.88	18.19	17.82
Rotational herbicide – alachlor	14.45	15.28	13.92	13.65	12.95	18.44	20.12	17.26	17.43	16.95
Weed free check	18.00	17.07	16.03	15.48	15.05	21.70	22.34	19.67	20.39	19.44
Weedy check	15.44	11.70	11.61	10.91	11.23	17.87	16.35	15.25	14.51	14.81
LSD (p =0.05)	N.S.	2.19	0.60	2.07	1.13	2.64	2.13	0.86	2.12	1.27

Note: Interaction between green manuring and weed control measures were non-significant during all the stages of observations

Effect of weed control measures

As regard to the total REY of system, weed free check was recorded significantly higher yield over rest of the treatments during the years 2013, 2014 as well as in pooled results, while it was on the same level with fixed herbicide during the years 2011 and 2012. Among the use of fixed and rotational herbicide, significantly higher total REY of the rice-groundnut cropping system were obs recorded over weedy check, which remained at par with each other. The interaction effect between green manuring and weed control measures were found to be non-significant during all the years of experimentation and in pooled results. Effective weed control along with higher total REY of the system by incorporation of green manuring to *Kharif* rice and application of pre emergence herbicide for rice and groundnut are confirmative with the present investigation. Singh *et al*. (2009) noticed that under dry seeding, higher grain yield was recorded with pre- emergence application of pendimethalin 1.50 kg/ha. The difference in yield might be due to differences in application mode and efficacy of herbicides against weed species. Similar results were obtained by Kaur and Singh (2015) under sequential use of pre- and post-emergence herbicides, resulting in more equivalent grain yield and net returns.

It can be concluded that the green manuring management practices stimulated significantly higher microbial soil health in respect to soil microbial populations, enzyme activities, soil microbial biomass carbon, CO_2 evolution due to maximum contribution of organic matter as compared to the without green manuring in both the crops. The microbial soil indicators were not adversely affected by herbicides during all the stages of the *Rabi* groundnut and initially suppressed due to toxic effect of herbicides at initial stage (30 DAT) in rice crop during *Kharif* season. In option to getting higher productivity, application of fixed herbicide improves the total REY of the system.

REFERENCES

Adhikary P, Shil S and Patra PS. 2014. Effect of herbicides on soil microorganisms in transplanted chilli. *Global Journal of Biology, Agriculture and Health Sciences* **3**(1): 236–238.

Bamboo N, Pasyat M, Samal A, Kujur M, Maharana JK and Patel AK. 2013. Effect of four herbicides on soil organic carbon, microbial biomass-C, enzyme activity and microbial population in agricultural soil. *International Journal of Environmental Science and Technology* **3**: 100–112.

Bera S and Ghosh RK. 2013. Soil physico-chemical properties and microflora as influenced by bispyribac-sodium 10% SC in transplanted *Kharif* Rice. *Rice Science* **20**(4): 298–302.

Burns RG. 1978. Enzyme activity in soil: Some theoretical and practical considerations. pp. 295–340. In: Soil Enzymes, Burns, R.G. (Ed.). Academic Press, London.

Constenla MA, Riley D, Kennedy SH, Rojas CE, Mora LC and Stevans, JEB. 1990. Paraquat behaviour in Costa Rican soils and residues in coffee. *Journal of Agriculture Food Chemistry* **38**: 1985–1988.

Dick RP. 1997. Soil enzyme activities as indicator of soil quality. pp. 121–56 In: *Biological Indicators of Soil Health*, (Eds. Pankhurst *et al.*). CAB International, Wellingford.

Govekar YR, Mahadkar UV, Dahiphale AV Pawar LG, Nevase VB, Mane MJ and Gosavi SP. 2014. Effects of different tillage systems and herbicide on soil microflora of Lablab bean rhizosphere. *Indian Journal of Weed Science* **46**: 370–372.

Kaur Simerjeet and Surjit Singh. 2015. Bio-efficacy of different herbicides for weed control in direct-seeded rice. *Indian Journal of Weed Science* **47**: 106–109.

Kumar Rajinder, Dinesh Badiyala, Neelam Sharma and Suresh Gautam. 2015. Effect of long-term application of herbicides on soil microbial demography in rice-wheat cropping sequence. *Indian Journal of Weed Science* **47**: 71–74.

Latha, PC and Gopal H. 2010. Effect of herbicides on soil microorganism. *Indian Journal of Weed Science* **42**: 217–22.

Martin JP. 1950. Use of acid, rose bengal and streptomycin in the plate method for estimating soil fungi. *Soil Science* **69**: 215.

Nannipieri P, Kandeler E and Ruggiero P. 2002. Enzyme activities and microbiological and biochemical process in soil. pp. 1–33. In: Enzymes in the Environment, (Eds. Burns RG and Dick RP). Marcel Dekker, New York.

Nazreen C, Mohiddin J, Srinivasulu M, Rekhapadmini A, Ramanamma P and Rangaswamy V. 2012. Interaction effect on insecticides on enzymatic activities in black soil from groundnut (Arachishypogaea L.) field. *Environment Research and Engineering Management* **2**: 21–28.

Noories JR. 1959. Isolation and identification of isolate Azotobacter. *Laboratory Practices* **8**: 239–240.

Panse VG and Sukhatme PV. 1985. *Statistical Methods for Agricultural Workers,* ICAR, New Delhi.

Pikovskaya RI. 1948. Mobilization of phosphorous in soil in connection with vital activity by some microbial species. *Microbiologia* **17**: 362–370.

Singh B, Malik RK, Yadav A and Nandal DP. 2009. Herbicide efficacy in seeded rice with different methods under wet and dry conditions. *Indian Journal of Weed Science* **41**: 37–40.

Tejada M, Gonzalez JL, García-Martínez AM and Parrado J. 2008. Effects of different green manures on soil biological properties and maize yield. *Bioresource Technology* **99**: 1758–1767.

Tilak KVBR. 2004. Response of Sesbania Green Manuring and Mungbean Residue Incorporation on Microbial Activities for Sustainability of a Rice-Wheat Cropping System. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* **105**: 189–196.

Wang QK, Wang SL and Liu YX. 2008. Response to N and P fertilization in a young Eucalyptus dunniiplantation: Microbial properties, enzyme activities and dissolved organic carbon. *Applied Soil Ecology* **40**: 484–90.

Indian Journal of Weed Science **50**(3): 287–289, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Effect of nitrogen fertilizer and weed management practices on weed growth and crop yield of zero-till transplanted rice

Dibakar Ghosh*, Raghwendra Singh[1] and Subhash Chander

ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482 004

[1]*ICAR-Indian Institute Of Vegetable Research, Varanasi, Uttar Pradesh 221 305*

**Email: dghoshagro@gmail.com*

Article information

DOI: 10.5958/0974-8164.2018.00061.8

Type of article: Research note

Received : 30 March 2018

Revised : 11 August 2018

Accepted : 17 August 2018

Key words

Crop yield, Fertilizer, Nitrogen, Transplanted rice, Weed management

ABSTRACT

The application of N at recommended or higher dose (33% higher than recommended) effectively enhanced the growth and yield of rice crop by suppressing the weed growth in zero-till transplanted rice. Hand weeding thrice at 25, 55 and 75 days after transplanting (DAT) was the best in reducing weed growth and ultimately increased the grain yield of zero-till transplanted rice. Among the herbicidal methods, tank mix application of bispyribac-Na + 2,4-D minimized the weed growth at early stage and enhanced rice grain yield.

Rice is the most important staple crop for more than half of the population in India. The most common growing method of rice is manual transplanting of seedlings in puddled soils, creating a hard pan below the plough layer. This practice involves huge amount of water (3000-5000 L of water to produce 1 kg rice) (Bouman *et al.* 2002), which is becoming increasingly scanty. Continuous practice of puddling deteriorates soil health and also emits greenhouse gases emission, particularly methane. On the other hand early heavy rainfalls during rice seeding also hamper the proper crop establishment. These above situations have compelled scientists and researchers to test zero-till transplanted rice cultivation. Weeds are recognized as the major biological constraints to the production of rice under zero-till condition (Singh *et al.* 2008 Ghosh *et al.* 2016). Many agronomic aspects of land management influence the composition, density and diversity of a community of weeds; particularly nitrogen (N) fertilization alters soil fertility affecting not only crop growth, but also diversity and growth of associated weeds (O'Donovan *et al.* 1997, Rao and Matsumoto 2017). Weeding in Asia is commonly done by labour; however, due to unavailability of labour at critical time and higher cost, herbicides are considered to be an alternative to hand weeding (HW) (Rao and Matsumoto 2007). Hence, the present investigation was undertaken to study the effect of different N and weed management practices on weed growth and performance of rice crop in zero-till transplanted condition.

A field experiment was carried out during rainy season of 2013 at experimental farm of ICAR-Directorate of Weed Research, Jabalpur (23°132' N, 79°582'E, and 390 m above mean sea level), Madhya Pradesh. The soil was clay loam in texture, neutral (7.2) in reaction, medium in organic carbon (0.79%), available nitrogen (312 kg/ha) and phosphorus (18 kg P_2O_5/ha) but high in available potassium (291 kg K_2O/ha). The experiment was laid out in a split-plot design with five N levels as main factor (0, 40, 80, 120 and 160 kg N/ha) and four weed management methods as sub-factors. The weed management practices comprised of single post-emergence (POST) herbicide (fenoxaprop-p-ethyl at 60 g/ha), tank mix application of POST herbicides (bispyribac-Na + 2,4-D at 25 + 500 g/ha), conventional hand weeding (HW) practice and weedy check for comparison. The area of each plot was 60 m^2 (5 × 12 m). Nitrogen was applied in the form of urea as per treatment and a basal dose of P_2O_5 and K_2O at 60 kg/ha each were applied through single super phosphate and muriate of potash, respectively. Nitrogen was applied in three equal splits, as basal, maximum tillering and panicle initiation stage. The 25 days old seedlings of rice cv. *Kranti* was transplanted in zero-till condition (without puddling) with spacing of 20 x 10 cm during third week July. The herbicides were applied with a knapsack sprayer filted with flat-fan nozzles at 25 days after transplanting (DAT) with spray volume of 500 L/ha, and HW was done at 25, 55 and 75 DAT for conventional approach. Data were collected randomly from each plot for three replications. For weed density, permanent quadrates (2 × 2 m) were earmarked in each plot after rice transplanting and then weed data were taken from these areas before and 25 days after application of POST herbicides. For weed biomass, weeds were cut at ground level and washed with tap water, sun dried, hot-air oven-dried at 70°C for 48 h, and then weighed. Plant height and tiller number of rice were documented at 50 DAT; and panicle number and grain yield of rice were recorded at harvest. The data of actual weed density were transformed by square root transformation before analysis. The statistical analysis of data was done using SAS Windows Version 9.4. The means were compared based on the least significant difference (LSD) test at 0.05 probability level.

Weed flora

The dominant weeds associated with rice were *Echinochloa colona* (L.) Link, *Dinebra retroflexa* (Vahl) Panzer, *Cyperus iria* (L.), *Alternanthera sessilis* R.Br. and *Commelina benghalensis*. However, other weed flora consists of *Ludwigia parviflora* (L.), *Eclipta alba* (L.) Hassk, *Caesulia axillaris* and (L.). and *Physalis minima*.

Effect on weed density and biomass

Throughout the crop growth period, different nutrient management practices with varying level of N had no significant effect on the total weed density in rice, whereas, different weed management practices significantly lowered down the total weed density at 50 DAT in rice (**Table 1**). As compared to HW (one HW out of three HW), the application of herbicides *i.e.* bispyribac-Na + 2,4-D and fenoxaprop-p-ethyl at 25 DAT effectively minimized the total weed density at 50 DAT in zero-till transplanted rice. At early crop growth stage (50 DAT), among the different N management practices, the application of N at lower dose (40 and 80 kg/ha) restricted the growth of rice crop (data not presented) and facilitated the weed growth which ultimately resulted higher biomass accumulation of total weeds in rice. The plots received N at lower dose was insufficient to supply N for proper growth of rice crop. On the other hand, N application at recommended and higher dose (120 and 160 kg/ha) enhanced the crop growth and eventually suppressed the growth of weeds. Under control situation (0 kg N/ ha), the availability of N was inadequate for the proper growth of both crop and weeds. At harvest, biomass accumulation by total weeds was the maximum when N was applied at 2/3 of recommended dose. As compared to recommended dose (120 kg/ha), when N was applied at 33% higher rate significantly lowered down the biomass accumulation of total weeds by increasing the growth

Table 1. Effect of nitrogen fertilizer and weed management practice on weed density and biomass, plant growth and grain yield in zero-till transplanted rice

Treatment	Weed density (no./m^2)		Weed biomass (g/m^2)		Plant height (cm) at 60 DAT	Tiller no./m^2 at 60 DAT	Panicle no./m^2	Grain yield (t/ha)
	25 DAT	50 DAT	50 DAT	Harvest				
Nitrogen management								
40 kg/ha	12.0 (143)	9.0 (80)	221	233	72.2	246	222	1.51
80 kg/ha	12.0 (143)	10.1 (101)	275	439	71.8	233	237	1.70
120 kg/ha	12.0 (143)	9.7 (93)	181	363	70.8	277	253	1.91
160 kg/ha	13.7 (188)	10.2 (103)	194	195	71.6	273	251	1.94
Control	12.3 (151*)	10.3 (107)	182	189	71.5	228	203	1.11
LSD (p=0.05)	NS	NS	48.9	122.4	NS	24.3	26.6	0.16
Weed management								
Bispyribac-Na + 2,4-D (25 + 500 g/ha at 25 DAT)	12.7 (160)	8.4 (69)	51	318	71.1	249	242	1.91
Fenoxaprop-p-ethyl (60 g/ha at 25 DAT)	11.8 (140)	8.1 (65)	321	361	71.3	259	240	1.74
Hand weeding thrice (at 25, 50 and 75 DAT)	13.0 (169)	11.0 (120)	114	61	70.9	255	236	1.98
Weedy	12.0 (144)	11.5 (133)	356	396	73.1	242	214	0.89
LSD (p=0.05)	NS	1.3	66.3	94.1	NS	NS	18.3	0.17

*Original figures in parentheses were subjected to square-root transformation $\sqrt{x+0.5}$ before statistical analysis; DAT-Days after transplanting of rice crop. At early crop growth stage, as compared to weedy, the tank mix application of bispyribac-Na + 2,4-D at 25 DAT significantly reduced the total weed dry biomass by 86% in zero-till transplanted rice. On the other hand, HW thrice performed better than the herbicides in reducing biomass accumulation by weeds. It may be due to that, the effect of herbicides in reducing germination and growth of weeds was not enough for subsequent weed flashes (emerged after herbicide application).

Crop growth and yield

Different N and weed management practices had no significant effect on plant height of rice at 60 DAT. With the increment of N dose, the tiller and panicle number of rice increased. Significantly higher tiller and panicle number was recorded in the plots receiving the N at recommended dose or 33% higher than the recommended dose indicating that lower N dose was not adequate for proper growth of rice crop. On the other hand, different weed management had no significant effect on tiller production by rice crop at 60 DAT, but the panicle number/m^2 varied significantly with weed management methods. The application of N at recommended or higher dose (33%) significantly increased the grain yield of rice. Amongst weed management practices, the maximum yield was recorded with hand weeding thrice (at 25, 55 and 75 DAT) and it was at par with bispyribac-Na+2,4-D at 25+500 g/ha at 25 DAT. Ghosh *et al*, (2017) also found that the tank mix application of bispyribac-Na + azimsulfuron effectively decreased the growth of diverse weed flora in zero-till direct-seeded rice and subsequently enhanced the rice grain yield. In the current experimentation, crop was transplanted in zero-till condition and the field topography was medium upland in nature, as a result it was very difficult to maintain the standing water in the zero-till condition. And also, the field was heavily infested with weeds, and weeds were germinated in repeated flushes, as a result the performance of rice crop was meagre and resulted in lower rice grain yield.

REFERENCES

Bouman BAM and Tuong TP. 2001. Field water management to save water and increase its productivity in irrigated lowland rice. *Agricultural Water Management* **49**: 11–30.

Ghosh D, Singh UP, Brahmachari K, Singh NK and Das A. 2017. An integrated approach to weed management practices in direct-seeded rice under zero-tilled rice-wheat cropping system. *International Journal of Pest Management* **63**: 37–46.

Ghosh D, Singh UP, Ray K and Das A. 2016. Weed management through herbicide application in direct-seeded rice and yield modeling by artificial neural network. *Spanish Journal of Agricultural Research* **14**: e1003, 10 pages.

O'Donovan JT, Mandrew DW and Thomas AG. 1997. Tillage and nitrogen influence weed population dynamics in barley. *Weed Technology* **11**: 502–509.

Rao AN and Matsumoto H. 2017. Weed management in rice in the Asian-Pacific region. Asian-Pacific Weed Science Society (APWSS), The Weed Science Society of Japan, Japan and Indian Society of Weed Science, India.

Rao AN, Johnson DE, Sivaprasad B, Ladha JK and Mortimer AM. 2007. Weed management in direct-seeded rice. *Advances in Agronomy* **93**: 155–257.

Singh, S, Ladha JK, Gupta RK, Lav B and Rao AN. 2008. Weed management in aerobic rice systems under varying establishment methods. *Crop Protection* **27**: 660–671.

Indian Journal of Weed Science **50**(3): 290–293, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Effects of nitrogen levels and weed management in direct-seeded rice

Anurag Kumar Singh*, M.K. Singh and Sneha Kumari

Department of Agronomy, Institute of Agricultural Sciences, BHU, Varanasi, Utter Pradesh 221 005

**Email: anuragrau@gmail.com*

Article information

DOI: 10.5958/0974-8164.2018.00062.X

Type of article: Research note

Received : 12 May 2018
Revised : 26 June 2018
Accepted : 6 August 2018

Key words

Direct seeded rice
Nitrogen levels
Weed management

ABSTRACT

A field experiment was conducted at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi to study effect of nitrogen level and weed management in direct-seeded rice. Treatment consisted of 12 treatment combinations which was laid out in the split-plot design having nitrogen levels (100, 120, 140 and 160 kg N/ha) in main plot and three weed management practices, *viz*. weedy, two hand weeding and bispyribac-sodium 25g/ha *fb* Cono-weeding in sub-plots replicated thrice. Two hand weeding recorded significantly lower weed biomass and density and better performance of crop growth and yield attributes and yield followed by bispyribac-Na 25 g/ha *fb* cono-weeding. In case of nitrogen application of 160 kg N/ha showed better performance of growth, yield attributes and yield as compared to other nitrogen treatments. It was observed that application of nitrogen 160 kg/ha and two hand weeding was found best treatment for higher grain yield and net returns.

Rice (*Oryza sativa*), the staple food of more than half of the population of the world, is an important target to provide food security and livelihoods for millions. Direct-seeding of rice (DSR) refers to the process of establishing the crop from seeds sown in the field and is an alternative to transplanting that can reduce the cost of rice establishment. Direct seeding of rice avoids the need for nursery preparation, uprooting of seedlings and transplanting. However, weeds are one of the major constraints in the success of DSR.

Crop fertilization is one important component of integrated weed management and it has been observed that nitrogen (N) fertilizer plays an important role in the competitive balance between weeds and rice (Raun and Johnson 1999, Camara *et al*. 2003). Therefore, manipulation of crop fertilization is a promising agronomic practice in reducing weed interference in crops (Cathcart *et al.* 2004, Blackshaw *et al.* 2005). Production potentiality of rice can be fully exploited with suitable nitrogen level and weed management practices.

Weeds usually grow faster than crop plants and thus absorb nutrient earlier resulting in lack of nutrients for growth of plant. Nitrogen fertilization has pronounced effect on the growth of weeds plant. Weeds not only reduce the amount of N available to the crops but also suppress the crop growth (Blackshaw 2003). Camara *et al.* (2003) reported that nitrogen is the major nutrient added to increase crop yield but it is not always recognized that altered soil nitrogen levels can influence crop-weed competitive interactions. Mahajan and Timsina (2011) reported that increasing N application rate up to 150 kg N/ha caused significant improvement in grain yield when the weeds were well controlled either by pendimethalin 1 kg/ha *fb* bispyribac-Na 25 g/ha or by pendimethalin 1 kg/ha *fb* bispyribac-Na 25 g/ha + 1 HW, respectively.

Therefore, in view of the above facts, the present investigation carried out during *Kharif* season of 2016 at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, with the objectives of study the effect of nitrogen rate and weed management on growth and yield of direct seeded rice, effect of nitrogen rate and weed management on weed growth in direct seeded rice and work out economics of treatment under study.

A field experiment was conducted during *Kharif* season of 2016 at Agricultural Research Farm, Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh (India). The soil of the experimental field was sandy clay loam in texture with pH 7.20 low in organic matter (0.43%) , low in available nitrogen

(202.7 kg/ha), medium in available phosphorus (18.0 kg/ha) and potassium (209.2 kg/ha). The experiment comprised of 12 treatments which was laid out in the split plot design having nitrogen levels (100, 120, 140 and 160 kg N/ha) in main plot and three weed management practices, *viz.* weedy, two hand weeding and bispyribac sodium 25 g/ha *fb* Cono-weeding in subplots replicated thrice. Rice hybrid Arize 6444 was sown in the rows under dry condition with proper soil moisture condition with help of *Kudal* (local furrow maker) at spacing of 18.5 cm using seed rate of 30 kg/ ha. Half doses of nitrogen as per treatment was applied at the time of sowing and rest half was split in two equal splits and applied at tillering and panicle initiation stages. Full doses of phosphorus (60 kg/ha) and potassium (60 kg/ha) was applied as basal at the time of sowing.

Two hand weeding was done as per the need of the treatment; one hand weeding was done at 20 days after sowing (DAS) and second was done at 40 DAS of the crop. Post-emergence application of bispyribac sodium 25 g/ha was applied as per treatment with Knapsack sprayer filled with flat fan nozzle using 300 lt. of water/ ha .The data on yield attributes and yield of rice were recorded at the time of harvesting. Weed species within the area of quadrate were cut close to the ground surface and air dried in hot air oven maintained at 70 to 75 ºC temperature. Crop was harvested when most of the panicles turned golden yellow. Harvesting was done manually by using sickle. The yields, thus obtained, were converted in kg/ha for presentation of results.

Effect on weed

Weed density recorded on 60 DAS (**Table 1**) revealed that amongst the nitrogen level, the minimum density of *Echinochloa colona, Echinochloa crus-galli, Cyperus difformis, Fimbristylis maliacea, Caesulia axillaris* and *Ammania baccifera* were observed in 100 kg N/ha. However, the maximum density of *E.colona, E.crus-galli* were recorded in 160 kg N/ha followed by 140 kg N/ha and 120 kg N/ ha. Weed population increased with higher rate of nitrogen, which may be due to more nitrogen supply and relatively higher absorbing capacity of weeds in comparison to crop. Similar findings have also been reported by Pysek and Leps (1991). The weed density of grasses and sedges increased significantly with increasing nitrogen rates whereas density of broad leaf weeds was not significantly increased with increasing the nitrogen rates. Amongst different weed management treatments, two hand weeding recorded significantly minimum population of weeds (grasses, sedges and broad leaf weeds) followed by bispyribac-Na *fb* cono-weeding and weedy. However, data revealed that bispyribac-Na *fb* cono-weeding recorded lesser population of weeds (grasses, sedges and broad leaf weeds) as compared to weedy. Similar results were also observed for weed biomass in case of grasses, sedges and broad-leaved weeds. Higher doses of nitrogen enhanced vigorous weed growth because weeds are capable to absorbing relatively higher amount of nitrogen than crop and flourished quickly than the crop. The findings have also been supported by Iqwal and Wright (1997). This may be due to reduced competition between weeds and crops for the light, space and nutrient which reduced the total biomass of weed. Similar findings are also reported by the Vaishya *et al.* (1992).

Effect on crop growth and yield

The significantly higher plant height, dry matter accumulation/m, total tillers/running row was obtained with nitrogen level 160 N/kg compared to 100 kg N/ha, 120 kg N/ha, 140 kg N kg/ha and statistically higher based on the observations recorded **(Table 2)**. The taller plant in 160 kg N/ha might be due to better use of available growth resources like light and temperature which may result in higher nitrogen absorption for the synthesis of

Table 1. Effect of nitrogen rates and weed management on weed density and weed biomass at 60 DAS in dry direct-seeded rice

Treatment	Density of weeds (no./ m^2)										Weed biomass (g/ m^2)			
	Grasses			Sedges			Broad-leaf weeds			Total weeds	Grasses	Sedges	Broad-leaf weeds	Total
	E. colona	*E. crus-galli*	Total	*C. difformis*	*F. maliaceae*	Total	*C. axillaris*	*A. baccifera*	Total					
Nitrogen level														
100 kg/ha	3.0(9)	2.2(5)	3.1(15)	3.5(14)	2.2(4)	4.0(18)	4.5(23)	2.6(8)	5.3(32)	8.1(65)	4.3(21)	4.6(23)	7.1(59)	10.2(103)
120 kg/ha	3.1(10)	2.3(5)	3.8(16)	3.7(15)	2.3(5)	4.2(19)	4.8(25)	2.9(9)	5.7(35)	8.4(69)	4.5(22)	4.8(25)	7.4(63)	10.6(111)
140 kg/ha	3.4(12)	2.4(6)	4.2(18)	4.0(17)	2.3(5)	4.6(22)	5.1(29)	3.1(10)	6.0(40)	9.0(80)	4.9(26)	5.2(29)	8.1(72)	11.3(127)
160 kg/ha	3.6(13)	2.5(7)	4.4(20)	4.3(19)	2.5(6)	4.9(25)	5.5(32)	3.4(12)	6.4(45)	9.5(89)	5.3(29)	5.6(33)	8.6(81)	12.0(143)
LSD (p=0.05)	0.19	0.17	0.24	0.23	NS	0.26	0.32	0.38	0.41	0.20	0.35	0.35	0.53	0.33
Weed management														
Weedy	4.6(20)	3.3(10)	5.6(31)	5.4(29)	3.1(9)	6.2(37)	7.1(49)	4.3(18)	8.3(68)	11.7(136)	6.7(44)	7.1(50)	11.2(124)	14.8(218)
Two hand weeding	1.9(3)	1.4(1)	2.2(4)	2.2(4)	1.6(2)	2.5(5)	2.7(7)	1.6(2)	3.2(9)	4.5(19)	2.6(6)	2.8(7)	4.2(17)	5.6(30)
Bispyribac-Na 25g/ha *fb* conoweeding	3.4(11)	2.3(5)	4.2(16)	4.0(15)	2.4(5)	4.5(20)	5.2(26)	3.1(9)	6.0(36)	8.6(72)	4.9(23)	5.2(26)	8.1(65)	10.8(115)
LSD (p=0.05)	0.93	0.13	0.12	012	0.25	0.13	0.16	0.18	0.20	0.89	0.15	0.17	0.27	0.23

Table 2. Effect of nitrogen rates and weed management on growth attributes (60 DAS), yield attributes, yield and economics in dry direct-seeded rice

Treatment	Plant height (cm)	Dry matter (g/ running m)	Leaf area index	Chlorophyll content (%)	Tillers (no./ running m)	Panicle length (cm)	Panicle weight (g)	Effective tillers (no./m^2)	No of grains/ panicle	Test weight (g)	Grain yield (t/ha)
Nitrogen level											
100 kg/ha	63.2	349.6	2.65	38.8	271	23.0	6.15	408.8	159	24.6	5.4
120 kg/ha	64.5	356.9	2.70	39.6	276	23.5	6.28	417.3	162	25.2	5.6
140 kg/ha	66.0	364.8	2.76	40.5	282	24.0	6.42	426.6	166	25.7	5.7
160 kg/ha	67.4	372.6	2.82	41.3	288	24.5	6.55	435.8	169	26.3	5.9
LSD (p=0.05)	0.58	3.10	0.027	0.34	2.5	0.21	0.06	3.76	1.44	NS	.05
Weed management											
Weedy	62.1	343.7	2.60	38.1	266	22.6	6.05	401.9	156	24.2	5.4
Two hand weeding	67.4	373.0	2.82	41.4	289	24.5	6.56	436.2	169	26.2	5.9
Bispyribac-Na 25 g/ha *fb* conoweeding	66.2	366.2	2.77	40.6	283	24.1	6.44	428.2	166	25.8	5.8
LSD (p=0.05)	NS	3.70	0.028	0.41	2.87	0.25	0.07	4.34	1.69	NS	0.058

protoplasm responsible for rapid cell division subsequently increasing the plant in shape and size. The higher dry matter accumulation running row/m in 160 kg N/ha might be due better growth. The higher number of total tillers/ running m in 160 kg N/ ha might be due to ability of effective utilization of plant growth resources with advancement of life cycle. The findings have also been supported by Sharief *et al.* (2006). The higher LAI recorded in 160 kg N/ha might be due to more number of leaves/m^2. The higher chlorophyll content in 160 kg N/ha was due to more uptake of nitrogen as compared to remaining level of nitrogen. Also higher chlorophyll content may be due to more accumulation of nitrogen from the soil and chlorophyll content in leaves is directly associated with nitrogen uptake. The higher number of effective tillers/m^2 recorded in 160 kg N/ha and 140 kg N/ha might be due to better growth and early initiation of tillers before start of reproductive growth. The findings have been also supported by Ramamoorty *et al.* (2007). Panicle weight (g), panicle length (cm), number of grains/ panicle and 1000-grain weight were significantly higher in 160 kg N /ha than the 100 kg N/ha, 120 kg N/ ha and 140 kg N kg/ha which might be due to ability of hybrid rice cultivar of better growth which may result in the better development of yield attributing characters. The higher values of growth and yield attributes recorded by 160 kg N/ha might be due to higher plant height, number of leaves, leaf area, total tillers.

The grain yield was significantly higher in 160 kg N/ha as compared to other nitrogen levels. Also significantly higher grain yield in 160 kg N/ha might be due to synchronization of tillers that help in early emergence of productive panicles and panicle weight possibly due to better utilization capacity of available nutrients which helped in determining the relatively more yield. Higher dose of nitrogen might have increased number of panicles/m^2 as well as number of grains per panicle and 1000-grain weight. The findings have also been supported by Srinivasan and Angayarkanni (2008).

Plant height at all the stages of observations was not influenced significantly due to different weed management practices but two hand weedings recorded higher plant height as compared to bispyribac-Na *fb* cono-weeding and weedy. It might be due to less competition for space, sunlight and other inputs. The dry matter accumulation/ m running row recorded at all the stages of observations of the crop was significantly higher in two hand weedings compared to bispyribac-Na *fb* cono-weeding **(Table 2)**. Hand weeding twice (20 and 40 DAS) was found most promising to reduce the weed dry matter as compared to other treatments. The results are in agreement with Vaishya *et al.* (1992). The crop treated with two hand weeding recorded higher number of total tillers/m^2 whereas bispyribac-sodium *fb* cono-weeding had significantly higher number of tillers/m^2 as compared to weedy. The panicle length, numbers of effective tillers/m^2, number of grains/ panicle and test weight were found significantly higher in two hand weedings than bispyribac-Na *fb* cono-weeding. The grain yield was also significantly higher in two hand weedings than bispyribac-Na *fb* cono-weeding. The higher grain yield in weed management might be due to higher number of effective tillers/m^2 and number of filled grains/ panicle. Nitrogen level 160 kg N/ha obtained maximum gross return at two hand weeding plot followed by 140 kg N/ha with two hand weeding, 120

Table 3. Effect of nitrogen rates and weed management on cost of cultivation, gross return, net return and B: C ratio of direct-seeded rice

Treatment	Cost of cultivation ($x10^3$ `/ha)	Gross return ($x10^3$ `/ha)	Net return ($x10^3$ `/ha)	B: C ratio
Nitrogen 100 kg/ha + weedy	34.14	85.87	51.72	2.4
Nitrogen 100 kg/ha with two hand weeding	41.34	101.79	60.44	2.5
Nitrogen 100 kg/ha with bispyribac-Na 25g/ ha *fb* cono weeding	37.29	100.66	63.36	2.7
Nitrogen 120 kg/ha + weedy	34.59	97.50	62.91	2.8
Nitrogen 120 kg/ha with two hand weeding	41.79	104.83	63.03	2.5
Nitrogen 120 kg/ha with bispyribac-Na 25 g/ha *fb* cono weeding	37.74	102.39	64.65	2.7
Nitrogen 140 kg/ha + weedy	35.04	98.64	63.60	2.8
Nitrogen 140 kg/ha with two hand weeding	42.24	106.45	64.21	2.5
Nitrogen 140 kg/ha with bispyribac-Na 25 g/ha *fb* cono weeding	38.19	105.67	67.48	2.8
Nitrogen 160 kg/ha + weedy	35.49	99.79	64.30	2.7
Nitrogen 160 kg/ha with two hand weeding	42.69	121.41	78.72	2.9
Nitrogen 160 kg/ha with bispyribac-Na 25 g/ha *fb* cono weeder	38.64	107.25	68.61	2.8

N kg/ha with two hand weeding and100 N kg/ha with two hand weeding, respectively **(Table 3)**. It was revealed that nitrogen level 160 kg N/ha obtained maximum net return as compared to other nitrogen level and weed management combinations followed by nitrogen level 140 kg N/ha and 120 kg N/ha, respectively. The nitrogen level 160 kg N/ha at two hand weeding recorded maximum benefit cost ratio as compared to other nitrogen level and weed management combinations followed by nitrogen level 140 kg N/ha with bispyribac-Na *fb* cono-weeder weeding and 120 kg N/ha with two hand weeding as compared to rest of the treatment combinations, respectively.

REFERENCES

Blackshaw RE, Brandt RN, Janzen HH, Entz T, Grant CA and Derksen DA. 2003. Differential response of weed species to added nitrogen. *Weed Science* **51**(4): 532–539.

Blackshaw RE, Molnar LJ and Larney FJ. 2005. Fertilizer, manure and compost effects on weed growth and competition with winter wheat in western Canada. *Crop Protection* **24**(2): 971–980.

Camara KM, Payne WA and Rasmussen PE. 2003. Long-term effects of tillage, nitrogen, and rainfall on winter wheat yields in the Pacific Northwest. *Agronomy Journal* **95**(4): 828–835.

Cathcart RJ, Chandler K and Swanton CJ. 2004. Fertilizer nitrogen rate and the response of weeds to herbicides. *Weed Science* **52**(2): 291–296.

Iqwal J and Wright D. 1997. Effect of nitrogen supply on competition between wheat and three annual weed species. *Weed Research* **37**(4): 391–400.

Mahajan G, Chauhan BS and Johnson DE. 2009. Weed management in aerobic rice in Northwestern Indo-Gangetic Plains. *Journal of Crop Improvement* **23**(4): 366–382.

Mahajan M and Timsina J. 2011. Effect of nitrogen rates and weed control methods on weeds abundance and yield of direct seeded rice *Archives of Agronomy and Soil Science* **57**(3): 239–250.

Pysek P and Leps J. 1991. Response of a weed community to nitrogen fertilization: a multivariate analysis. *Journal of Vegetation Science* **2**(2): 237–244.

Ramamoorthy K, Krishnamurthi VV and Balasubramanian A. 1997. Effect of time of nitrogen application on growth, yield and economics of irrigated rice. *Madras Agricultural Journal* **84**(4): 647–649.

Raun WR and Johnson GV. 1999. Improving nitrogen use efficiency for cereal production. *Agronomy Journal* **91**(3): 357–363.

Sharief AE, El-Kalla SE, El-Kassaby AT, Ghonema MH and Abdo GMQ. 2006. Effect of biochemical fertilization and times of nutrient foliar application on growth, yield and yield components of rice. *Journal of Agronomy* **5**(2): 212–219.

Srinivasan S and Angayarkanni A. 2008. Effect of INM on yield and nutrient uptake by rice in STCR experiment. *Agricultural Science Digest* **28**(2): 130–132.

Vaishya RD, Kumar S and Shrivastava A. 1992. Chemical weed control in puddled broadcast rice. *Indian Journal of Weed Science* **24**(4): 72–74.

Indian Journal of Weed Science **50**(3): 294–297, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Efficacy of weed management practices in transplanted rice under southern dry zone of Karnataka

G.N. Dhanapal*, S. Kamala Bai, M.T. Sanjay, P. Nagarjun and A. Sandeep

University of Agricultural Sciences (B), MRS, Hebbal, Bengaluru, Karnataka 560 024

Email: dhanapalgn@yahoo.com

Article information

DOI: 10.5958/0974-8164.2018.00063.1

Type of article: Research note

Received : 02 June 2018
Revised : 23 August 2018
Accepted : 30 August 2018

Key words

Bensulfuron-methyl + pretilachlor, Triafamone + ethoxysulfuron, Transplanted rice, Weed index

ABSTRACT

A field experiment was conducted during *Kharif* 2016 and 2017 at Zonal Agriculture Research Station, V.C. Farm, Mandya (Southern dry Zone, Karnataka) to study the efficacy of various weed management practices on weeds in transplanted rice. The experiment consists of ten treatments replicated thrice in a randomized complete block design. Among the various treatments, significantly the lowest weed density (18.3-22.0 no./m^2) and weed biomass (5.4-6.3 g/m^2) was noticed with hand weeding at 25 and 45 DAS, which was at par with pre-emergence application (PE) of bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfuron applied at 30 days after transplanting (DAT). Weed management with bensulfuron-methyl + pretilachlor (60 + 600 g/ha) PE *fb* triafamone + ethoxysulfuron (60 g/ha) applied at 25 DAT recorded significantly higher paddy grain and straw yields and higher economic returns.

Rice (*Oryza sativa* L.) is one of the most important global food grain crop. In India rice is contributing 45% to the total food grain production and is grown in an area of 44.1 million ha with a production of 106.64 million tonnes and productivity of 2.42 t/ha (Bhatt *et al.* 2017). Rice suffers from various biotic and abiotic production constraints among which weed competition is one of the major yield limiting biotic constraint. The reduction in paddy yield due to weed competition ranges from 9-51% (Mani *et al.* 1986). With the advent of capital intensive technology like dwarf high yielding varieties tailored to respond to external inputs like fertilizers, irrigation and new intensive cropping systems also aggregated the problem of weeds (Yaduraju and Mishra 2002). The direct and most important effect of weeds is the reduction in crop yields due to competition for water nutrients and sunlight, with impaired quality of grains while causing some nuisance at the time of harvest (Rao *et al.* 2007).

The productivity of transplanted rice to a greater extent depends on adequate and efficient weed management. Transplanted rice faces diverse type of weed flora, consisting of grasses, broad-leaved weeds and sedges. They usually grow faster than rice and absorb available water, nutrient earlier than the rice and suppress rice growth. Effective control of weeds had increased the grain yield by 85.5% (Mukherjee and Singh 2005). Herbicide use offers best alternative method for selective and economical control of weeds right from the beginning, giving crop an advantage of good start and competitive superiority. However, no single herbicide is effective for broad-spectrum weed control in transplanted rice. Combination products consisting of two or more herbicides having greater activity on diverse weed flora due to differential mode of action and have become popular in recent years. With this background, the present investigation was undertaken to quantify the bio-efficacy of combination of herbicides against complex weed flora and yield of transplanted rice.

The field experiment was conducted during *Kharif* 2015 and 2016 at Zonal Agricultural Research Station, V.C. Farm, Mandya to quantify the bio-efficacy of combination of herbicides against complex weed flora, and yield of transplanted rice. The soil type was sandy loam soil. The treatment combinations tested were, bensulfuron methyl + pretilachlor (60 + 600 g/ha) pre-emergence application (PE) at 0-3 days after transplanting (DAT) *fb* passing of cono weeder at 25 DAT, oxadiargyl (100 g/ha) PE at 0-3 DAT *fb* passing of cono weeder at 25 DAT, bispyribac-Na (20 g/ha) post-emergence application (PoE) at 15-20 DAT followed by *(fb)* passing of cono weeder at 35-40 DAT, triafamone +

ethoxysulfuron (60 g/ha) PoE at 15-20 DAT *fb* passing of cono weeder at 35-40 DAT, bensulfuron-methyl + pretilachlor (60+600 g/ha) PE *fb* bispyribac-Na (20 g/ha) PoE at 25-30 DAT, oxadiargyl (100 g/ha) PE *fb* bispyribac-Na (20 g/ha) PoE at 25-30 DAT, bensulfuron-methyl + pretilachlor (60 + 600 g/ha) PE DAT *fb* triafamone + ethoxysulfuron (60 g/ha) at 25-30 DAT, oxadiargyl (100 g/ha) at 0-3 DAT *fb* triafamone + ethoxysulfuron (60 g/ha) at 25-30 DAT, hand weeding 25 and 25 DAT and weedy check. These treatment combinations were replicated thrice in randomized complete block design (RCBD).

Rice variety '*Rasi*' was transplanted at a spacing of 30 × 10 cm and fertilizer level of 125 kg N, 62.5 kg P_2O_5 and 62.5 kg K_2O/ha. The gross and net plot sizes were 4.0 × 3.0 m and 3.2 × 3.5 m, respectively. The species wise weed density data was collected using a quadrate (50 × 50 cm) on 60 DAT (days after transplanting). Data averaged over three replications and two spots per replication. From this, density of major weed species/m^2 (sedges, grass and broad-leaf weeds) was worked out (**Table 1**). The density of weeds' category - sedge, grass and broad-leaf weeds on 60 DAT were worked out (**Table 2**). In addition, biomass of weeds' category–sedges, grass and broad-leaf weeds (g/m^2) were also collected at 60 DAT (**Table 1**). The data on weeds' density and biomass were analyzed using transformation of square root of $(\sqrt{x+1})$ and log $(\sqrt{x+2})$, depending on the variability. The data on rice grain and straw yield was collected after the rice harvest. The economics of weed management practices was worked out. The data collected on different traits was statistically analyzed using the standard procedure and the results were tested at five per cent level of significance as given by Gomez and Gomez (1984).

Weed flora

The extent of growth and yield loss caused by weeds depends on weed species and their density in a crop community. Major weed flora observed in the experimental plots were; *Cyperus difformis, Cyperus iria* (among sedges), *Panicum repens, Paspalum distichum* and *Echinochloa colona* (among grasses), *Alternenthera sessilis, Monochoria vaginallis, Marselia quadrifoliata, Ludwigia parviflora* (among broad-leaf weeds).

Weed density and biomass

Among different category of weeds, density and biomass of broad-leaf weeds (40.02%) was higher followed by sedges (37.45%) and grasses (22.39%) at 60 DAT in both 2016 and 2017 (**Table 1**). Among the various treatments significantly the lowest weed density (22.0 and 18.3 in 2016 and 2017, respectively) and biomass (6.3 g/m^2 in 2016 and 5.4 g/m^2 in 2017, respectively) was noticed with hand weeding at 25 and 45 DAT similar results are observed by Singh *et al.* (2006). However, it was at par with application of bensulfuron-methyl + pretilachlor (60 + 600 g/ha) PE *fb* triafamone + ethoxysulfuron (60 g/ha) PoE and oxadiargyl (100 g/ha) PE *fb* triafamone + ethoxysulfuron (60/ha) PoE at 30 DAT. Other herbicidal combinations like bensulfuron-methyl + pretilachlor (60 + 600 g/ha) PE *fb* bispyribac-Na (20 g/ha) PoE at 30 DAT and oxadiargyl (100 g/ha) PE *fb* bispyribac-Na (20 g/ha) PoE at 30 DAT were also found effective in suppressing the weeds effectively in both the years, indicating the necessity of combination of herbicides to manage complex weed flora in transplanted rice. The higher broad spectrum weed control was observed with sequential application of PE herbicide and PoE herbicides or manual weeding which is in conformity with Parthipan and Ravi (2014) and Bhatt *et al.* (2017).

There was a considerable reduction in weed emergence at the initial crop growth stage with adopted weed management treatments. Rice established vigorously in these treatments due to effective control of weeds with either manually or chemically. The initially vigorous crop stand provided spatial advantage to crop in suppressing the weeds below threshold level even at later stages.

Rice grain yield

Among the various weed management treatments, bensulfuron-methyl 60 g/ha + pretilachlor 600 g/ha PE *fb* triafamone + ethoxysulfuron 60 g/ha PoE 25 DAT recorded significantly higher rice grain yield (5.35 t/ha) and straw yield (7.66 t/ha) followed by hand weeding at 25 and 45 DAT (4.80 and 6.96 t/ha, respectively) in 2016 (**Table 2**). Whereas in 2017 hand weeding at 25 and 45 DAT recorded the highest grain and straw yields (5.95 and 6.95 t/ha, respectively) and statistically found at par with bensulfuron-methyl 60 g/ha + pretilachlor 600 g/ha PE *fb* triafamone + ethoxysulfuron 60 g/ha post-emergence (PoE) at 25 DAT (5.84 and 6.56 t/ha, respectively). Reduced competition for moisture, space, light and nutrients between crop and weeds along with effective suppression of weeds by combination of herbicides as helped in obtaining higher yield in both the years as reported by Upasani

Table 1. Weed density and weed biomass as influenced by weed management practices in transplanted rice at 60 DAT during 2016 and 2017

Treatment	Dose (g/ha)	Time (DAT)	Weed density (no./m²)				Weed biomass (g/m²)			
			Sedges #	Grasses +	Broad-leaf#	Total #	Sedges +	Grasses +	Broad-leaf#	Total #
2016										
Bensulfuron-methyl + pretilachlor *fb* passing of conoweeder	60+600	0-3/25	1.26 (16.6)	2.76 (7.0)	1.15 (12.7)	1.58 (36.3)	2.90 (7.5)	2.07 (3.3)	1.00 (8.2)	1.32 (19.1)
Oxadiargyl *fb* passing of conoweeder	100	0-3/25	1.20 (17.6)	2.92 (8.0)	1.23 (15.7)	1.60 (41.3)	2.95 (8.6)	2.24 (4.4)	1.09 (10.5)	1.38 (23.9)
Bispyribac-Na *fb* passing of conoweeder	20	15-20/35-40	1.35 (20.3)	3.06 (8.7)	1.29 (17.7)	1.69 (46.7)	3.76 (13.2)	2.59 (5.9)	1.17 (12.9)	1.53 (32.1)
Triafamone+ ethoxysulfuron *fb* passing of conoweeder	60	15-20/35-40	1.26 (18.3)	2.94 (8.3)	1.21 (16.0)	1.64 (42.7)	3.32 (10.6)	2.41 (5.5)	1.09 (11.5)	1.46 (27.4)
Bensulfuron-methyl + pretilachlor *fb* bispyribac-Na	60 + 600 *fb* 20	0-3/25-30	1.09 (11.3)	2.43 (5.0)	1.13 (11.7)	1.47 (28.0)	2.17 (3.8)	1.61 (1.6)	0.89 (5.8)	1.12 (11.9)
Oxadiargyl *fb* bispyribac-Na	100 *fb* 20	0-3/25-30	1.18 (13.6)	2.52 (5.7)	1.09 (11.0)	1.51 (30.3)	2.41 (4.9)	1.67 (1.8)	0.87 (5.6)	1.16 (12.4)
Bensulfuron-methyl + pretilachlor *fb* triafamone+ ethoxysulfuron	60 + 600 *fb* 60	0-3/25-30	1.06 (9.6)	2.60 (6.3)	1.08 (10.0)	1.44 (26.0)	2.02 (3.0)	1.80 (2.4)	0.83 (4.8)	1.08 (10.3)
Oxadiargyl *fb* triafamone + ethoxysulfuron	100 *fb* 60	0-3/25-30	1.04 (9.3)	2.69 (6.7)	1.08 (10.7)	1.46 (26.7)	2.01 (3.0)	1.88 (2.6)	0.84 (5.1)	1.11 (10.8)
Hand weeding at 25 and 45 DAT	-	25, 45 DAT	0.96 (7.6)	2.51 (5.7)	1.02 (8.7)	1.37 (22.0)	1.69 (1.9)	1.59 (1.5)	0.67 (2.7)	0.91 (6.2)
Weedy check	-	-	1.51 (30.6)	4.34 (18.3)	1.54 (32.7)	1.92 (81.7)	5.11 (25.5)	4.15 (16.6)	1.51 (30.7)	1.87 (72.4)
LSD (p=0.05)			0.31	1.39	0.23	0.17	0.91	0.95	0.21	0.15
2017										
Bensulfuron-methyl + pretilachlor *fb* passing of conoweeder	60+600	0-3/25	1.01 (10.6)	1.10 (11.6)	1.17 (13.0)	1.55 (35.3)	1.99 (3.3)	2.38 (4.9)	0.92 (6.3)	1.21 (14.5)
Oxadiargyl *fb* passing of cono weeder	100	0-3/25	1.08 (12.0)	1.14 (12.3)	1.11 (11.0)	1.56 (35.3)	2.28 (4.5)	2.71 (6.4)	0.94 (6.7)	1.29 (17.6)
Bispyribac-Na *fb* passing of cono weeder	20	15-20/35-40	1.26 (18.6)	1.33 (22.0)	1.33 (20.3)	1.77 (61.0)	2.98 (8.4)	3.63 (12.9)	1.19 (14.4)	1.55 (35.8)
Triafamone + ethoxysulfuron *fb* passing of cono weeder	60	15-20/35-40	1.11 (11.0)	1.09 (12.3)	1.23 (16.3)	1.59 (39.6)	2.15 (3.6)	2.49 (5.6)	1.04 (9.4)	1.29 (18.7)
Bensulfuron-methyl + pretilachlor *fb* bispyribac-Na	60 + 600 *fb* 20	0-3/25-30	1.01 (9.3)	1.02 (9.3)	1.07 (9.6)	1.46 (28.3)	1.86 (2.6)	2.05 (3.3)	0.79 (4.1)	1.07 (10.1)
Oxadiargyl *fb* bispyribac-Na	100 *fb* 20	0-3/25-30	1.08 (13.0)	1.23 (17.3)	1.12 (13.0)	1.59 (43.3)	2.43 (5.4)	3.21 (10.0)	0.99 (8.8)	1.36 (24.3)
Bensulfuron-methyl + pretilachlor *fb* triafamone+ ethoxysulfuron	60 + 600 *fb* 60	0-3/25-30	0.94 (8.0)	0.97 (8.3)	0.91 (6.6)	1.35 (23.0)	1.69 (2.0)	1.90 (2.7)	0.66 (2.7)	0.95 (7.4)
Oxadiargyl *fb* triafamone + ethoxysulfuron	100 *fb* 60	0-3/25-30	1.15 (12.6)	1.23 (16.3)	1.09 (11.6)	1.60 (40.6)	2.41 (4.9)	3.13 (9.1)	0.93 (7.3)	1.34 (21.4)
Hand weeding at 25 and 45 DAT	-	25, 45 DAT	0.94 (7.0)	0.84 (5.3)	0.89 (6.0)	1.30 (18.3)	1.63 (1.6)	1.61 (1.6)	0.61 (2.1)	0.87 (5.4)
Weedy check	-	-	1.37 (21.6)	1.50 (30.0)	1.48 (28.3)	1.91 (80.0)	3.50 (11.2)	4.71 (21.3)	1.41 (23.5)	1.76 (56.0)
LSD (p=0.05)			0.35	0.28	0.25	0.21	0.81	0.97	0.23	0.20

Data within the parentheses are original values; Transformed values, # : log $\sqrt{x+2}$, +: square root of ($\sqrt{x+1}$); DAT: Days after transplanting

et al. (2012). Unweeded control gave the lowest paddy grain yield due to severe competition from all types of weeds. Similar trend was noticed with respect to weed index.

Economics

Economics is the ultimate criteria for acceptance or rejection and wider adoption of any technology. Among the various treatments, herbicide combination of bensulfuron-methyl + pretilachlor *fb* triafamone + ethoxysulfuron recorded higher net returns of ` 62,530/ha in 2016 and ` 65,600/ha in 2017 with higher benefit: cost ratio in both the years (3.08 and 3.19 in 2016 and 2017, respectively) compared to other treatments. This may be attributed to effective weed management at critical stages by integration of effective pre- and post-emergence herbicides which resulted in higher grain with

Table 2. Ricegrain and straw yields weed index and economics as influenced by weed management practices during 2016 and 2017

Treatment	Dose (g/ha)	Time (DAT)	Rice grain yield (t/ha)		Straw yield (t/ha)		Weed index (%)		Net returns (×10^3`/ha)		B:C
			2016	2017	2016	2017	2016	2017	2016	2017	2016
Bensulfuron-methyl + pretilachlor *fb* passing of conoweeder	60+600	0-3 / 25	4.63	4.93	6.51	5.57	3.54	17.1	48.22	49.30	2.53
Oxadiargyl *fb* passing of conoweeder	100	0-3 / 25	4.37	3.70	6.41	5.05	8.96	37.7	47.04	34.25	2.62
Bispyribac-Na *fb* passing of conoweeder	20	15-20 / 35-40	3.56	3.98	5.38	4.72	25.83	33.0	32.42	35.90	2.08
Triafamone+ ethoxysulfuron *fb* passing of conoweeder	60	15-20 / 35-40	4.46	3.87	6.37	5.37	7.08	34.9	47.36	36.69	2.59
Bensulfuron-methyl + pretilachlor *fb* bispyribac-Na	60 + 600 *fb* 20	0-3 / 25-30	4.69	5.48	6.66	6.53	2.29	7.9	49.45	59.33	2.77
Oxadiargyl *fb* bispyribac-Na	100 *fb* 20	0-3 / 25-30	3.64	3.86	5.30	4.93	24.17	35.1	20.72	22.47	1.49
Bensulfuron-methyl + pretilachlor *fb* triafamone+ ethoxysulfuron	60 + 600 *fb* 60	0-3 / 25-30	5.35	5.84	7.66	6.56	-11.46	1.8	62.53	65.60	3.08
Oxadiargyl *fb* triafamone + ethoxysulfuron	100 *fb* 60	0-3 / 25-30	4.24	3.78	6.01	4.68	11.67	36.5	46.15	36.18	2.71
Hand weeding at 25 and 45 DAT	---	25, 45 DAT	4.80	5.95	6.96	6.95	0.00	0.0	50.78	65.70	2.56
Weedy check	--	--	1.70	3.47	2.22	3.73	64.58	41.6	4.26	31.80	1.17
LSD (p=0.05)			1.00	1.17	1.39	1.18	NA	NA	NA	NA	NA

NA: not analysed; DAT: days after transplanting

reduced cost of cultivation as reported by Bhatt *et al.* 2017. The lowest B:C ratio (1.17 and 1.30 in 2016 and 2017, respectively) was obtained in the weedy check plot in both the years.

The herbicide combination of bensulfuron-methyl + pretilachlor 660 g/ha as pre-emergence *fb* triafamone + ethoxysulfuron 60 g/ha post-emergence were very effective in controlling weeds in transplanted rice and resulted in higher grain and straw yield with better economic returns due to reduced cost of cultivation.

REFERENCES

Gomez KA and Gomez AA. 1984. *Statistical Procedure for Agricultural Research. An International Rice Research Institute*, a willey – inter Science, John wiley and sons Inc. New York, United states of America.

Mani VS, Gautam KC and Chakraberty TK. 1986. Losses in crop yield in India due to weed growth. *Journal of Plant Protection in the Tropics* **2**: 142-158.

Mukherjee D and Singh RP. 2005. Effect of micro-herbicides on weed dynamics, yield and economics of transplanted rice (*Oryza sativa*). *Indian Journal of Agronomy* **50**: 292-295.

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

Singh VP, Govindra Singh, Singh RK, Abnish Kumar, Dhyani VC, Kumar M. and Sharma G. 2006. Effect of herbicides alone and in combination on direct seeded rice. *Indian Journal of Weed Science* **37**(3&4): 197-201.

Bhatt PS, Yakadri M. Madhavi S, Sridevi and Leela Rani P. 2017. Productivity of transplanted rice as influenced by herbicide combinations. *Indian Journal of Weed Science* **49**(2): 128–131.

Upasani RR, Kumari P, Thakur R and Singh MK. 2012. Effect of seed rate and weed control methods on productivity and profitability of wet land rice under medium and low land condition. *Indian Journal of Weed Science* **44**: 98-100.

Yaduraju NT and Mishra JS. 2002. Herbicides –boon or bane. *Pestology* **26**: 43-45

Indian Journal of Weed Science **50**(3): 298–301, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Weed management in groundnut under rice-fallow

E. Aruna* and G. Karuna Sagar

Agricultural Research Station, ANGRAU, Utukur, Kadapa, Andhra Pradesh 516 126

**Email: arunaettapu@gmail.com*

Article information

DOI: 10.5958/0974-8164.2018.00064.3

Type of article: Research note

Received : 3 June 2018
Revised : 15 August 2018
Accepted : 22 August 2018

Key words
Imazethapyr
Pendimethalin
Quizalofop-ethyl
Rice fallow groundnut
Weed management

ABSTRACT

A field experiment was conducted at Agricultural Research Station, Utukur, Kadapa, Andhra Pradesh, India during *Rabi* seasons of 2016 and 2017 to test the efficacy of herbicides in rice-fallow groundnut. It is common that previous rice volunteer plants will come in the succeeding crops after rice. Keeping all this in view, the experiment was conducted with six weed control treatments arranged in a randomized block design (RBD) with four replications. Pre-emergence application of pendimethalin 1.5 kg/ha followed by post-emergence application of imazethapyr 75 g/ha at 18-20 DAS recorded lower density of both broad-leaved and grassy-weeds. Weed free throughout the crop period recorded higher pod yield (4.24 t/ha), which was at par with hand weeding twice at 20 and 40 DAS (4.19t/ha) and pendimethalin 1.5 kg/ha as pre-emergence followed by imazethapyr 75 g/ha as post-emergence at 18-20 DAS (3.91 t/ha). Higher benefit:cost ratio (2.20) was recorded with pre-emergence application of pendimethalin 1.5 kg/ha followed by post-emergence application of imazethapyr 75 g/ha at 18- 20 DAS.

Groundnut (*Arachis hypogaea* L.) is one of the most important edible oilseed crop extensively cultivated in the world. It is called the king of the oilseeds. Groundnut is also called as wonder nut and poor men's cashew nut. It is a low-priced commodity, but a valuable source of all the nutrients. India occupies the first place with regard to the area and the production in the world. About 7.5 million hectares are put under it annually and the production is about seven million tonnes (Anonymous 2016). But the country ranks eighth in productivity, which is lower by about 100 kg than the world average. It is grown throughout the year *i.e., Kharif, Rabi* and summer seasons. During *Rabi*, being a short duration crop and having biological nitrogen fixing capability, groundnut can be fit in different cropping systems.

Rice-groundnut cropping system is one of the predominant systems in south India. Among different constraints that limit the productivity of groundnut, weed menace is one of the serious bottlenecks as peanut is confronted with repeated flush of diverse broad-leaved, grassy and sedges throughout the growing season which cause substantial yield loss of 15-75% (Jat *et al.* 2011). The critical period of grass weed control was found to be from four to nine weeks after planting whereas, the critical period of broad-leaved weeds control was from two to eight weeks in groundnut (Wesley *et al*. 2008). Pre-emergence herbicide pendimethalin (Patel *et al.* 2013) and post-emergence herbicides imazethapyr (Kalhapure *et al.* 2013) and quizalofop-ethyl (Samant and Mishra 2014) were found effective to control weeds in groundnut in different parts of the country. Pendimethalin inhibits root and shoot growth. It controls weed population and prevents weeds from emerging, particularly during the crucial development phase of the crop. Its primary *mode of action* is to prevent plant cell division and elongation in susceptible species (Simerjeet Kaur *et al*. 2014). Quizalofop-ethyl effectively controls narrow leaf weeds in broad-leaved crops. Imazethapyr absorbed by plant roots and foliage, being translocated to meristematic regions where it inhibits the biosynthesis of valine, leucine and isoleucine preventing cell division. It controls both broad-leaved weeds and grasses. The field experiment was conducted to see any change in weed flora in groundnut under rice fallow situation and the effectiveness of common weedicides used in groundnut under rice fallow situation with suitable weed management practices.

A field experiment was conducted during *Rabi* seasons of 2016 and 2017 at Agricultural Research Station, Utukur, Kadapa on Alfisols with sandy-clay-loam texture and spheroidal moderate structure. The experimental soil was low in available nitrogen (139 kg/ha), high in available phosphorus (57 kg/ha) and high potassium (460 kg/ha) with pH 8.27 and EC 0.06 dS/m. The experiment was laid out in randomized block design with four replications. The treatments comprised of un-weeded control, weed free, two hand weedings (20 and 40 DAS), pre-emergence application of pendimethalin 1.5 kg/ha followed by one hand weeding at 25 DAS, pre-emergence application of pendimethalin 1.5 kg/ha followed by post-emergence application of quizalofop-ethyl 50 g/ha at 20-30 DAS, pre-emergence application of pendimethalin 1.5 kg/ha followed by post-emergence application of imazethapyr 75 g/ha at 20-30 DAS. The test variety '*Dharani'* was sown on november 16^{th} in 2016 and november 18^{th} in 2017 with spacing of 22.5 × 10 cm in the plot of 4.5 × 3.6 m size.

All the cultural practices like seed rate (188 kg/ha), spacing (22.5 × 10 cm), fertilizer application (30-40-50 kg NPK/ha) and irrigations were followed as per university recommendation except weeding. Pendimethalin was applied as pre-emergence at two days after sowing. While, the post-emergence herbicides were applied at 18- 20 DAS when the weeds were at 2-3 leaf stage. Data on weed density and dry weight were taken before and 20, 40 days after application of herbicide and at harvest by throwing 0.25 sqm. quadrate randomly at four places in a plot. At the end of cropping season, yield was recorded from net plot area and computed to per hectare. Cost of cultivation, gross returns and net returns were calculated based on the prevailing price of inputs and outputs. Benefit: cost ratio was calculated on the basis of gross returns divided by the cost of cultivation.

The most dominant broad-leaved weeds were *Digera arvensis, Eclipta alba, Phyllanthus maderaspatensis* and *Parthenium hysterophorus, w*hile the dominant grassy weeds include *Echinochloacolona* and *Panicum repens.*

Effect on weeds

Pre-emergence application of pendimethalin at 1.5 kg/ha effectively controlled both broad-leaved and grassy weeds in the initial stages up to twenty days compared to the unweeded check. Pendimethalin prevented the weeds from emerging, particularly during the initial twenty days of crucial development phases of the crop as reported by Jat *et al. (*2011) and Sathyapriya *et al.* (2013). But it did not control the paddy volunteer plants effectively. The data on weed density at 20 and 40 days after post-emergence application of herbicides showed significant reduction in both broad-leaved and grass weed population including volunteer paddy (grown from seeds fallen from previous crop) when imazethapyr was applied as post-emergence at 18-20 DAS (**Table 1**).

Imazethapyr was effective in reducing weed density significantly, it resulted in significant reduction of total weed biomass. However, application of quizalofop-ethyl as post-emergence controlled only grassy weeds leaving uncontrolled the broad-leaved weed population like *Eclipta alba* and *Digera arvensis* in both the years. Significant sedge population was not observed in the experimental plot in both the years. Higher total weed dry weight was recorded with unweeded check which reduced the pod yield by 78.5% over weed free situation. Significant reduction in weed dry weight was observed with weed management treatments. Lower weed index (1.17) was with hand weeding twice at 20 and 40 days after sowing. Among herbicide

Table 1. Weed density (no./m²) at different stages as influenced by weed management in rice fallow groundnut (pooled of two years)

Treatment	Broad-leaved weeds			Narrow leaved weeds		
	Before spray	20 DAA	40 DAA	Before spray	20 DAA	40 DAA
Pendimethalin 1.5 kg/ha + one hand weeding at 25 DAS	2.52(9.0)	3.38(14)	3.20(11)	0.70(0)	1.43(2)	1.54(3)
Pendimethalin 1.5 kg/ha + quizalofop-ethyl 50 g/ha at 20-30 DAS	3.06(11)	5.57(34)	5.53(32)	0.83(0)	1.17(2)	1.14(1)
Pendimethalin 1.5 kg/ha + imazethapyr75 kg/ha at 20 - 30 DAS	2.11(7)	2.48(7)	3.0(9)	0.81(0)	0.70(0)	1.14(1)
Two hand weedings (20 and 40 DAS)	6.76(48)	2.76(20)	3.54(14)	8.32(81)	2.09(7)	3.63(10)
Unweeded control	7.17(55)	7.45(58)	8.59(7)	9.40(97)	10.4(124)	6.84(48)
Weed free	0.70(0)	0.70(0)	0.70(0)	0.70(0)	0.70(0)	0.70(0)
LSD (p=0.05)	1.36	1.29	1.42	1.52	1.37	0.97

Data were parentheses square root transformed treatments, lower weed index (1.66) was with pre-emergence application of pendimethalin followed by post-emergence application of imazethapyr at 18-20 DAS.

Effect on crop

Plant height was not significantly influenced by the weed management treatments. Higher number of pods/plant (18.75) was registered with weed free treatment which was on par with hand weeding twice at 20 and 40 DAS and pre-emergence application of pendimethalin1.5 kg/ha followed by post-emergence application of imazethapyr 75g/ha at 20- 30 DAS. Patra and Naik (2001) also reported increased pod number due to weed control treatments. The differential contribution of yield components towards pod yield was obtained with different treatments. Effective control of weeds by herbicides might have resulted in better availability of soil moisture and nutrients as evidenced by the beneficial effect on crop growth. Higher level of these parameters could be attributed to low crop-weed competition. Shelling percentage and 100 kernel weight were not significantly influenced by the weed management treatments (**Table 3**).

All the weed management practices significantly enhanced pod and haulm yield over weedy check and highest pod yield (4.24 t/ha) was obtained in weed free treatment throughout the crop period, which was however at par with hand weeding twice at 20 and 40 DAS (4.19 t/ha) and pre-emergence application of pendimethalin 1.5 kg/ha followed by post-emergence application of imazethapyr 75 g/ha at 18-20 DAS (3.91 t/ha). While, the lowest pod yield of 0.91 t/ha was observed in unweeded control. Higher haulm yield was registered with weed free treatment which was significantly superior over pre-emergence application of pendimethalin 1.5 kg/ha followed by post-emergence application of quizalofop-ethyl 50g/ha at 18-20 DAS and weedy check. This might be due to the fact that weed free environment in crop facilitated better peg initiation and development at the critical growth stages of groundnut which ends to increase in number of pods/plant and pod yield. Singh *et al.* (2017) also reported the beneficial effect of pre-emergence application of pendimethalin 1000 g/ha followed by post-emergence application of imazethapyr 75 g/ha in lowering weed density and weed biomass of both broad-leaved and grassy-weeds and significantly increasing dry matter accumulation, number of pods/plant, pod yield, haulm yield and biological yield in groundnut over all other herbicidal treatments.

All the weed control treatments recorded higher gross returns and B: C ratio over weedy check (**Table 3**). Highest gross returns was registered with weed free treatment (` 1,58,925/) followed by two hand weedings at 20 and 40 DAS (` 1,57,050) and pre-emergence application of pendimethalin followed by post-emergence application of imazethapyr at 18-20 DAS (` 1,46,737). While the lowest gross returns were observed in unweeded check. Pre-emergence application of pendimethalin 1.5 kg/ha followed by post-emergence application of imazethapyr 75 g/ha at18-20 DAS recorded higher benefit-cost ratio (2.20) due to higher pod yield and subsequently lower cost of cultivation of groundnut crop. To maintain weed free throughout the crop growth period more number of labour was engaged which increased the cost of cultivation and the same was reduced in herbicide treatments. Rao *et al.* (2011) also reported higher net returns and benefit-cost ratio with pre- and post-emergence application of herbicides in groundnut.

Table 2. Weed biomass, weed control efficiency and weed index as influenced by weed management in rice fallow groundnut (pooled of two years)

Treatment	Weed biomass (g/m^2)		Weed control efficiency (%)		Weed index (%)
	20 DAA	40 DAA	20 DAA	40 DAA	
Pendimethalin 1.5kg/ha + one hand weeding at 25 DAS	2.12	11.61	95.52	80.44	7.91
Pendimethalin 1.5kg/ha + quizalofop-ethyl 50 g/ha at 20-30 DAS	4.19	18.69	91.15	68.51	20.38
Pendimethalin 1.5kg/ha + imazethapyr75 kg/ha at 20 - 30 DAS	0.35	8.125	99.26	86.31	1.66
Two hand weedings (20 and 40 DAS)	2.75	18	94.19	69.68	1.17
Unweeded control	47.37	59.37	-		78.5
Weed free	0	0	100	100	-
LSD (p=0.05)	18.5	9.0	-	-	-

DAA- Days after application

Table 3. Growth, yield and economics of groundnut as influenced by weed management (pooled of two years)

Treatment	Plant height (cm)	No. of pods / plant	Shelling percentage	100 kernel weight (g)	Pod yield (t/ha)	Haulm yield (t/ha)	Gross returns (x10^3 `/ha)	Cost of cultivation (x10^3 `/ha)	B:C ratio
Pendimethalin 1.5kg/ha + one hand weeding at 25 DAS	21.75	16.50	67.79	45.91	3.90	6.179	146.21	69.05	2.11
Pendimethalint 1.5 kg/ha + quizalofop – ethyl50 g/ha at 20-30 DAS	23.25	16.56	69.16	45.42	3.37	5.603	126.52	66.45	1.90
Pendimethalin 1.5 kg/ha+ imazethapyr 75 kg/ha at 20 - 30 DAS	21.40	18.40	69.87	46.56	3.91	6.300	146.74	66.66	2.20
Two hand weedings (20 and 40 DAS)	21.85	18.03	68.12	46.63	4.19	6.334	157.05	72.00	2.18
Unweeded control	22.76	10.52	69.52	45.90	0.91	2.247	34.05	64.00	-0.53
Weed free	22.30	18.75	76.64	46.53	4.24	6.339	158.92	85.00	1.86
LSD (p=0.05)	NS	1.97	NS	NS	2.89	1.93	-	-	-

Price of groundnut – ` 37,500/tonne

It can be concluded that, pre-emergence application of pendimethalin 1.5 kg/ha followed by post-emergence application of imazethapyr 75 g/ha at 18-20 DAS was effective in controlling both broad-leaved weeds and grasses in groundnut under rice fallow.

REFERENCES

Anonymous. 2016. *Agriculture At a Glance*. Ministry of Agriculture and Cooperation, Government of India, New Delhi.

Jat RS, Meena HN, Singh AL, Jaya NS and Misra JB. 2011. Weed management in groundnut (*Arachis hypogaea* L.) in India-A review. *Agricultural Reviews* **32**(3): 155–171.

Kalhapure AH, Shete BT and Bodake PS. 2013. Integration of chemical and cultural methods for weed management in groundnut. *Indian Journal of Weed Science* **45**(2): 116–119.

Patel HF, Patel JC, Maheriya VD and Patel BB. 2013. Integrated weed management in *Kharif* groundnut (*Arachis hypogaea* L.). *A Quarterly Journal of Life Sciences* **10**(1b): 320–321.

Patra AK and Naik BC. 2001. Integrated weed management in rainy season groundnut. *Indian Journal of Agricultural Sciences* **71**: 378–380.

Rao SS, Madhavi M and Reddy CR. 2011. Integrated approach for weed control in *Rabi* groundnut (*Arachis hypogaea* L.). *Journal of Research ANGRAU* **39**(1): 60–63.

Singh SP, Yadav RS, Kumawat A,Bairwa RC and Reager ML. 2017**.** Groundnut productivity and profitability as influenced by weed control measures. *Indian Journal of Weed Science* **49**(4): 360–363.

Samant TK and Mishra KN. 2014.Efficacy of post-emergence herbicide quizalofop - ethyl for controlling grassy weeds in groundnut. *Indian Journal of Agricultural Research* **48**(6): 488–492.

Sathyapriya R, Chinnusamy C, Manickasundaram P and Babu C. 2013. A review on weed management in groundnut (*Arachis hypogaea* L.). *International Journal of AgriculturalScience and Research* **3**(1): 163–172.

Simerjeet Kaur, Tarundeep Kaur and Bhullar MS. 2014. Bio-efficacy of brand formulations of pendimethalin - penda 30 EC and markpendi 30 EC for Control of Phalaris minor Retz. in Wheat. *Journal of Krishi Vigyan 2014* **3**(1): 10–12

Wesley JV, Burke IC, Clewis SB, Thomas WE and Wilcut JW. 2008. Critical period of grass vs. broad-leaf weed interference in peanut. *Weed Technolgy* **22**: 68–73.

Indian Journal of Weed Science **50**(3): 302–304, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Weed population, weed biomass and grain yield of wheat as influenced by herbicides application

Raghubar Sahu*, Kumari Sharda, Dharmendra Kumar and S.K. Mandal
Krishi Vigyan Kendra, Banka, Bihar 813 102
**Email: raghubar.bhu@gmail.com*

Article information

DOI: 10.5958/0974-8164.2018.00065.5

Type of article: Research note

Received : 18 August 2018
Revised : 29 September 2018
Accepted : 30 September 2018

Key words
Isoproturon
Metsulfuron-methyl
Weed population
Weed biomass
Wheat

ABSTRACT

A field experiment was conducted during *Rabi* seasons of 2015-16 and 2016-17 at Banka (Bihar) to evaluate the weed population, weed biomass and grain yield as influenced by herbicide application in wheat (*Triticum aestivum* L.). Seven weed species, *viz. Phalaris minor*, *Cynodon dactylon*, *Chenopodium album*, *Oxalis purpurea*, *Anagallis arvensis*, *Medicago denticulata* and *Rumex dentatus* infested the wheat field. Post-emergence application of sulfosulfuron 75% WG (25 g/ha) + metsulfuron-methyl 20% WP (2 g/ha) at 30 days after sowing (DAS) was very effective against broad-leaf weeds and annual grasses, and recorded significantly lower density and biomass of these weeds at 60 DAS as compared to isoproturon 75% WP 1.0 kg/ha, sulfosulfuron 75% WG 50 g/ha, metsulfuron-methyl 20% WP 4 g/ha and weedy check. Ear length, effective tillers/m^2, grains/spike, grain and straw yields were also significantly higher in sulfosulfuron (25 g/ha) + metsulfuron-methyl (2 g/ha) as compared to other herbicide treatments.

Weeds are one of the major biotic constraints in wheat production as they compete with crop for nutrients, moisture, light and space (reference). Weeds possess many growth characteristics and adaptations which enable them to successfully exploit the numerous ecological niches. Apart from an ineffective control measure against mimicry weeds like *Phalaris minor* and *Avena ludoviciana*, manual weeding also involves high cost (Chhokar *et al.* 2012). The present situation of labour shortage and increase in wages has only worsened the situation. Under such situations, herbicides are far cheaper and more readily available resources than labor for hand weeding. When there is complex weed flora, infestation in wheat crop, the efficacy achieved by one herbicide belonging to single group is limited because of narrow spectrum of weed control. Uncontrolled weeds are reported to cause up to 66% reduction in wheat grain yield (Kumar *et al.* 2011) or even more depending upon the weed density, type of weed flora and duration of infestation. Loss in yield depends upon weed type, density, timing of emergence, wheat density, wheat cultivar and soil and environmental factors (Chhokar and Malik 2002). Among the grasses, *Phalaris minor* and broad-leaved weeds *ie*. *Rumex dentatus*, *Chenopodium album*, *Anagallis arvensis*, *Medicago denticulata*, *Melilotus alba*, *Fumaria parviflora*, *Coronopus didymus etc.* are of major concern in wheat under rice–wheat system (Chhokar *et al*. 2006). Chemical weed control is a preferred practice due to scarce and costly labour as well as lesser feasibility of mechanical or manual weeding especially in broadcast wheat. Recent investigations have vouched the importance of herbicide combinations in enhancing wheat productivity through control of wide spectrum of weeds.

A field experiment was conducted during *Rabi* seasons of 2015-16 and 2016-17 at farmer's field of Banka District as an On Farm Trial to evaluate the effect of herbicides namely, isoproturon, sulfosul-furon and metsulfuron-methyl on weed population dynamics and weed biomass in wheat crop. The geographical location of the farm lies at 24°30'N latitude and 86°30'E latitude at an altitude of 79 m from the mean sea level. The soil of experimental site was sandy-clay-loam in texture with neutral pH value (7.17). It was low in organic C (0.49%) and available N (197.5 kg/ha), medium in available P (16.4 kg/ha) and available K (210.9 kg/ha). The field experiment involving six weed management practices (weedy check, isoproturon 1.0 kg/ha at 30 DAS, sulfosulfuron 50 g/ha at 30 DAS, metsulfuron-methyl 4 g/ha at 30 DAS, sulfosulfuron 25 g/ha + metsulfuron-methyl 2 g/ha at 30 DAS and weed free) was conducted in a randomized block design replicated thrice with the wheat cultivar *'HD-2733'*. The land was prepared by giving two ploughing each followed by planking with the help of a tractor-drawn cultivator. The sowing of wheat was done behind the plough after preparation of field on November 24, 2015 and November 20, 2016 at 22.5 cm row spacing. A uniform fertilizer dose of 120, 60, 40 kg N, P_2O_5 and K_2O/ha in the form of urea, di-ammonium phosphate and muriate of potash was applied to each experimental unit, respectively. Full dose of phosphorus, potassium and half dose of nitrogen were applied at sowing and remaining half dose of nitrogen was top dressed in two split doses after first and third irrigation. Treatment-wise post-emergence herbicides were applied at 30 DAS by knapsack sprayer fitted with flat-fan nozzle using water volume of 300 L/ha. Wheat was harvested at full physiological maturity, sun-dried for a week and threshed manually. Weed and crop samples were collected from each individual plot for studying various crop and weed characters. Weed samples were collected by placing a quadrat (0.5 × 0.5 m) randomly at two places in each plot. The data on weed density and weed biomass were subjected to square root ($\sqrt{x+1}$) transformation before statistical analysis to obtain homogeneity of variances. The data on density and biomass of total weeds were taken at 60 DAS and grain yield (t/ha) was recorded at the time of harvesting.

Density and biomass of weeds

The experimental field was infested with two grassy weeds, *viz. Phalaris minor* and *Cynodon dactylon* and five broad-leaved weeds, *viz. Chenopodium album, Oxalis purpurea, Anagallis arvensis, Medicago denticulata* and *Rumex dentatus*. Herbicidal treatments significantly reduced the density and biomass of grasses and broad-leaved weeds than weedy check. Sulfosulfuron (25 g/ha) + metsulfuron-methyl (2 g/ha) was found to be the most effective against broad-leaf weeds and annual grasses, and recorded significantly lower density and biomass of these weeds at 60 DAS than isoproturon at 1.0 kg/ha, sulfosulfuron at 50 g/ha, metsulfuron-methyl at 4.0 g/ha and weedy check (**Table 1**). Application of sulfosulfuron (25 g/ha) + metsulfuron-methyl (2 g/ha) reduced the weed population and weed biomass by 72.3% and 72.2%, respectively. Owing to synergetic enhancement or additive effects, herbicidal combinations in general were better than sole application of herbicides in effectively reducing the total weed population and weed biomass. This is in conformity with the findings of (Katara *et al.* 2015, Ahmadi and Nazari Alam 2013, Sheibani and Ghadiri 2011).

Among the different treatments, 100 per cent weed control efficiency against grassy and broad-leaved weeds was recorded in weed free followed by sulfosulfuron 25 g/ha + metsulfuron-methyl 2.0 g/ha, metsulfuron-methyl 4.0 g/ha, sulfosulfuron 50 g/ha and isoproturon 1.0 kg/ha at 30 DAS.

Effect on crop

All the weed control measures recorded significantly higher yield attributes and grain yield over weedy check (**Table 2**). Application of sulfosulfuron 25 g/ha + metsulfuron-methyl 2.0 g/ha recorded longer ear, more effective tillers/m², heavier 1000-grain weight, more grain and straw yields which were significantly higher than those in metsulfuron-methyl 20% WP 4 g/ha, sulfosulfuron 50 g/ha and isoproturon 1.0 kg/ha applied plot, weed free treatment. These results are in conformation with those of (Baghestani *et al.* 2008, Chhokar *et al.* 2008, Santos 2009 and Singh *et al.* 2012) who

Table 1. Weed population, weed biomass and weed control efficiency as influenced by herbicide application in wheat (pooled data of 2 years)

Treatment	60 DAS						WCE (%)		
	Weed population (no./m²)			Weed biomass (g/m²)					
	P. minor	BLW	Total weed	Biomass of *P. minor*	Biomass of BLW	Total weed biomass	Grassy weeds	Broad-leaved weeds	Total weeds
Isoproturon 1000 g/ha 30 DAS	3.0(9.8)	3.3(11.6)	6.1(38.0)	9.6 (93.9)	7.5(57.5)	17.0(290.0)	51.42	56.35	54.79
Sulfosulfuron 50 g/ha 30 DAS	1.7(4.0)	1.9(4.8)	3.7(14.4)	6.0(36.6)	4.5(21.2)	10.5(110.4)	81.05	83.95	82.79
Metsulfuron-methyl 4 g/ha 30 DAS	1.5(3.1)	1.7(3.9)	3.2(11.0)	5.0(26.3)	3.9(16.4)	9.0(81.3)	86.39	87.53	87.33
Sulfosulfuron + metsulfuron-methyl 25 + 2 g/ha 30 DAS	1.2(2.4)	1.3(2.6)	2.4(7.0)	4.1(17.8)	2.9(9.6)	7.0(50.6)	90.78	92.68	92.11
Weedy check	4.0(17.4)	4.9(24.8)	8.9(79.5)	13.9(193.4)	11.4(131.9)	25.3(641.6)	0.00	0.00	0.00
Weed free	1.0(0)	1.0 (0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	100	100	100
LSD (p=0.05)	0.30	0.31	0.59	0.84	0.96	1.87	-	-	-

*Data subjected to square root ($\sqrt{x+1}$) transformation and figures in parenthesis are original value

Table 2. Yield attributes and yield of wheat as influenced by herbicide application (pooled data of two years)

Treatment	Dose (g/ha)	Time of application (DAS)	Ear length (cm)	Yield attributes			Yield (t/ha)		Harvest index (%)
				Effective tillers/m^2	1000-grain weight	Grains /spike	Grain	Straw	
Isoproturon	1000	30	7.32	136.80	37.39	35.52	3.19	4.54	41.26
Sulfosulfuron	50	30	7.60	149.83	36.77	37.97	3.49	5.04	40.93
Metsulfuron-methyl	4	30	7.87	152.23	36.98	39.30	3.55	5.21	40.54
Sulfosulfuron + metsulfuron-methyl	25+2	30	8.81	171.81	37.93	43.62	3.98	5.82	40.60
Weedy check	-	-	6.53	103.81	37.95	30.59	2.50	3.49	41.73
Weed free	-	-	9.00	185.19	37.36	44.51	4.32	6.32	40.58
LSD (p=0.05)			0.88	17.38	NS	4.22	0.41	0.57	NS

reported that herbicides offer sizeable increase in crop productivity corresponding to their weed control spectrum.

The minimum yield was found with weedy check due to higher infestation of weeds resulting in strong competition of weeds with crop for growth factors (moisture, light, nutrients and space). The present results are in conformity with the findings of Sharma *et al.* (1999) and Rana *et al.* (2017).

The differences in 1000-grain weight and harvest index due to weed management treatments were non-significant. The herbicide treatments metsulfuron-methyl 4.0 g/ha, sulfosulfuron 50 g/ha and isoproturon 1.0 kg/ha were on par with each other in recording more ear length, effective tillers/m^2 and grain yield after sulfosulfuron 25 g/ha + metsulfuron-methyl 2.0 g/ha and weed free. Guillen-Portal *et al.* (2006) revealed that the grain number/spike significantly decreased in the presence of weed. The higher spike in herbicides treated plots may be attributed to effective weed control and allocation of more resources to crop plants than weeds (Cheema and Akhtar 2005).

It is concluded that all herbicide treatments reduced weed population and biomass and increased wheat grain and straw yields as compared with the weedy check. Among herbicides, sulfosulfuron 25 g/ ha+ metsulfuron-methyl 2.0 g/ha provided maximum reduction in the total weed population and biomass and the highest yields which were at par with weed free conditions and significantly higher than all other treatments of weed management.

REFERENCES

Ahmadi A and Nazari Alam J. 2013. Efficiency of new herbicide of sulfosulfuron plus metosulfuron in weed control of wheat. *International Journal of Agronomy Plant Production* **4**: 714–718.

Baghestani MAZE, Soufizadeh S, Beheshtian M, Haghighi A, Barjasteh A, Birgani DG and Deihimfard R. 2008. Study on the efficacy of weed control in wheat with tank mixtures of grass herbicides with broad-leaved herbicides. *Crop Protection* **27**: 104–111.

Cheema MS and Akhtar M. 2005. Efficacy of different post-emergence herbicides and their application methods in controlling weeds in wheat. *Pakistan Journal of Weed Science Research* **11**(1-2): 23–30.

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

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

Chhokar RS, Sharma RS and Sharma I. 2012. Weed management strategies in wheat-A review. *Journal of Wheat Research* **4**(2): 1–21.

Chhokar RS, Singh S and Sharma RK. 2008. Herbicides for control of isoproturon resistant little seed canary grass (*Phalaris minor*) in wheat. *Crop Protection* **27**: 719–726.

Guillen Portal FR, Stougaard RN, Xue Q and Eskridge KM. 2006. Compensatory mechanisms associated with the effect of spring wheat seed size on wild oat competition. Crop *Science* **46:** 935–945.

Kumar S, Angiras NN and Rana SS. 2011. Bio-efficacy of clodinafop-propargyl + metsulfuron-methyl against complex weed flora in wheat. *Indian Journal of Weed Science* **43:**195–198.

Katara P, Kumar S and Rana SS. 2015. Influence of pinoxaden in combination with other herbicides on nutrient depletion by weeds in wheat. *Indian Journal of Weed Science* **47**(4): 371–375.

Rana SS, Badiyala D and Brari Parita. 2017. Evaluation of herbicide combinations for controlling complex weed flora in wheat. *Indian Journal of Weed Science* **49**(4): 335–340.

Santos BM. 2009. Drip-applied metam potassium and herbicides as methyl bromide alternatives for *Cyperus* control in tomato. *Crop Production***28**: 68–71.

Sharma BD, Nanwal RK and Panwar RS. 1999. Evaluation of herbicides for weed control in wheat (*Triticum aestivum* L.). *Indian Journal of Weed Science* **31**(1&2): 99–100.

Sheibani S and Ghadiri H. 2011. Integration effects of split nitrogen fertilization and herbicide application on weed management and wheat yield. *Journal of Agronomy Science and Technology* **14**: 77–86.

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

Indian Journal of Weed Science **50**(3): 305–308, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Tank mix application of tembotrione and atrazine to reduce weed growth and increase productivity of maize

Puscal Sharma*[1], Buddhadeb Duary and Raghavendra Singh[1]
Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal 731 236
[1]ICAR-National Organic Farming Research Institute, Tadong, Gangtok 737 102
**Email: raghavenupc@gmail.com*

Article information

DOI: 10.5958/0974-8164.2018.00066.7

Type of article: Research note

Received : 7 April 2018
Revised : 27 July 2018
Accepted : 2 August 2018

Key words

Atrazine

Kharif maize

Stefes mero surfactant

Tembotrione

Yield

ABSTRACT

The experiment was carried out during *Kharif* (wet) season of 2014 at Agricultural Farm of Palli Siksha Bhavana, Visva-Bharati, Sriniketan, West Bengal to find the effect of tank mix application of tembotrione and atrazine on weed growth and productivity of *Kharif* maize. Nine treatments comprising of herbicide tembotrione as early post-emergence at 80, 100, 120 g/ha alone and in combination with atrazine at 500 g/ha, sole application of atrazine at 1000 g/ha and weeding twice at 25 and 40 DAS and unweeded control were assigned in a randomized block design in three replication. Results revealed that the experimental field was infested with all categories of weeds including grassy, broad-leaved and sedges. Among them the most predominant weeds were *Ludwigia parviflora*, *Cynodon doctylon*, *Cyperus rotundus* and *Fimbristylis miliacea*. Overall weed infestation caused about 48% reduction in yield of maize. Combined application of tembotrione with atrazine was significantly superior to its sole application in all the doses tested. Tembotrione at 100 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha considerably reduced the weed infestation- registering lower weed density, dry weight, weed index, higher weed control efficiency and increase in values of growth and yield attributes and yield of maize, which were comparable with tembotrione at 80 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha and tembotrione at 120 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha. Thus, early post-emergence application of tembotrione at 80-100 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha appeared to be the most promising weed management practice for higher weed control efficiency, yield, gross and net return of *Kharif* (wet) season maize in lateritic soil of West Bengal.

Maize is one of the most important cereal crops in the world agricultural both as food and feed. There is no cereal on the earth which has so immense potentiality; hence, it is called as 'Queen of cereals'. It is grown in almost all the states of India. It occupies an area of about 600 million/ha, which accounts for about 23% of the total area in the continent. It is next to rice, wheat and sorghum with regard to area and production in India. The crop is predominantly grown in *Kharif* (wet) season in India. The major yield reducing factors for maize cultivation in India are weeds (Pandey *et al*. 2001). Frequent rainfall, high temperature and higher relative humidity in *Kharif* season encourage germination, growth and heavy infestation of weeds in maize. Maize crop is infested with all categories of weeds including grassy, broad-leaved and sedges. The crop was infested with a wide range of weed flora, *viz. Cynodon dactylon, Echinochloa colona*, among the grasses; *Cyperus iria, Fimbristylis miliacea* among the sedges; and *Ludwigia parviflora, Commelina nudiflora, Cyanotis axillaris, Phyllanthus niruri, Melochia corchorifolia* among the broad-leaved weeds as major weeds out of which *Echinochloa colona, Cyperus rotundus, Commenlina benghalensis* and *Trianthema portulacastrum* dominated during early stages.

Weeds emerge along with the germination of maize seeds and grow rapidly in the early stage of crop growth, causing severe crop weed competition. In case, the weeds are not brought under control at right time, there is 50-60% reduction in yield (Chidda Singh 2009). However, the most critical period for crop weed competition is first six weeks after planting of crop because initial slow growth and wider row spacing of maize, coupled with congenial weather conditions allow the weed growth which may reduce yield by 28-100% (Dass *et al.* 2012). Inadequate weed management especially during the first six weeks after sowing may cause maize yield losses ranging from 50 to 90% (Chikoye *et al.* 2004). Yield reduction in maize results from high competition between the crop and weed for water, light, nutrients especially when the competing weeds are of the same family with maize (Oerke and Dehne 2004). In maize generally, pre-emergence application of atrazine, pendimethalin, alachlor and post-emergence application of 2,4-D are being used. Applications of triazine group herbicides have been found effective to reduce the weed intensity in maize. Out of which, mix application of herbicides is coming out as very essential tool to tackle the problem of complex weeds in many crops including maize. Tembotrione is a new selective post-emergence herbicide that has been recently introduced for use in maize mixing with recommended herbicide atrazine. But it is essential to study the efficacy of the herbicide in different doses against different weed species in maize either alone or in combination with atrazine.

A field experiment was conducted during *Kharif* season of 2014 at Agriculture Farm, Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal. The farm is situated at 23°39' N latitude and 87°42' E longitude with an average altitude of 58.9 m above mean sea level under sub-humid, semiarid region of West Bengal. The soil was sandy loam in texture, slightly acidic in reaction (pH 6.8), low in organic C (0.46%) and available N (149.6 kg/ha), high in available P (28.42 kg/ha) and medium in available K (129.5 kg/ha). The experiment comprising of nine treatments was laid out in a randomized block design with three replications. The treatments under experimentation were tembotrione at 80 g/ha + stefes mero surfactant 733 g/ha, tembotrione at 80 g/ha + stefes mero surfactant 733 g/ha + atrazine 500 g/ha, tembotrione at 100 g/ha + stefes mero surfactant, tembotrione at 100 g/ha + stefes mero surfactant 733 g/ha + atrazine 500 g/ha, tembotrione at 120 g/ha + stefes mero surfactant , tembotrione at 120 g/ha + stefes mero surfactant 733 g/ha + atrazine 500 g/ha, atrazine 1000 g/ha, hand weeding 25 and 40 DAS , unweeded control. The treatments was applied with the help of knapsack sprayer after the sowing of seed. The powder or liquid formulation was diluted in the water according to the different doses and 1.2 L of spray solution per plot was applied for each treatment. The maize variety '*Kaveri Super 2020'*, was fertilized with 120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha. All other recommended agronomic practices and plant protection measures were adopted to raise the crop. Data on weed population dynamics, dry weed biomass along with plant growth and yield attributes were recorded during the growth period. Weed control efficiency (%) was computed using the dry weed biomass of weeds.

Weed flora

The experimental field was infested with three categories of weeds under six families. The total number of weeds species was 9 out of which *Cynodon dactylon, Echinochloa colona,* among the grasses*; Cyperus iria, Fimbristylis miliacea* among the sedges; and *Ludwigia parviflora, Commelina nudiflora, Cyanotis axillaris, Phyllanthus niruri, Melochia corchorifolia* among the broadleaved weeds were present as major weeds (**Table 1**). Similar type of weed flora was reported by Ahmed and Susheela (2012), Haji *et al.* (2012), Dangwal and Singh (2013).

Effects on weed

The highest density and dry weed biomass of the entire weed species was recorded in unweeded control at both 45 DAS and 60 DAS. Among the herbicidal treatments application of tembotrione at 120 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha registered the lowest number and dry weight of *Cynodon dactylon*. No *Melochia corchorifolia* and *Phyllanthus niruri* was registered in treatments with the application of tembotrione at 80 g/ha + stefes mero surfactant at 733 g/ha + atrazine at 500 g/ha, tembotrione at 100 g/ha + stefes mero at 733 g/ha + atrazine at 500 g/ha, tembotrione at 120 g/ ha + stefes mero at 733 g/ha, tembotrione at 120 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ haand atrazine 1000 g/ha (**Table 1**). Similar trend was observed in case of dry weight of *Melochia corchorifolia* and *Phyllanthus niruri*at 45 DAS and 60 DAS (**Table 2**).

All the three doses of tembotrione (80, 100, 120 g/ha) with surfactant and combination of atrazine 500 g/ha effectively controlled *Ludwigia parviflora, Cynotis axillaris* and *Commolina nudiflora*. Similar trend was observed in case of dry weight of *Ludwigia parviflora, Cynotis axillaris and Commolina nudiflora* at 45 DAS and 60 DAS. No *Cyperus rotundus* was registered in treatments with the application of tembotrione at 80 g/ha + stefes mero surfactant at 733 g/ha + atrazine at 500 g/ha, tembotrione at 100 g/ha + stefes mero at 733 g/ha + atrazine at 500 g/ha, tembotrione at 120 g/ha + stefes mero at 733 g/ha, tembotrione at 120 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha and atrazine 1000 g/ha. Similar trend was observed in case of dry weight of *Cyperus rotundus*. The lowest count and biomass of *Fimbristylis miliacea*was registered under treatment tembotrione at 120 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha at 45 DAS and 60 DAS. All the herbicidal treatments are effectively controlled the count and dry weight of other weeds (*Echinocloa colona*) at both 45 DAS and 60 DAS. Among the herbicidal treatments, the lowest number and dry weight of total weeds was registerd in the higher doses of tembotrione at 120 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha at 45 DAS and 60 DAS.

Effects on crop

Weed infestation caused about 48% yield reduction in *Kharif* maize. The average girth of cob of maize varied significantly among the treatments. The highest average girth of cob was recorded in the tembotrione at 120 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha, which was statistically at par with tembotrione at 80 g/ha + stefes mero at 733 g/ha + atrazine 500 g/ha, tembotrione at 100 g/ha + stefes mero at 733 g/ha + atrazine 500 g/ha, hand weeding at 25 and 40 DAS. The highest number of kernals/cob was recorded in hand weeding at 25 and 40 DAS, which was statistically at par with tembotrione at 80 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha, tembotrione at 100 g/ha + stefes mero at 733 g/ha + atrazine 500 g/ha, tembotrione at 120 g/ha + stefes mero at 733 g/ha + atrazine 500 g/ha (**Table 3**). The highest number of kernel rows/cob was recorded in hand weeding at 25 and 40 DAS, which was statistically at par with tembotrione at 80 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha, tembotrione at 100 g/ha + stefes mero at 733 g/ha + atrazine 500 g/ha, tembotrione at 120 g/ha + stefes mero at 733 g/ha,

Table 1. Effect of treatments on weed density of different weeds (no./m²) at 60 DAS of maize

Treatment	*C. dactylon*	*M. corchorifolia*	*P. niruri*	*L. parviflora*	*C. axillaris*	*C. nudiflora*	*C. rotundus*	*F. mileaceae*	Other weeds	Total
Tembotrione at 80 g/ha + stefes mero at 733 g/ha at 17 DAS	6.77 (45.33)	3.03 (8.66)	2.61 (6.33)	82.67	36.33	24.00	3.58 (12.33)	36.67	2.48 (5.66)	258.00
Tembotrione at 80 g/ha + stefes mero at 733 g/ha + atrazine at 500 g/ha at 17 DAS	3.58 (12.33)	0.71 (0)	0.71 (0)	15.33	12.00	7.67	0.71 (0)	16.33	0.71 (0)	63.67
Tembotrione at 100 g/ha + stefes mero at 733 g/haat 17 DAS	5.46 (29.33)	2.97 (8.33)	2.42 (5.33)	80.33	32.00	21.67	1.47 (1.66)	31.67	0.71 (0)	210.33
Tembotrione at 100 g/ha + stefes mero at 733 g/ha + atrazine at 500 g/ha at 17 DAS	3.39 (11)	0.71 (0)	0.71 (0)	14.33	10.67	6.00	0.71 (0)	14.67	0.71 (0)	56.67
Tembotrione at 120 g/ha + stefes mero at 733 g/ha at 17 DAS	5.12 (25.66)	0.71 (0)	1.68 (2.33)	72.67	31.33	21.67	0.71 (0)	23.33	1.47 (1.66)	178.67
Tembotrione at 120 g/ha + stefes mero at 733 g/ha + atrazine at 500 g/ha at 17 DAS	2.80 (7.33)	0.71 (0)	0.71 (0)	5.00	4.67	5.33	0.71 (0)	6.67	0.71 (0)	29.00
Atrazine at 1000 g/ha at 17 DAS	4.67 (21.33)	0.71 (0)	0.71 (0)	20.00	12.00	10.00	0.71 (0)	14.67	0.71 (0)	78.00
Two hand weeding at 25 and 40 DAS	3.67 (13)	1.58 (2)	1.35 (1.33)	16.67	6.00	5.33	4.30 (18)	12.67	0.71 (0)	75.00
Unweeded control	8.07 (64.66)	3.67 (13)	4.38 (18.66)	90.33	56.67	33.33	5.93 (34.66)	63.67	4.26 (17.66)	392.67
LSD (p=0.05)	4.11	0.35	0.30	11.13	4.62	3.49	0.54	4.57	0.28	18.2

Figures in parentheses are the original values. The data was transformed to $\sqrt{x+0.5}$ before analysis

Table 2. Effect of treatments on dry weight of different weeds (g/m²) at 60 DAS of maize

Treatment	*C. dactylon*	*M. corchorifolia*	*P. niruri*	*L. parviflora*	*C. axillaris*	*C. nudiflora*	*C. rotundus*	*F. mileaceae*	Other weeds	Total
Tembotrione at 80 g/ha + stefes mero at 733 g/ha at 17 DAS	9.51	1.32 (1.24)	59.22	11.29	0.78 (0.10)	3.59	2.76 (7.14)	7.23	2.00 (3.53)	102.85
Tembotrione at 80 g/ha + stefes mero at 733 g/ha + atrazine at 500 g/ha at 17 DAS	2.40	0.71 (0)	12.11	3.25	0.71 (0)	1.17	0.71 (0)	3.01	0.71 (0)	21.94
Tembotrione at 100 g/ha + stefes mero at 733 g/haat 17 DAS	6.89	1.29 (1.16)	58.56	11.73	0.80 (0.14)	2.67	1.16 (0.88)	6.46	0.71 (0)	88.49
Tembotrione at 100 g/ha + stefes mero at 733 g/ha + atrazine at 500 g/ha at 17 DAS	1.87	0.71 (0)	10.31	2.72	0.71 (0)	0.81	0.71 (0)	2.71	0.71 (0)	18.41
Tembotrione at 120 g/ha + stefes mero at 733 g/ha at 17 DAS	6.29	0.71 (0)	46.04	8.77	0.75 (0.05)	2.58	0.71 (0)	5.48	1.25 (1.08)	70.31
Tembotrione at 120 g/ha + stefes mero at 733 g/ha + atrazine at 500 g/ha at 17 DAS	1.77	0.71 (0)	5.75	1.39	0.71 (0)	0.76	0.71 (0)	1.67	0.71 (0)	11.34
Atrazine at 1000 g/ha at 17 DAS	3.86	0.71 (0)	14.52	3.08	0.71 (0)	1.56	0.71 (0)	3.16	0.71 (0)	26.18
Two hand weeding at 25 and 40 DAS	3.18	0.86 (0.24)	12.13	1.62	0.72 (0.02)	0.86	2.20 (4.36)	3.28	0.71 (0)	25.69
Unweeded control	26.70	1.94 (3.31)	87.27	17.74	1.45 (1.65)	6.04	6.13 (37.0)	16.29	3.07 (8.95)	202.94
LSD (p=0.05)	4.11	0.16	5.86	1.52	0.15	0.37	0.26	0.33	0.15	12.03

Figures in parentheses are the original values. The data was transformed to $\sqrt{x+0.5}$ before analysis

Table 3. Effect of treatments on yield components, economics and weed control efficiency of maize cultivation

Treatment	Avg. girth of cob (cm)	No. of kernels per cob	No. of kernel rows per cob	500 kernel wt. (g)	Grain yield (t/ha)	Weed control efficiency (%) 60 DAS
Tembotrione at 80 g/ha + stefes mero at 733 g/ha at 17 DAS	10.27	290.9	10.67	70.83	3.45	49.4
Tembotrione at 80 g/ha + stefes mero at 733 g/ha + atrazine at 500 g/ha at 17 DAS	14.38	376.7	13.00	80.61	4.10	89.2
Tembotrione at 100 g/ha + stefes mero at 733 g/haat 17 DAS	11.41	303.1	11.33	72.5	3.77	56.6
Tembotrione at 100 g/ha + stefes mero at 733 g/ha + atrazine at 500 g/ha at 17 DAS	14.96	380.1	13.33	81.14	4.57	90.9
Tembotrione at 120 g/ha + stefes mero at 733 g/ha at 17 DAS	12.08	314.7	12.00	77.88	3.80	65.4
Tembotrione at 120 g/ha + stefes mero at 733 g/ha + atrazine at 500 g/ha at 17 DAS	15.04	368.4	12.33	79.52	4.31	94.4
Atrazine at 1000 g/ha at 17 DAS	12.15	307.7	11.67	74.06	3.80	87.1
Two hand weeding at 25 and 40 DAS	15.04	383.9	13.67	81.01	4.52	87.3
Unweeded control.	9.69	257.3	9.33	65.21	2.37	0.0
LSD (p=0.05)	2.25	48.56	1.76	18.28	0.48	-

tembotrione at 120 g/ha + stefes mero at 733 g/ha +atrazine 500 g/ha. Test weight of maize varies significantly tembotrione at 100 g/ha + stefes mero surfactant at 733 g/ha + atrazine500 g/ha recorded the highest test weight, which was statistically at par with tembotrione at 80 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha, tembotrione at 100 g/ ha + stefes mero surfactant at 733 g/ha, tembotrione at 120 g/ha + stefes mero surfactant at 733 g/ha, tembotrione at 120 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha, atrazine 1000 g/ha, hand weeding 25 and 40 DAS. The treatment tembotrione at 100 g/ha + stefes mero surfactant at 733 g/ha + atrazine 500 g/ha recorded the highest grain yield (4.57 t/ha), which was at par with tembotrione at 80 g/ha + stefes mero at 733 g/ha + atrazine 500 g/ha, tembotrione at 120 g/ha + stefes mero at 733 g/ha + atrazine 500 g/ha and hand weeding at 25 and 40 DAS. This result corroborates with the findings of Singh *et al.* (2012), Idziak and Woznica (2014), Sharma *et al.* (2000), Reddy *et al.* (2000), Deshmukh *et al.* (2009). Higher weed control efficiency in these treatments facilitated better availability of space, light and nutrients resulting in higher values of growth attributes, more number of grains ultimately higher yield. Among the herbicidal treatments, the combined application of tembotrione and atrazine registered the highest weed control efficiency (94.4%) at 60 DAS but was very close to that of tembotrione at 100 g/ha + stefes mero at 733 g/ha + atrazine at 500 g/ha, tembotrione at 80 g/ha + stefes mero surfactant at 733 g/ha + atrazine at 500 g/ha. Similar type of results was obtained by Singh *et al.* (2012), Woznica and Idziak (2014).

REFERENCES

Ahmed MAA and Susheela R. 2012.Weed management studies in *Kharif* maize. *Journal of Research ANGRAU* **40**(3): 121–123.

Chikoye D, Schulz S and Ekeleme F. 2004. Evaluation of integrated weed management practices for maize in the northern Guinea savannah of Nigeria. *Crop Protection* **23**: 895–900.

Dangwal LR and Singh A. 2013. A Survey of weed flora in maize fields of district Rajouri (J&K), India. *International Journal of Scientific Research*. **1**: 6–9.

Dass S, Kumar A, Jat SL, Parihar CM, Singh AK, Chikkappa GK and Jat ML. 2012. Maize holds potential for diversification and livelihood security. *Indian Journal of Agronomy* **57**(3rd IAC Special Issue): 32–37.

Deshmukh LS, Jadhav AS, Jathure RS and Raskar SK. 2009. Effect of nutrient and weed management on weed growth and productivity of *Kharif* maize under rainfed condition. *Karnataka Journal of Agricultural Sciences* **22**(4): 889–891.

Haji ID, Hunshal CS, Malligwad LM, Basavaraj B and Chimmad VP. 2012. Effect of pre- and post-emergence herbicides on weed control in maize (*Zea mays* L.). *Karnataka Journal of Agricultural Sciences* **25**(3): 392–394.

Oerke EC and Dehne HW. 2004. Safeguarding production losses in major crops and the role of crop protection. *Crop Protection* **23**(4): 275–285.

Pandey AK, Prakash V. Singh and Mani VP. 2001. Integrated weed management in maize (Zea mays). *Indian Journal of Agronomy* **46**(2): 260–265.

Reddy CN, Reddy MD and Devi MP. 2000. Effect of weed management on weed growth and crop productivity in maize sunflower cropping system. *Indian Journal of Weed Science* **32**(4): 213–215.

Sharma AR, Toor AS and Sur HS. 2000. Effect of intercultural operations and scheduling of atrazine application on weed control and productivity of rainfed maize (*Zea mays*) in Shiwalik foothills of Punjab. *Indian Journal of Agricultural Sciences* **70**(11): 757–761.

Singh C. 2009. Modern techniques of raising field crops. *Oxford and IBH publishing co. pvt. Ltd. New Delhi,* 101–102.

Singh VP, Guru SK, Kumar A, Banga A and Tripathi N. 2012. Bioefficacy of tembotrione against mixed weed complex in maize. *Indian Journal of Weed Science* **44**(1): 1–5.

Woznica Z and Idziak R. 2014. Impact of tembotrione and flufenacet plus isoxaflutole application timings, rates, and adjuvant type on weeds and yield of maize. *Chilean Journal of Agricultural Research* **74**(2): 129–134.