www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(4): 745-753

www.thepharmajournal.com
Received: 06-01-2022
Accepted: 09-02-2022

G Manisankar
Ph.D., Research Scholar, Department of Agronomy, Palli Siksha Bhavana, Visva Bharati University, Sriniketan, West Bengal, India

Pritam Ghosh
Assistant Professor, Department of Agronomy, Palli Siksha Bhavana, Visva Bharati University, Sriniketan, West Bengal, India

Ganesh Chandra Malik
Professor, Department of Agronomy, Palli Siksha Bhavana, Visva Bharati University, Sriniketan, West Bengal, India

Mahua Banerjee
Assistant Professor, Department of Agronomy, Palli Siksha Bhavana, Visva Bharati University, Sriniketan, West Bengal, India

Corresponding Author:
G Manisankar
Ph.D., Research Scholar, Department of Agronomy, Palli Siksha Bhavana, Visva Bharati University, Sriniketan, West Bengal, India

Recent trends in chemical weed management: A review

G Manisankar, Pritam Ghosh, Ganesh Chandra Malik and Mahua Banerjee

Abstract
Weed management in agriculture is a critical juncture. Several factors are responsible for reducing the crop productivity in worldwide. However, weed infestation is the major biotic constraint. Weeds deplete the crop environment by compete with nutrients, space, water and light. This competition leads to reduction in crop yield considerably. Weed free condition during the critical period of crop weed competition is absolutely important for getting maximum yield. Weeds can be effectively managed by cultural, physical, chemical and biological methods. All those methods of weed control have its own advantage and disadvantages. Among all those methods, hand weeding is an effective method of weed management. At the same time increasing laborer cost and scarcity of laborer during peak period of agricultural operation led to search for alternative methods. In this above context, chemical method is most effective and economical way of weed management. Herbicide offer effective weed control during before crop planting as a pre plant herbicide, after crop planting and before weed emergence as a pre-emergence herbicide and after weed emergence in a standing crop as a post emergence herbicide. Apart from the weed control, excessive and inappropriate uses of chemical herbicides have gradually resulted in the wide problems of food and environmental contamination in recent days. Now a days new advanced technologies are coupled with chemical weed management for increase its efficiency. The aim of the review paper is to detailly address the recent chemical weed management technologies like herbigation, nanoherbicides, herbicide mixtures, low dose herbicides, new spotted sprayer technology, drone application of herbicides and stale seed bed technique by herbicides. This new generation technologies are used for manage the labour shortage and fasten the timely agricultural operation. Hence, these recent technologies helps to reduce the herbicide dose and decrease environmental contamination as well as increase the profitability. From this review, it could be concluded that, implementation of new generation weed management technologies in agriculture helps to efficient weed control, manage the labour shortage, reduce the environmental contamination and enhance the crop productivity.

Keywords: Chemical weed management, drone application of herbicides, herbigation, low dose herbicides, nanoherbicides, spotted sprayer technology

Introduction
Weed is often called a plant growing out of place and out of time. In elaborate, weed is plant growing in a place and time when we want to grow some other plants or no plants to grow at all. Weeds are unwanted, prolific, competitive and harmful to the environment by occurring in every cultivable and non-cultivable lands. In worldwide about 30,000 plant species have been identified as definite weed out of it 18,000 cause serious loss to crops (Reddy and Reddy, 2007) [18]. Several factors are responsible for reducing the crop productivity in worldwide. However, Weeds are the major biotic constraint. Weeds deplete the crop environment by compete with nutrients, space, water and light. This competition leads to reduction in crop yield considerably. Weeds are not only reduced the yield of crops but also cause inconvenience by interfere with agricultural operations. Weeds present in the off season on field bunds, wastelands and irrigation channels act as harbour for pest and diseases. Contamination of food grains with weed seeds is harmful to human health and reduce the grain quality. According to Directorate of Weed Research, Jabalpur, in India losses caused by weeds in agriculture are estimated to be 33% followed by insects (26%) and diseases (20%) in 2016. Recent estimate shows that weed causes an annual loss of rupees 2000 crores to Indian agriculture, which is more than the combined losses caused by insect pests and plant pathogens (Gharde *et al.*, 2018) [10]. Timely weed management is an important agro-technique for successful crop cultivation. Weed free condition during the critical period is absolutely important for getting maximum yield. Weeds can be effectively managed by cultural (Tillage, planting method, varieties, planting density,

irrigation, fertilizer application, drainage and cropping system), physical (Hand weeding, hand hoeing, digging, mowing, cutting, dredging, chaining, burning and flaming), chemical and biological methods. All those methods of weed control have its own advantage and disadvantages. Among all those methods, hand weeding is an effective method of weed management. During hand weeding all the weeds are efficiently removed that including the weeds associated with particular crop and the weed resembles the crop morphology (Mimicry weed). At the same time increasing laborer cost and scarcity of laborer during peak period of agricultural operation led to the search for alternative methods. This constraint forces the farming community to move towards a next viable option. In this above context, chemical method of weed management is most effective and economical way of weed management (Sureshkumar and Durairaj, 2016) [22]. Herbicide offer effective weed control during before crop planting as a pre plant herbicide, after crop planting and before weed emergence as a pre emergence herbicide and after weed emergence in a standing crop as a post emergence herbicide. Apart from this, herbicidal weed management saves time, energy and cost of weeding. While choosing an herbicide for successful weed management, we remember to maintain the environmental and ecological balance. The environmental and ecological balance are maintained by using low dose, low residual and high efficiency herbicide. Now a days new advanced technologies are coupled with chemical weed management for increase its efficiency. Very few studies have been focused on advance weed management technologies that may change substantially over the next decades. Hence, the objective of the review paper is carried out to evaluate and detailly address the recent trends of chemical weed management in agriculture.

Chemical weed management

Chemicals that used to kill or inhibit the growth of plants are called herbicides. The usage of herbicide has been increasing rapidly since 1944. Now a days, many new chemical molecules have become available for weed control. At present, every type of weed problem can be solved with herbicides (Sureshkumar and Durairaj, 2016) [22]. In many instances, they offer most practical, effective and economical means of weed control. In the past 40 years, man has greatly improved the weeding efficiency by supplementing the conventional weeding methods with herbicides. From the time of green revolution, farmers are using more chemicals to kill the weeds and gain more profit. It has saved the farmers from labour scarcity during peak period of agricultural operation, repeated inter cultivations for controlling weeds and helped to obtaining satisfactory weed control where physical methods often fail. Hence, herbicides may be considered as one of the most effective and economical way to control the weeds. However, apart from the all positive effects, herbicides also has lot of negative aspects regarding degradation in the soil and not eco - friendly. Pesticide use pattern in India is furnished in Fig. 1.

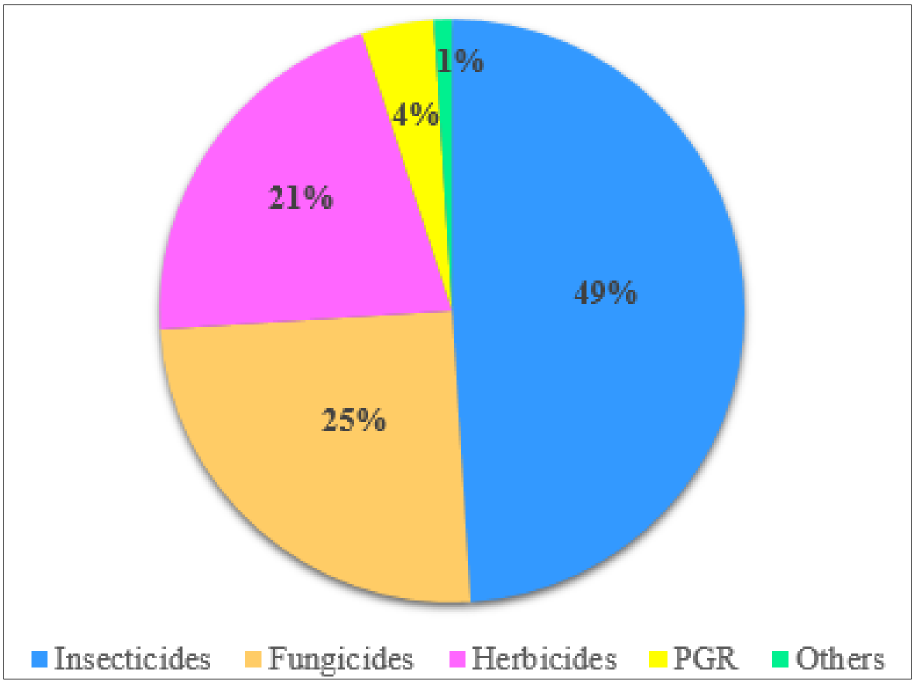


Fig 1: Pesticide use pattern in India on 2017

Potential benefits of Herbicides

1. In monsoon season, continuous rainfall may make physical weeding infeasible. Herbicides can be used to ensure freedom of crops from weeds under such a condition.
2. During the early crop growth period frequent weeding is essential for boosting the crop growth. In recent days, the labour rich countries like India, Pakistan, Bangladesh, Nepal, Nigeria and Sudan are also facing bottleneck labour demand. The soil applied herbicides can be give help to these kinds of issues.
3. Herbicides can employed to control the weeds when they emerge from the soil and it eliminate crop weed interference even at a very early stage of crop growth. But in the physical methods, weeds are removed after they attain certain height and possess considerable competition to the crops. Hence, the timely weed management is satisfied by herbicides.
4. Herbicides having potential to kill many weeds that survive by mimicry. for example, wild oat (*Avena fatua*)

in wheat and barnyard grass (*Echinochloa* species) in rice. Weeds that resemble crop plants are usually escape from physical weeding.

5. Herbicidal weed control does not need strict row spacing but in physical weed control, crop rows have to be sufficiently wide to accommodate weeding implements otherwise manual weeding has to be resorted.
6. Herbicides gave long lasting control of perennial weeds and brushes than physical method. Many modern herbicides can translocate considerably deep in the underground system of weeds and damage them. In case of physical method, only top portion above the soil is mostly removed and able to regenerate by underground organs in a subsequent season.
7. Herbicides are convenient to use on spiny weeds which cannot be reached manually.
8. Herbicides are safe on erodable lands where tillage may accelerate soil and water erosion.
9. Herbicides kill the weeds in situ without permitting their dissemination. But in manual weeding, vegetative propagules of the weeds are drag them to new sites.
10. Herbicide sprays easily reach the weeds growing in obstructed situations.

Some other benefits of using herbicide includes, reduce labour requirement, greater possibility of farm mechanization, easier crop harvesting and lower cost of farm produce. In dry land agriculture, herbicidal weed control ensures higher water use by crops and less crop failures due to drought.

Limitations of Herbicides

Like any other method of weed control, herbicides also have their own limitations. But with proper precautions these limitations can be overcome markedly. Important limitations in the use of herbicides are as follows.

1. In herbicidal control, there is no automatic signal to stop a farmer who may be applying the chemical inaccurately till he sees the results in the crops sprayed.
2. Even when herbicides are applied accurately, these may interact with environment to produce unintended results. Herbicide drifts, wash off and runoff can cause considerable damage to the neighboring crops leading to unwarranted quarrels.
3. Depending upon the diversity in faming, a variety of herbicides must be stocked on a farm to control weeds in different fields. On the contrary, in physical method a farmer has to possess only one or two kinds of weeding implements for his entire farm.
4. Application of herbicide requires considerable skill on the part of user. He must be able to identify the weed type and possess considerable knowledge to select a proper herbicide and their proper usages. Sometimes, an error in the use of herbicides can be very costly.
5. In herbicide treated soils, usually crop failures cannot be made up by planting a different crop of choice. The selection of the replacement crop has to be based on its tolerance to the herbicide already applied.
6. Military use of herbicides is the greatest misfortune of discovery. In Vietnam, 2, 4, D and 2, 4, 5-T used for defoliating forests leading to miseries the innocent civilians. In future, the chemical warfare with residual herbicides may be even more devastating, which must be avoided at all costs.

Current scenario of chemical weed management in India

In India, herbicides are being used on more than 20 million hectares, which constitute about 10% of the total cropped area in the country (Choudhury *et al.*, 2018) [5]. The pesticide market in India is relatively small (US $ 1 billion) when compared to global market (US $ 33 billion). The share of herbicides is nearly 20% of the total pesticides used and is expected to grow. Although the herbicides have been in use for over past 3 decades but usage has been increased recently. Wheat, rice, soybean and sugarcane are the major crops of herbicide use with approximate share of 28, 20, 9 and 7%, respectively (Yaduraju, 2012) [24]. According to Choudhury *et al.* (2016) [6], as per the herbicide use in Indian agriculture, butachlor (6032 tons) and glyphosate (6003 tons) were the highest consumed herbicides followed by paraquat (2068 tons), pretilachlor (2418 tons) and pendimethalin (1444 tons). The present annual installed capacity of herbicide production in India is about 6000 tones. A large portion of the available herbicides in India are used for plantation crops. Due to the increased use of low dose and high efficacy herbicides that replacing the conventional high dose herbicides like 2,4-D and isoproturon. The amount of herbicide consumption has decreased but the acreage under herbicidal weed management has been increased. Two major herbicides *viz*., butachlor in rice and isoproturon in wheat are being substituted largely by low dose herbicides *viz*., pyrazosulfuron in rice and sulfosulfuron in wheat. The consumption of butachlor has decreased gradually from 2005. Pretilachlor became more popular compared to butachlor in the rice market. In last five years, pretilachlor has a steady production of around 1900 ton per year (Choudhury *et al.*, 2016) [6].

Recent trends in chemical weed management

1. Herbigation

Herbigation is the process of application of herbicides to the soil along with irrigation water. This method was started in 1960 and has rapidly gained acceptance. In recent years, with the rapid expansion of drip and sprinkler irrigation, this technique has spread to other areas. Application of herbicides along with the irrigation water is generally effective for controlling weeds in only portion of the area wetted by the irrigation water. The use of irrigation systems to apply herbicides is a relatively recent development in weed control technology. Herbigation through trickle irrigation system may have higher degree of acceptability in arid climates. In sprinkler irrigation systems should be checked for constant pressure throughout the pipeline, uniform orifice size, sprinkler head type, leaky gaskets and holes in the pipelines. Surface irrigation fields should be leveled or graded to a uniform slope. Irrigation borders and furrows should have a uniform height and width. According to El Gindy (1988) [9], reported that application of herbicide along with irrigation water to tomato and cucumber plants observed weed control efficiency of 55.5%, 68% and 65.9% in furrows, sprinkler and drip irrigation systems respectively, compared to traditional spraying method. In the same research observed that drip irrigation method reduced the weed growth by 56.3% and 36.5% compared to furrows and sprinkler irrigation systems. Kanimozhi *et al.* (2019) [13] observed that, higher weed control efficiency of 80.8% was recorded with pre emergence application of oxyfluorfen at 0.188 kg a.i ha^{-1} under herbigation through micro sprinkler in non - cropped situation compare to others treatments. Research findings have established a fact that, some of the herbicides exhibit good activity by providing control of target weeds when applied through irrigation water. Herbigation insures no additional costs of application. The extent of herbicide movement through irrigation systems is entirely depend on the solubility, adsorption, volatility and efficient use of both water as well as herbicide (Sujith *et al.*, 2003) [21].

2. Nanoherbicides

Nanoherbicides are formulated with the help of nanosized preparations or nano materials based herbicide formulations (Table 1). Nanoherbicides are defined as nano materials based herbicide formulations exploiting the potential to effectual delivery of chemicals in a target site. Excessive and inappropriate uses of chemical herbicides have gradually resulted in the wide problems of food and environmental contaminations. Nanomaterials based formulations could improve the efficacy of the herbicide, enhance the solubility and reduce the toxicity in comparison with the conventional herbicides. Herbicides are loaded on nanomaterials to facilitate the higher bioavailability and thus ensure better eradication of weeds (Table 1). Nanoherbicides consists minute particles of herbicidal active ingredients and large specific surface led increased affinity to the target. Nanoherbicides also enhanced the wettability and dispersion of agricultural formulations. Nanoemulsions, nanoencapsules, nanocontainers and nanocages are some of the nanoherbicide formulations (Khatem *et al.*, 2016) [14]. Basically, nano formulations should possess the ability to degrade faster within the soil and slow rate within the plants that have the residue level below the criteria. Sodium dodecyl sulphate (SDS) is used to enhance the photodegradation of nanoparticle in the soil. Most of the herbicides available in the market are designed in such a way that either they kill or control the above ground part of the weed plants and none of them inhibits the activity of viable underground plant parts like rhizomes or tubers, which act as a source for regeneration of weed in subsequent season (Dashora and Kanika, 2018) [7]. Nanoherbicide in 1-100 nm range will try to mingle with the soil particles and destroy weed seeds and weeds via their roots. Developing a target specific molecule of herbicide encapsulated along with nanoparticle is aimed for specific receptor in the roots of target weeds, which penetrates into the roots system of the weeds and reaches the parts that inhibit glycolysis of food reserves in the root system. This causing the specific weed plant to starve due to lack of food and ultimately get killed (Hess, 2018). Detoxification of herbicide residues is necessary, because excessive use of herbicides for a longer period of time leaves the residues in the soil and causes damage to the succeeding crops (Chinnamuthu and Boopathi, 2009) [4]. Also, a continuous use of the same herbicide for long durations renders the weed resistant to that particular herbicide. Weeds survive and spread through underground structures such as tubers and deep roots may controlled to avoid weed infestation in subsequent season. At the same time, ploughing the weed infected field or removing weeds by hand can make these unwanted plants spread to uninfected areas (Prasad *et al.*, 2014) [17]. Each weed plant produces thousands of seeds every growing season. In some cases, the buried seeds can sprout even after 20 years. Frequent tilling of the soil can multiply weeds that spread through root fragments. The easiest way to eliminate weeds is to destroy their seed banks in the soil and prevent them from germinating when weather and soil conditions become favourable for their growth (Buhler, 1997) [3]. Being very small, nanoherbicides will be able to blend with the soil and eradicate weeds even after critical period of crop weed competition by slow releasing nature helps to arrest the weed seed bank deposition in an eco-friendly way without leaving any toxic residues. Application of nanotechnology in agriculture is presented in Fig.2.

Table 1: Commonly used nanoparticles in agriculture

S. No.	Nanoparticle	Uses in agriculture
1.	Polymeric nanoparticles	▪ Effective delivery of agrochemicals ▪ Superior biocompatibility ▪ Minimize the impact on non-target organism
2.	Silver nanoparticles	▪ Enhance the plant growth ▪ Act as anti-microbial property
3.	Nano alumino silicates	▪ Enhance the efficiency of pesticides
4.	Titanium dioxide	▪ Disinfecting agent for water
5.	Carbon nanomaterials (Graphene, Graphene oxide and carbon dots)	▪ Improved seed germination
6.	Nano rods	▪ Transport auxin growth regulator ▪ Plant physiological changes ▪ Phytotoxicity inhibitor

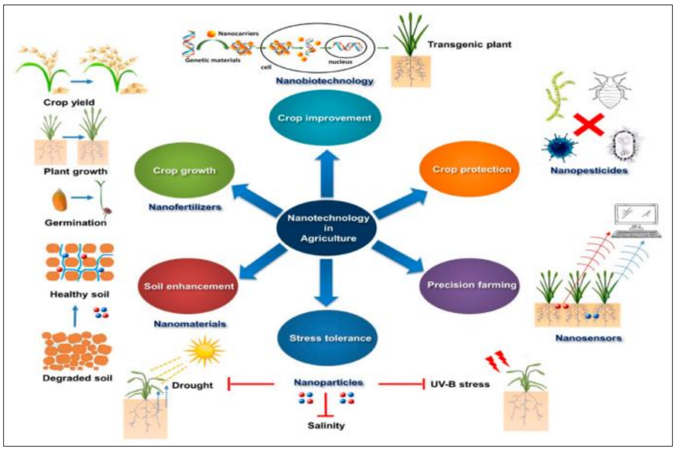


Fig 2: Application of nanotechnology in agriculture

3. Herbicide mixture or herbicide combinations

Herbicide combination or mixtures are used for effective and economical weed control. In this method, two or more herbicides are combinedly used to manage the diversified weed flora to saves time and labour in a weed management programme. Herbicide combination offer certain advantage like broad spectrum weed control, synergistic or additive effect, prevention the detoxification of one herbicide in a mixture and reduction of herbicide dosage. There is two type of herbicide mixtures, one is the tank mixture made with desired herbicides and rates just before application and another one is the concoated herbicide mixture are formulated by companies at the time of manufacturing. Several herbicide mixtures formulated under various trade names by different manufacturers for specific weed situation (Reddy and Reddy, 2007) [18]. Mixing compatible herbicides from different chemical families may improved the control of specific weed populations. For example, 2,4-D is applied with dicamba for control the broad leaf weeds. Interestingly, the herbicide combinations having potential to control several weed types at a same time. For example, the combinations of mesosulfuron + iodosulfuron, clodinafop + metsulfuron and sulfosulfuron + metsulfuron are used to control both grasses and broad leaf weeds in wheat. The combination product of chlorimuron ethyl + metsulfuron methyl and bensulfuron methyl + pretilachlor is recently used in many farmers field to control the sedges and grassy weeds in rice. In soybean crop, pendimethalin + imazethapyr and imazamox + imazethapyr combinations are used to controls the grasses and broad leaf weeds. At present, 37 herbicide combinations of two active ingredients are available in our country (Table 2). Recently, Pesticide Registration Committee and Central Insecticide Board has given approval for the combination pesticides having three active ingredients (Choudhury *et al.*, 2018) [5]. New combination products containing three active ingredients will be very useful for controlling the grassy weeds, broad leaf weeds and sedges at a same time. Hence, it will saves the application cost and time. Registered herbicide combinations in India are furnished in Table 2.

Table 2: List of registered herbicide combinations in India as on 01.07.2021 (Anonymous, 2021)

S. No.	Herbicide combinations	Manufacturer detail
1.	Anilofos 24% + 2, 4-D 32% (EC)	Aventis Crop science Ltd.
2.	Bensulfuron methyl 0.6% + Pretilachlor 6% (GR)	Nagarjuna Agrichem Ltd.
3.	Carfentrazone ethyl 20% + Sulfosulfuron 25% (WG)	FMC India Pvt Ltd.
4.	Carfentrazone ethyl 0.43% + Glyphosate 30.82% (EW)	FMC India Pvt Ltd.
5.	Clodinafop propargyl 9% + Metribuzin 20% (WP)	Crystal Plant Protection Ltd.
6.	Clodinafop propargyl 15% + Metsulfuran methyl 1% (WP)	UPL Ltd.
7.	Clodinafop propargyl 16.5% + Sodium acifluorfen 8% (WP)	UPL Ltd.
8.	Clomazone 20% + 2,4 - diethyl ester 30% (EC)	FMC India Pvt Ltd.
9.	Clomazone 22.5% + Metribuzin 21% (WP)	FMC India Pvt Ltd.
10.	Fenoxaprop-p-ethyl 7.77% + Metribuzin 13.6% (EC)	Bayer Crop Science Ltd.
11.	Fluxapyzoxad 62.5% + Epoxyconazole 62.5% (EC)	BASF India Ltd.
12.	Fomesafen 11.1% + Fluazifop-p-butyl 11.1% (SL)	Syngenta India Ltd.
13.	Hexazinone 13.2% + Diuron 46.8% (WP)	Dupont India Ltd.
14.	Imazamox 35% + Imazethapyr 35% (WG)	BASF India Ltd.
15.	Imazethapyr 2% + Pendimethalin 30% (EC)	BASF India Ltd.
16.	Indaziflam 1.65% + Glyphosate Isopropyl ammonium 44.63% (SC)	Bayer Crop Science Ltd.
17.	Metsulfuron methyl 10% + carfentrazone ethyl 40% (DF)	Dupont India Ltd.
18.	Mesosulfuron methyl 3% + Idosulfuron methyl sodium 0.6% (WG)	Bayer Crop Science Ltd.
19.	Metsulfuron methyl 10% + Chlorimuron ethyl 10% (WP)	Dupont India Ltd.
20.	Metribuzin 42% + Clodinafop propargyl 12% (WG)	UPL Ltd.
21.	Oxyfluorfen 2.5% + Isopropyl amine salt of Glyphosate 41% (SC)	ADAMA India Pvt Ltd.
22.	Penoxsulam 0.97% + Butachlor 38.87% (SE)	Dow Agro Science Pvt Ltd.
23.	Penoxsulam 1.02% + Cyhalofop butyl 5.1% (OD)	Dow Agro Science Pvt Ltd.
24.	Pretilachlor 6% + Pyrazosulfuron ethyl 0.15% (GR)	UPL Ltd.
25.	Pretilachlor 30% + Pyrazosulfuron ethyl 0.75% (WG)	UPL Ltd.
26.	Propaquizafop 5% + Oxyfluorofen 12% (EC)	ADAMA India Pvt Ltd.
27.	Propaquizafop 2.5% + Imazethayper 3.75% (ME)	ADAMA India Pvt Ltd.
28.	Sodium aceflourofen 16.5% + Clodinafop-propargyl 8% (EC)	UPL Ltd.
29.	Sulfentrazone 28% + Clomazone 30% (WP)	FMC India Pvt Ltd.
30.	Sulfosulfuron 75% + Metsulfuron 5% (WDG)	UPL Ltd.
31.	Mesotrione 2.27% + Atrazine 22.7% (SC)	Syngenta India Ltd.
32.	Pendimethalin 35% + Metribuzin 3.5% (SE)	GSP Crop Science Pvt Ltd.
33.	Pendimethalin 38.4% + Pyrazosulfuron ethyl 0.85% (ZC) [Mixed formulation of CS (capsule suspension) and SC (suspension concentrate)]	UPL Ltd.
34.	Penoxsulam 1% + Pendimethalin 24% (SE)	Rallis India Ltd.
35.	Bispyribac sodium 20% + Pyrazosulfuron ethyl 15% (WDG)	Coromandel International Ltd.
36.	Fomesafen 12% + Quizalofop ethyl 3% (SC)	Crystal Crop Protection Ltd.
37.	Pyriftalid 31% + Bensulfuron methyl 15.7% (SC)	Syngenta India Ltd.

4. Low dose herbicides

The escalating problems of weed infestation must be mitigated viably by the application of herbicides and we do not have any other feasible option in our hand. The only thing is we have to shift ourselves from conventional approaches to safer alternatives. In our early days of chemical weed control, herbicides employed are of high doses like more than 1 kg per hectare. Some herbicides of them are still in use. But their consumption is in decreasing trend. According to Heap (2007) [11], indiscriminate use of herbicides for weed control during the past few decades has resulted in serious ecological and environmental problems. The efficacy of any herbicide is predominately depending upon the dose used (Steckel *et al.*, 1997) [20]. Registered herbicide doses are set to achieve upper limits of weed control under varying weed compositions, densities, weed growth stages and environmental conditions. This may be an overestimation of the dose that required to get adequate control (Zhang *et al.*, 2000) [25]. To ensure satisfactory weed control even under unfavourable regimes of crop production factors, manufacturers often recommended higher than necessary doses of an herbicide. However, it is not always necessarily to apply full herbicide dose (Talgre *et al.*, 2008) [23]. Moreover, modern weed science also emphasizes and following an ecological approach to keeping weed populations below threshold levels rather than eradicating them (Barroso *et al.*, 2009) [2]. Numerous herbicide molecules at lower than recommended rates are effective enough to provide satisfactory weed control without sacrificing yields and increasing weed infestation in the following years (Zhang *et al.*, 2000) [25]. New generation low dose and high efficiency herbicides are used instead of conventional herbicides for reducing the environmental load. For example, atrazine was recommended to control annual weeds in maize at the rate of 2 to 4 kg ha^{-1}. Now, the same herbicide is recommended to use only at the rate of 1 to 2 kg ha^{-1}. The same efficacy is achieved by low dose instead of conventional dose. Some low dose herbicides used for rice and wheat were mentioned in Table 3.

Table 3: Low dose and high efficiency herbicides for weed control in rice and wheat

S. No	Crop	Herbicide	Dosage a.i / ha	Weed species controlled
1.	Rice	Bensulfuron methyl 0.6% + Pretilachlor 6% GR (Pre emergence)	660 g	*Cyperus iria, Cyperus difformis, Fimbristylis miliacea, Marsilea quadrifolia, Eclipta alba, Ammannia baccifera and Ludwigia parviflora.*
2.		Metsulfuron methyl 10% + Chlorimuron ethyl 10% WP (Pre and Post emergence)	4 g	*Cyperus iria, Cyperus difformis, Fimbristlylis miliacea, Eclipta alba, Ludwigia parviflora, Cyanotis axillaris, Monochoria vaginalis and Marsilea quadrifolia.*
3.		Pyrazosulfuron ethyl 10% WP (Pre emergence)	20 g	*Cyperus iria, Cyperus difformis, Fimbristylis miliacea, Monochoria vaginalis and Ludwigia parviflora.*
4.		Bispyribac sodium 10% SC (Early Post emergence)	20 g	*Cyperus difformis, Cyperus iria and Ischaemum rugosum.*
5.		Metsulfuron methyl 20% WP (Pre emergence)	4 g	*Cyperus rotundus, Spheanochlea species, Fimbristylis miliacea, Ludwigia parviflora and Marsilea quadrifoliate.*
1.	Wheat	Clodinafop propargyl 15% WP (Post emergence)	60 g	*Phalaris minor.*
2.		Sulfosulfuron 75% WG (Post emergence)	25 g	*Phalaris minor, Chenopodium album and Melilotus alba.*
3.		Metribuzin 70% WP (Pre and Post emergence)	175 g	*Phalaris minor, Chenopodium album and Melilotus alba.*
4.		Sulfosulfuran 75% + Metsulfuron methyl 5% (Post emergence)	32 g	*Phalaris minor, Chenopodium album, Medicago denticulata, Coronopus didymus, Rumex species, Melilotus alba and Anagallis arvensis.*
5.		Isoproturon 50% (Post emergence)	1 kg	*Phalaris minor, Avena fatua and Poa annua.*

5. New generation spot sprayer technology

Excessive use of herbicides creates pressure and challenges on the agriculture industry. Approximately each year farmers spend $ 25 billion for buying 3 billion pounds of herbicides. But this huge volume of chemicals never reaches weeds. Rather, it lands on healthy plants or soil or carried away with rainwater. Application of herbicides by conventional technology leads to lose farmers money on herbicides that are sprayed in non-targeted areas. However, this excessive and un appropriate use contaminate the soil and harming the environment. Meanwhile, repetitive use of same herbicides develops the problem of herbicide resistance. This inefficiency is mainly because of the poor precision of the conventional sprayers. Advanced new generation technologies available for smart spraying of solution, which can reduce 90% herbicide cost by selective application on weeds only. These prominent technologies enabled with GPS guidance, machine learning algorithms and computer vision for weed recognition. Currently this spot spraying technologies are very limitedly adopted by growers. Weed seeker is one of the good example for this technology, which utilize computer algorithms to locate the green vegetation and activate spray nozzles to apply a nonselective herbicide on the target. Sprayers equipped with this new technology are having capacity to reduce the total amount of herbicide use. These technologies primarily used for controlling weed flora in fallow ground (Dmytro, 2020) [8].

Fig 3: Identification of weeds by spotted sprayer technology

In addition, farm spraying algorithms can distinguish the plants, exclude empty soil from the spraying range and mark specific parameters of a weed canopy.

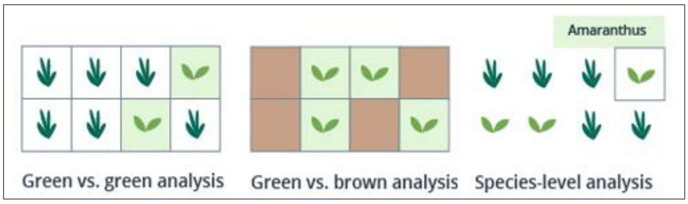


Fig 4: Identify and distinguish the crop, weed and soil in spotted sprayer

Stage I - Find and define

Sprayers equipped with cameras can capture real time images of the spraying area in the field. Based on the trained inputs about weed morphology, machine learning algorithms can identify weeds in images and label them as targets for spraying.

Stage II - Decide and act

As soon as a camera captures an image and AI (Artificial intelligence) software analyses, if it for the presence of weeds, robotic nozzles target those weeds with high precision and spray a herbicide that's adequate for the weed size and age. Just as an inkjet printer applies ink only to targeted points and in specific colours while avoiding white spaces. Farm spraying technology helps to apply the herbicides only on targeted plants with precise dosages and avoids areas of open soil using advanced optics power. When a weed passes underneath the sensor, it signals its linked spray nozzle to precisely deliver herbicide to kill the weed. This new generation sprayer having potential to reduce the amount of chemical applied by up to 90%.

Fig 5: Image captured by spotted sprayer technology in cropped field

Stage III - Analyse and improve

Selective spraying can reduce the use of chemicals and potentially cut the global annual consumption of herbicides by up to 2.5 billion pounds. This smart spraying technology can show farmers to exact amount of product required for control the targeted species and reduce the cost of cultivation.

6. Drone application of herbicides

Drone technology is a phenomenal innovation having potential to transform the way of routine manual activities are carried out in agriculture. Agricultural industries are globally increasing the use of drone technology to modernize farming. The drone used for agricultural activities is known as agriculture drone. Unmanned aerial vehicles (UAV) commonly named as drones, they are small aerial platforms weighing up to 20 kg. Drones can be operated in two ways *viz*., directly**,** in which a human has complete control of the vehicle by wireless remote and autonomously**,** in which the vehicle is able to control itself and follow a route based on the data from GPS or other sensors (Lnes, 2018) [15]. Drones are designed to carry the sensors that can provide real time information about the crop status, so that decision on agricultural operations is made efficiently and precisely. Artificial intelligence (AI) and machine learning can be combined with NDVI (Normalised Difference Vegetation Index) imaging technology gave high resolution images captured by drones to understanding the soil conditions, plant health, weed infestation and crop yield prediction. Every individual plant can be located separately and analysed using image processing algorithms. Using this result, farmers can take preventive actions to control the spread of diseases and make other management practices. Timely actions should necessarily taken to prevent the losses from biotic stresses such as weeds, insect pests and diseases. Optimum fertilization, rationalised irrigation, impact of climate change and unpredictable weather were also analysed using data collected by drones and satellite based remote sensing. In India, forty drone start-ups are engaged to enhancing the technological standards and decrease the agriculture drone prices to make it affordable and popular among farmers. The Maharashtra state government has been encouraging drone companies to work with them. Recently Maharashtra government, World Economic Forum (WEF) and Centre for the Fourth Industrial Revolution (CFIR) signed an MoU to explore the possibilities of using drones for several government initiatives. Farmers of Dahanu Palghar tribal villages in Maharashtra have learned to use drones for organic farming, fish farming, crop rotation, bio control, hydroponics, biowaste management in their orchards and farms. The agricultural labour shortage in peak periods opened up several opportunities for the use of drones in agriculture. In weed management point of view, drones are efficiently used for spraying of herbicides and other agrochemicals. Agricultural spraying operations are carried out by using drone is already widespread in south east Asia, South Korea for approximately 30%. Application of agrochemicals through drones are very fine and it can be targeted to specific areas to maximize the efficiency, saves time and chemical costs. However, it also reduces the leaching loss of agrochemicals. In fact, many experts estimated that aerial spraying is five times faster with drones than traditional machinery.

7. Stale seedbed technique

Stale (false) seedbed is defined as a seedbed that prepared several days or weeks or months prior to sowing or planting a crop to encourage the flushing out germinable weed seeds prior to planting and eradicate them to reduce the subsequent weed germination after planting. Stale seed bed technique is a preventive weed control measure, which exhausts soil seed bank before crop is sown and reduces the weeds regeneration. Normally the emerged weed flush can be effectively managed by incorporate with power tiller or killed by a non-selective herbicide. However, chemical methods is efficient and economically viable one (Manisankar *et al.*, 2020) [16]. In chemical method, non-selective herbicides used to control the emerged flushes before planting that facilitate less weed infestation after sowing. In India most of the farmers are small to marginal farmers. Scarcity of labour during peak period of agricultural operations and lack of agricultural implements leads to search alternative method for manage the emerged weed flush before planting. Hence, application of non-selective herbicides offers effective and efficient way to manage the emerged weeds.

The three 'golden rules' in Stale seedbed

There are three key pieces or golden rules in stale seedbed gave by Senthilkumar *et al.* (2019) [19].

1. Only 85-95% of weed seeds are dormant at any given time but 5-15% seeds are non-dormant and germinate very quickly.
2. Tillage is the most effective means of getting weed seeds to germinate
3. Most of the weed seeds can only emerge from top 5 cm or 2 inches of soil.

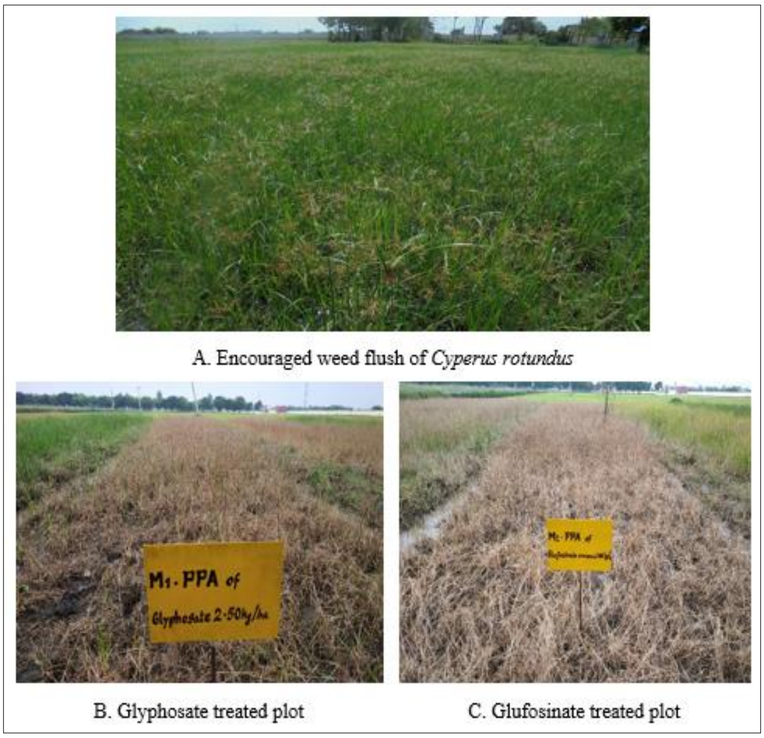
Preparation of stale seed bed

1. The area should be smooth and ready to plant.
2. Irrigate the area or wait for sufficient rain to germinate weed seeds.
3. About 7 to 10 days after the rain or irrigation, perform shallow tillage with a rake or hoe to kill the weeds. Otherwise, non-selective herbicides like glyphosate, glufosinate ammonium and paraquat can also used to kill the weeds.
4. Again irrigate the area or wait for sufficient rain to

germinate weed seeds.
5. About 7 to 10 days after the rain or irrigation, perform the same weed control measures given in point 3.
6. Now the area is ready for planting or sowing.

Roll of non-selective herbicides in stale seed bed

Application of non-selective herbicides is the best way to manage the emerged weed flushes in stale seed bed technique. In most of the rice growing areas, where one rice crop is being grown per year and rest of the period the fields are left as fallow. weeds grown enormously during this off season and poses serious threat in reducing the grain yield of rice. Rainfall during August-September months and soaking of main field during nursery period causes more weeds infestation and multiplication. *Cyperus* is one of the dominant weeds in wet land ecosystem that create difficulty during land preparation for rice cultivation (Manisankar *et al.*, 2020) [16]. Manual weeding of *Cyperus* before planting is laborious and increases the cost of weeding. Hence, encourage the weed flushes by stale seed bed technique and kill them by using non-selective herbicides is the viable option. Non selective herbicides like glyphosate, glufosinate ammonium and paraquat was used in many places to kill the weeds before planting. According to Manisankar *et al.* (2020) [16], pre plant application of glyphosate 2.5 kg ha^{-1} or glufosinate ammonium 1 kg ha^{-1} can efficiently control the weeds with in 7 days after application (Fig. 6). Also, these pre plant herbicides reduced the weed seed germination after crop planting compare to no pre plant herbicide applied plot. If *Cyperus* alone dominant before crop planting, it may effectively managed by application of halosulfuron methyl herbicide at 67.5 g a.i ha^{-1}. But the only thing is, halosulfuron effectively control the *Cyperus* in 2-3 leaf stages and this herbicide is inefficient to control the matured *Cyperus* plants. Weed management before crop planting considerably reduce the weed population during early stages of crop resulted in lesser crop weed competition, facilitate better crop growth and yield.



A. Encouraged weed flush of *Cyperus rotundus*

B. Glyphosate treated plot

C. Glufosinate treated plot

Fig 6: Encouraged weed flushes treated with non-selective herbicides in stale seedbed.

Conclusion

From the above review, it could be clearly concluded that chemical method of weed management is the efficient and economical method compare to other methods. In other hand, excessive and inappropriate uses of chemical herbicides have gradually resulted in the wide problems of food and environmental contaminations. In this context, this new generation technologies are used for precise application of herbicide in a target site and reduce the spray in non-targeted areas. Hence, these recent technologies help to reduce the herbicide dose and decrease environmental contamination as well as increase the profitability. Undoubtedly, in future these great promising technologies will rule the modern agriculture.

References

1. Anonymous. Directorate of Plant Protection, Quarantine and Storage. Haryana. July, 2021. http://ppqs.gov.in/divisions/cib-rc/registered-products.
2. Barroso J, Ruiz D, Escribano C, Barrios L, Fernandez CQ. Comparison of three chemical control strategies for *Avena sterlis*. Crop Protection. 2009;28:393-400.
3. Buhler DD. Implications of weed seed bank dynamics to weed management. Weed Science. 1997;45:329-336.
4. Chinnamuthu CR, Boopathi PM. Nanotechnology and agroecosystem. Madras Agricultural Journal. 2009;96:17-31.
5. Choudhury PP, Ghosh D, Amitava S, Sharma D. Herbicide use in agriculture: An Indian perspective. ISWS Golden Jublee International Conference. Directorate of Weed Research, Jabalpur, India. 2018, 238-264pp.
6. Choudhury PP, Singh R, Ghosh D, Sharma AR. Herbicide use in Indian agriculture. ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh. 2016, 1-

122pp.
7. Dashora A, Kanika S. Green synthesis of nanoparticles and their applications. Advanced Science, Engineering and Medicine. 2018;10:523-541.
8. Dmytro L. Smart spraying technology in agriculture for precise herbicide application. December 30, 2020. https://www.intellias.com/smart-spraying-technology-in-agriculture-for-precise-herbicide-application/.
9. El Gindy AM. Modern chemigation techniques for vegetable crops under Egyptian conditions. Misr Journal of Agricultural Engineering. 1988;5(1):99-111.
10. Gharde Y, Singh PK, Dubey RP, Gupta PK. Assessment of yield and economic losses in agriculture due to weeds in India. Crop Protection. 2018;107:12-18.
11. Heap I. The international survey of herbicide resistant weeds. Herbicide Resistance Action Committee (HRAC), North American Herbicide Resistance Action Committee (NAHRAC) and Weed Science Society of America (WSSA), Corvallis, USA. 2007.
12. Hess FD. Herbicide effects on plant structure, physiology and biochemistry. In: Altman Pesticide interactions in crop plants - beneficial and deleterious effects. Taylor and Francis. 2018, 13-34pp.
13. Kanimozhi G, Sathayamoorthy NK, Babu R, Prabhakaran J. Effect of herbigation through micro sprinkler on weeds flora, weed dry weight and weed control efficiency. International Journal of Chemical Studies. 2019;7(3):3528-3531.
14. Khatem R, Bakthi A, Hermosin MC. Comparison of the systemic nanoherbicide Imazamox - LDH obtained by direct synthesis and reconstruction: Preliminary results. Comunicaciones Congresos. 2016, 25pp.
15. Lnes H. Powerful roll of drones in agriculture. 2018. https://blog.agrivi.com/post/powerful-role-of-drones-in-agriculture_april2018.
16. Manisankar G, Ramesh T, Rathika S. Weed Management in Transplanted Rice through Pre Plant Application of Herbicides: A Review. International Journal of Current Microbiology and Applied Sciences. 2020;9(5):684-692.
17. Prasad R, Kumar V, Suranjit K, Prasad S. Nanotechnology in sustainable agriculture: Present concerns and future aspects. African Journal of Biotechnology. 2014;13:705-713.
18. Reddy TY, Reddy GHS. Principles of Agronomy. Kalyani Publishers. 2007, 384-420pp.
19. Senthilkumar D, Murali Arthanari P, Chinnusamy C, Bharathi C, Lavanya Y. Stale seed bed techniques as successful weed management practice. Journal Pharmacogncy Phytochemistry. 2019;SP(2):120-123.
20. Steckel GJ, Wax LM, Simmons FW, Phillips WH. Glufosinate efficacy on annual weeds is influenced by rate and growth stage. Weed Technology. 1997;11:484-488.
21. Sujith GM, Chandrakumar SS, Seshadri S. Herbigation: A New Vision for Weed Management - A Review. Crop Research. 2003;26(2):189-197.
22. Sureshkumar R, Durairaj. Weed characters and indices of transplanted rice as influenced by different weed management practices. International Journal of Agriculture Sciences. 2016;8(51):2221-2223.
23. Talgre L, Lauringson E, Koppel M. Effect of reduced herbicide dosages on weed infestation in spring barley. Zemdirbyste - Agriculture. 2008;95:194-201.
24. Yaduraju NT. Weed management perspectives for India in the changing agriculture scenario in the country. Pakistan Journal of Weed Sciences Research. 2012;18:703-710.
25. Zhang J, Weaver SE, Hamill AS. Risks and reliability of using herbicides at below labeled rates. Weed Technology. 2000;14:106-115.