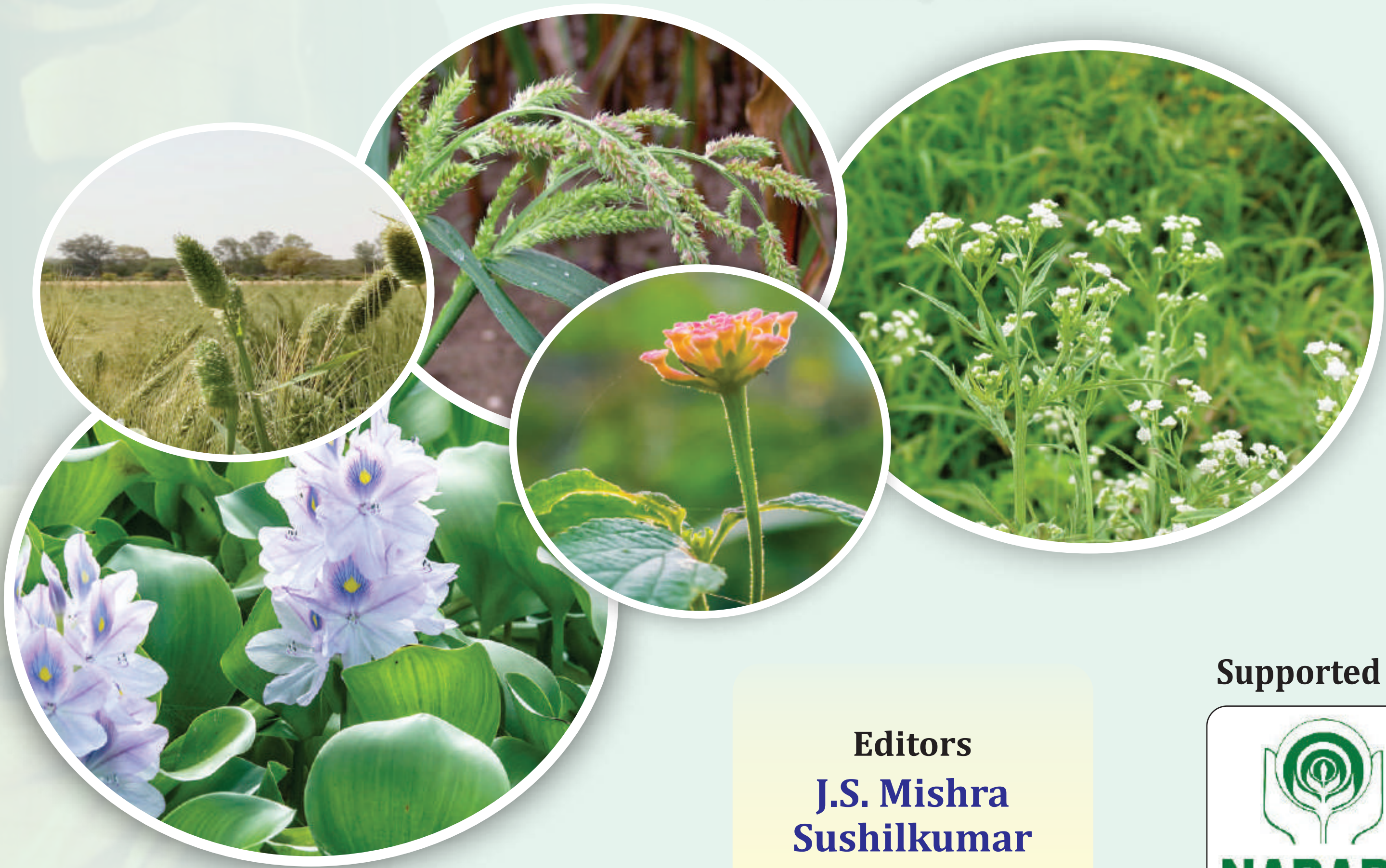
Azadi Ka Amrit Mahotsav

# Technological glimpses on weeds and their management

3rd IWC - 2022

## 3rd International Weed Conference
## Anand, INDIA




Editors
J.S. Mishra
Sushilkumar
A.N. Rao



Supported by
NABARD

Indian Society of Weed Science
ICAR - Directorate of Weed Research (DWR)
Maharajpur, Jabalpur - 482004, Madhya Pradesh, India

**Editors:**

**Dr. J.S. Mishra**
Secretary, Indian Society of Weed Science
Director, ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482 004, India
Email: jsmishra31@gmail.com

**Dr. Sushilkumar**
President, Indian Society of Weed Science
Principal Scientist,
ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482 004, India
Email: sknrcws@gmail.com

**Dr. A.N. Rao**
Chief Editor, Indian Journal of Weed Science
Consultant Weed Scientist, Plot: 1294A; Road: 63 A; Jubilee Hills, Hyderabad -500033, India
Email: adusumilli.narayanarao@gmail.com

**Correct citation of book:**
Mishra JS, Sushilkumar and Rao AN (Eds.). 2022. Technological glimpses on weeds and their management. Indian Society of Weed Science, Jabalpur, India, 81 p.

**Correct citation of chapter in book:**
Author (s). 2022. Title of chapter ....... Pp. ....... In: Technological glimpses on weeds and their management. (Eds. Mishra JS, Sushilkumar and Rao AN). Indian Society of Weed Science, Jabalpur, India.

ISBN - 978-81-931978-8-2

9 788193 197882



***Publisher:***
**Indian Society of Weed Science (ISWS)**, ICAR-Directorate of Weed Research (DWR)
Maharajpur, Jabalpur -482 004 India; http://www.isws.org.in/

**Technical support & cover design**
Mr. Gyanendra Pratap Singh

Printed at: Amrit Offset Press, Jabalpur, India; Phone- 0761-2413943

# Contents

**Weed management in rice seedling nurseries – The need and the means** 1-4
*–A.N. Rao*

**Effective and economical weed management technologies in CA-based rice-wheat-greengram system: Assessment evidence from central India** 5-8
*–A. Jamaludheen, P.K. Singh and Yogita Gharde*

**Weed management in direct-seeded rice - A success story** 9-12
*–Makhan Singh Bhullar, Tarundeep Kaur, Manpreet Singh, Jasvir Singh Gill and Pervinder Kaur*

**Integrated weed management in millets** 13-16
*–R.P. Dubey and J.S. Mishra*

**Management of *Orobanche* in mustard, tomato and brinjal in India** 17-21
*–S.S. Punia and T. Ram Prakash*

**Weed problem in rice-fallows and its management** 22-25
*–J.S. Mishra, A.S. Rao and Rakesh Kumar*

**Weed risk assessment – A tool to assess potential invasiveness of new plants** 26-32
*–M.C. Singh, V. Celia Chalam, Dhruv Singh, D. Sreekanth and Sushilkumar*

**Practical weed management in conservation agriculture systems** 33-38
*–T.K. Das and A.R. Sharma*

**Weed management in seed spices** 39-42
*–V.J. Patel, D.D. Chaudhari, H.K. Patel and B.D. Patel*

**Management of *Striga* in sugarcane** 42-46
*–C. Chinnusamy and P. Jones Nirmalnath*

**Chemical weed management in different crops** 46-51
*–V.K. Choudhary, M.P. Sahu and J.S. Mishra*

**Weed management in plantation crops** 52-55
*–P. Prameela, Savitha Antony and V.R. Krishna*

**Gaining control on herbicide-resistant weeds: Multiple techniques required** 56-57
*–Amit J. Jhala*

**Utilization of weed biomass** 58-60
*–K.K. Barman and Dibakar Roy*

**Tools and techniques for herbicide application and mechanical weed management** 61-66
*–C.R. Chethan, K. Manjunath, D.J. Shrinivasa, P.K. Singh, R.P. Dubey and J.S. Mishra*

**Impact of toxic weeds on livestock** 67-70
*–Ashutosh Mishra and Satya Nidhi Shukla*

**Biological control of Parthenium, water hyacinth and water fern: A few successes stories** 71-76
*–Sushilkumar*

**Some thoughts on the occasional failure of herbicides to manage weeds** 77-78
*–Amit J. Jhala*

**Herbicide application using drones: Advantages and constraints** 79-81
*–P. Murali Arthanari and R. Arockia Infant Paul*

# Preface

Weeds have negative impacts on agriculture, environment and the society. It has been estimated that weeds cause an annual loss of 11 billion US Dollars in 10 major crops in India. The alien invasive weeds like *Parthenium, Chromolaena, Mimosa, Lantana,* water hyacinth, salvinia, *etc*. have the potential to completely out-compete all native vegetation, and pose a serious threat to biodiversity in India. Weed management is an integral component of crop production. Despite the development and adoption of modern weed management practices, weeds continue to be a constant threat to agricultural productivity and environment. The development of herbicide resistance in weeds; weed flora shift; problem of alien invasive weeds; herbicide residue; impact of climate change on crop-weed interactions and herbicide efficacy, weed management in conservation agriculture, organic and natural farming, *etc.* continue to generate new challenges for agriculture and weed scientists. Therefore, continuous monitoring and refinement of technologies are needed to solve the emerging weed problems in a sustainable manner.

The Indian Society of Weed Science (ISWS) established in 1968, promotes research, education, and extension outreach activities related to weeds, provides science-based information to the public and policy makers, create awareness of weeds and their impacts on managed and natural ecosystems in the country. During more than a half century of its existence, the ISWS has been organizing national and international symposia, conferences and workshops on current themes and specific issues in different parts of the country. It is a matter of great pleasure that the **3rd International Weed Conference** is being organized at the Anand Agricultural University, Anand, Gujarat, India from 20-23 December, 2022. The Conference will provide an excellent opportunity to all stakeholders dealing with different aspects of weeds, to share their ideas and learn from international experiences.

This publication contains articles on major aspects of weed management by eminent scientists of the country and abroad, which will be useful to all our stakeholders including the young scientists, teachers, students, extension workers, and the farmers. We are thankful to all the authors for contributing the articles. We appreciate the efforts made by Mr. Gyanendra Pratap Singh in processing, and formatting of articles, and bringing out this publication in time.

The financial assistance received from Research and Development Fund of **National Bank for Agriculture and Rural Development (NABARD)** towards this publication is gratefully acknowledged.

J.S. Mishra
Sushilkumar
A.N. Rao

# Weed management in rice seedling nurseries – The need and the means

**A.N. Rao***
*Consultant Scientist (Weed Science), Hyderabad, Telangana 500033, India*
**Email: adusumilli.narayanarao@gmail.com*

Rice is an important staple food crop of India. India is the second-largest rice-producing country with a share of 22% in the world, India produced 124 Mt with average productivity of 2.7 t/ha of rice *i.e.* 4.1 t/ha paddy during 2020-21. During the post-independence period, India achieved about more than five-fold increase in rice production which enabled India emerging as the largest exporter of rice in the recent past due to several scientific technologies developed by Indian scientists and adopted by farming community. Yet, increasing population necessitates to look at areas where improvements can be made and taking technologies to farmers for adoption and improvement of the rice production further. In this article, the menace caused by the weeds and need for weed management in rice seedling nurseries is described and the identified technological means to manage weeds in the rice seedling nurseries are summarised.

## THE NEED - menace caused by weeds in the rice seedling nurseries

Rice is cultivated in different ecologies and by the adoption of different methods of rice establishment. During recent years, transplanted rice is being discouraged due to the concerns such as greater quantity of water used while water resources are depleting, increasing cost of cultivation due to increased labour cost, concern on greenhouse gas emissions (3.3 Mt per year methane emissions in India) from transplanted rice fields. However, many of the farmers in many of the Indian states are still adopting transplanted rice with an area of around 75% of total area of rice cultivation is being established using transplanting methods of rice establishment, because of several reasons. One reason for adoption of transplanted rice is its ability to limit weed growth because of differential sizes of the transplanted 20-day old rice seedlings and emerging weed seedlings in transplanted rice fields and water maintained in paddies acting as a barrier for weeds seedling emergence and growth. However, these advantages of transplanted rice are being evaded from the farmers by the weeds transplanted from the rice seedling nursery to the main transplanted rice fields.

The healthy rice seedlings are the key in increasing rice yield. The weeds present in rice nursery reduce the rice seedling vigour in the nursery. Because of the morphological similarities between *Echinochloa* spp. and rice (mimicry), *Echinochloa* spp. get unintentionally transplanted along with rice. The transplanted rice seedlings were reported to be highly competitive with transplanted rice as they establish quicker (less transplanting shock) than rice and compete with rice due to faster and vigorous growth (**Figure 1**) causing rice yield loss of 6% at 5% infestation to 73% at the 40% infestation level of *Echinichloa* spp. If all the rice hills in rice field were infested with transplanted *Echinochloa* spp., the yield loss would by 90%, which speaks of the intensity of the problem caused by transplanted *Echinochloa* spp. and the need to manage transplanted *Echinochloa* spp. It was also observed that the transplanted *Echinochloa* spp. are difficult to control with most of the herbicides used in transplanted rice and hence weed control in the rice seedling nurseries is the cheapest and most practical way of managing the mimicking transplanted *Echinochloa*

**Figure 1. Weeds transplanted along with rice growing vigorously in the transplanted rice hills**

spp. Hence, in transplanted rice cultivation, maintenance of rice seedling nursery free of weeds is most essential, in order to ensure vigorous rice seedlings, optimum stand in transplanted rice and also to reduce early weed competition by transplanted weeds in main transplanted rice field. In this article, weed management in rice seedling nurseries is dealt with, as weed management in transplanted rice fields is discussed in another section.

### THE MEANS – to manage weeds in rice seedling nurseries

The rice seedling nurseries are raised in different ways such as: wet-bed nursery; dry-bed nursery; mat-type nursery for using in machine transplanted rice and dapog method of raising seedling (**Figure 2**). In the wet-bed nursery and dry-bed nursery, organic manures like farm yard manure are being used for raising rice nursery and saturated conditions are maintained throughout which are very favorable for germination and establishment of wide range of weed species that compete with the rice seedlings in the nursery making them less vigorous. The weed seed contamination in rice seed contributes to the weed seedling occurrence in mat- type and dapog nurseries while it intensifies the weed problems in wet- and dry-bed nurseries types of nurseries.

### Weeds occurring in rice seedling nurseries

In rice seed bed, weeds begin to emerge in 4 to 5 days after sowing (DAS), and most weeds emerge in 7 to 8 days, then the number of emerging weeds decreases. Weeds in the rice seedling nurseries compete with rice seedlings and in certain instances may cause complete failure of the nursery, if proper care is not taken, depending on the associated weeds flora, environment associated and management practiced.

The weed management methods should depend on the weeds associated with rice seedling nurseries. The major weeds found infesting the rice nursery are: grasses including: *Dactyloctenium aegyptium* (L.) Willd., *Digitaria sanguinalis* (L.) Scop, *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) Beauv., *E. crus-pavonis*, *E. glabrescens* Munro ex Hook.f., *Panicum dichotomiflorum* Michx. *Sacciolepsis interrupta* (Willd.) Stapf, broad-leaved weeds such as: *Alternanthera sessilis* (L.) R.Br. ex DC., *Ammannia bacciferra* L., *Commelina communis* L., *Commelina banghalensis* L., *Digera arvensis* Forsk., *Eclipta alba* (L.) Hassk., *Ludwigia decurrens* Walter, *L. linifolia* Poir, *Physalis minima* L., *Phyllanthus niruri* L., *Trianthema portulacastrum* L., and the sedges: *Cyperus difformis* L., *Cyperus esculentus* L., *Cyperus iria* L. and *Cyperus rotundus* L., *Eleocharis acutangula* (Roxb.) Schult, *Fimbristylis littoralis* Gaudich. In Assam, *Eleocharis acutangula* (Roxb.) Schult. and *Cyperus* spp. introduction in the main field was primarily as rice seedlings contaminants.

### Methods of managing weeds in rice seedling nurseries

**Preventive measures:** A few of the important preventive measures that help manage weeds in rice seedling nurseries include: use of clean certified seed, which is free from weed seeds; proper land preparation and water management; cleaning out weeds in levees and field margins and cleaning implements to avoid spreading of weed seeds. Farmers normally raise the same piece of land for raising nursery and leave the nursery area unweeded

A. Wet-nursery – for manual transplanted rice

B. Mat-nursery for machine transplanted rice

**Figure 2. Healthy and weed seedling free nursery is the key for realising optimal productivity of transplanted rice**

without transplanting or delay transplanting in that area until all the area gets transplanted. Both the options used by farmers results in weeds proliferation and setting of seed which add to soil causing increased weed seed bank. Avoiding such practices and keeping the nursery area also planted early and keeping weed free helps in reducing weeds occurrence in the nursery raised in the following year/season. Normally farmers tend to use the seed produced in their own farm, which may contain weed seed. In order to get rid of weed seed in rice seed, rice seed purification with 2% salt solution can be done.

**Rabbing (parching) nursery soil:** Rabbing is the old age traditional practice followed in certain states of India by a few farmers. The word rab in Marathi signifies burning. This is a practice of burning refuse to parch the soil reserved for raising nurseries before the advent of monsoon. The ash provides nutrients and the weeds are reduced. Seedlings grow vigorously. The severity of weeds, pests and diseases greatly reduced in the transplanted crop from rabbed nurseries. In Gujarat state, rabbing is also used for raising finger millet nursey too.

**Stale seed bed technique**: This method involves irrigating the seed bed area and allowing weed seeds to are which killed by tillage or herbicide. Repeating this practice a few times helps deplete weed seed bank in nursey area and reduces weeds occurrence in the nursery.

**Soil solarisation**: Soil solarization with 30 µm thick transparent white polyethene sheet for one month prior to land preparation of the nursery was found beneficial in reducing the weed occurrence and obtaining healthy rice seedlings in the rice seedling nursey

**Increased rice seed rate**: Farmers use higher seed rate. Experimental evidence also indicates the lower weed density with higher rice seed rate compared to unweeded nursery. However, increased seed rate 100 g/$m^2$ was found to attain quite lower weed control efficiency (WCE) against *E. crus-galli* and *C. iria*. WCE with this method was found relatively higher for *T. portulacastrum* indicating that increasing seed rate is an effective method to reduce the weed density of braod-leaved weeds such as *T. portulacastrum*.

**Water management**: Maintenance of standing water level of 10 to 20 cm for 7 days before sowing was observed to help minimize weeds. Draining of water is essential prior to seeding of pre-germinated seed and during rice germination. Later, gradual increase in water level as per the rice seedling growth and maintenance of water depth at 3 to 5 cm reduces the weeds in seed bed.

**Manual weeding**: It is common practice for farmer family members to hand weed the nurseries (**Figure 3**). The manual removal of morphological similar weed seedlings from rice seedlings is difficult and *Echinochloa* species and other grasses remain unweeded in the nurseries. In addition, manual weeding in nursery is laborious, time consuming, costly and difficult. Weeds like *T. portulacastrum*, if left in the nursery after weeding, it again regenerates. Therefore, effective broad-spectrum herbicides are also required during nursery raising to prevent the infiltration of weed seedlings from nursery area to the main fields along with rice seedlings.

**Herbicides use:** In transplanted rice, many farmers use butachlor, pretilachlor and anilofos for weed control, however, these pre-emergence herbicides are less effective in rice nursery with phytotoxic effect on the emerging rice seedlings. Thus, post-emergence broad-spectrum herbicides can be of immense use for the rice farmers to manage weeds in rice seedling nurseries (**Table 1**). By using herbicide like bispyribac-sodium, weeds in one acre the nursery can be managed by less than ₹ 100. The industry in India is helping small holder farmers by bringing out small sachets with quantity of herbicide needed for one acre.

Among pre-emergence herbicides, pretilachlor + safener is as effective as post-emergence herbicides in managing grassy weeds in rice nurseries. Pendimethalin 0.75 kg/ha PE is also recommended by a few, but if the rice seedlings are submerged after application of pendimethalin, rice seedling mortality occurs. Hence, it is advised to avoid in wet-nurseries, however, may be recommended in dry-bed nurseries with a caution of not allowing rice seedling submergence after herbicide

**Figure 3. Wet-nursery in farmers' fields and manual weeding in rice seedling nurseries**

**Table 1. Promising herbicides for managing weeds in rice seedling nurseries**

| Herbicide | Rate | Time of application | Weeds controlled | Weeds not controlled/ comments |
|---|---|---|---|---|
| **Bensulfuron-methyl + pretilachlor** | 600 g/ha | 3-8 DAS | *Fimbristylis miliacea*, *Cyperus difformis*, *Echinochloa colona*, *Panicum tripheron*, *Panicum dilatatum*, *Glinus oppositifolius*, *Spilanthes acmella* and *Eclipta alba* | It is not effective in dry-bed nursery |
| **Bispyribac-sodium** | 20 g/ha | 10-15 DAS | *Echinochloa crus-galli*, *Cyperus iria* and *T. portulacastrum* | *Dactyloctenium aegyptium* |
| **Cyhalofop-butyl** | 80 g/ha | 14 DAS | *E. crus-galli* and *Echinochloa* spp. | Not effective on broad-leaved weeds (BLWs) |
| **Fenoxaprop-p-ethyl** | 50 g/ha | 15 DAS | *Echinochloa* spp., *Cyperus difformis*. | Formulation - Fenoxaprop-p-ethyl- is safe for rice; Not effective on BLWs |
| **Flucetosulfuron** | 25-30 g/ha | 15 DAS | *E. crus-galli*, *C. difformis* and *T. portulacastrum* | *D. aegyptium* and *P. niruri* |
| **Pretilachlor with safener** | 450 g/ha | 3 DAS | *E. crus-galli* and *Echinochloa* spp. | Not effective on *C. iria* and *C. difformis* and broad-leaved weeds like *T. portulacastrum* |
| **Pyrazosulfuron-ethyl** | 15 to 20 g/ha | 10 to 15 DAS | *Echinochloa* spp.; *C. iria*; *Rotala indica*; *Sagittaria* spp. *P. dichotomiflorum* | Do not have any effect on *C. communis* |
| **Pyribenzoxim** | 30 g/ha | 10 DAS | *C. iria*, *E. colona*, *Alternanthera sessilis*, *Commelina banghalensis* | |

application. On-farm studies in Nagaon district of Assam by Assam Agricultural university revealed on an average grain yield of 7.5 t/ha and benefit: cost ratio of 3.32 with treatment combination of pretilachlor 500 g/ha in rice nursery and pretilachlor 750 g/ha in the main field. It is essential for the farmers to adopt recommended safety measures and correct use of herbicide at recommended rate and time, for getting optimal benefit from the herbicide usage. Integration of herbicide usage with cultural methods is always profitable to farmers.

## Conclusion

The adoption of integrated weed management approach is preferable for effective and economical weed management in rice seedling nurseries, to avoid weed getting transplanted with rice, preventing yield losses caused by transplanted weeds in transplanted rice and to attain optimal productivity of transplanted rice.

## FURTHER READING


Nene YL. 2005. Rice research in South Asia through ages. *Asian Agri-History* **9**(2): 85–106

Pathak H, Mishra JP and Mohapatra T. 2022. *Indian Agriculture after Independence*. Indian Council of Agricultural Research, New Delhi 110 001. pp 426.

Rao AN. 2021. *Echinochloa colona* and *Echinochloa crus-galli*. Chapter 10. Pp. 197–239. In: (Eds. B.S. Chauhan *et al.*), *Biology and Management of Problematic Crop Weed Species*. Elsevier Inc.

Rao AN. Chandrasena N and Matsumoto H. 2017. Rice weed management in the Asian-Pacific region: An overview. Pp. 1–41. In: *Weed Management in Rice in the Asian-Pacific Region*. (Eds. Rao AN and Matsumoto H.). Asian-Pacific Weed Science Society (APWSS); The Weed Science Society of Japan, Japan and Indian Society of Weed Science, India.

Rao AN, Wani SP, Ramesha MS and Ladha JK. 2017. Rice Production Systems. Chapter 8. Pp. 185-205, In: (Eds. B.S. Chauhan *et al.*), *Rice Production Worldwide*. Springer International Publishing AG 2017, 185.

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.

Rao A N, Wani SP, Ramesha M and Ladha J K. 2015. Weeds and weed management of rice in Karnataka State, India. *Weed Technology* **29** (1): 1–17

Rao AN and Moody K. 1988. Weed control in rice seedling nurseries *Crop Protection* **7**: 202- 206.

Rao AN and Moody K. 1988. Dissemination of weeds in rice seedlings. *Tropical Pest Management* **34**(3): 288–290.

Rao AN and Moody K. 1987. Rice yield losses caused by transplanted *Echinochloa glabrescens* and possible control methods. Pp. 203–210, In: *Proceedings of the 11th Asian Pacific Weed Science Society Conference.* 29th Nov 5th Dec 1987, The Howard Plaza Hotel, Taipei, Taiwan.

# Effective and economical weed management technologies in CA-based rice-wheat-greengram system: Assessment evidence from central India

**A. Jamaludheen*, P.K. Singh and Yogita Gharde**
*ICAR - Directorate of Weed Research, Jabalpur, Madhya Pradesh 482004, India*
**Email: ajamaludheen@gmail.com*

Conventional tillage (CT) comprises of deep primary tillage followed by secondary cultivation operations and is commonly practiced in Indian agriculture. It is a multipurpose practice that helps in the emergence of seeds due to optimum placement providing sufficient amounts of water, light, and nutrients. It ensures nutrient availability and aeration of the soil layer. inspite of all the advantages, conventional tillage is adversely affecting the rural areas natural landscape and soil fertility. Heavy tillage implements are widely used in conventional tillage systems without regard for soil capability and fertility status. The rising cost of energy, labour, and other inputs renders CT system unsuitable and impractical due to the increased cost of crop production. Consequently, conservation agriculture (CA) is gaining momentum as a viable alternative suitable for current limited natural resources and changing climate scenario. Conservation agriculture is a system designed to achieve agricultural sustainability by improving the biological functions of the agro-ecosystem through the use of limited mechanical practices and the prudent application of chemical inputs.

Conservation agriculture is being widely practiced by farmers from the arctic circle (*e.g.* Finland) to the tropics (*e.g.* Kenya, Uganda) to about 50° latitude South (*e.g.* Malvinas/Falkland Islands); from sea level in several countries to 3,000 m altitude (*e.g.* Bolivia, Colombia), from extremely dry conditions with 250 mm a year (*e.g.* Morocco, Western Australia) to heavy rainfall areas with 2,000 mm a year. (*e.g.* Chile). CA has been adopted on over 257 million hectares globally in different cropping systems, and there is an increasing trend of its adoption in small-scale farming in Asian countries (Rahman 2017). In the last decade, CA system has expanded at an average rate of around 7 Mha per year globally, showing the increased interest of farmers in CA based production system, and the USA was topped in terms of area coverage under CA (Friedrich *et al.* 2017). It is also gaining popularity in India due to the widespread resource degradation problems that emerged as an after-effect of post-green revolution input-intensive conventional agriculture production system. CA is practiced in more than 3 million hectares under rice-wheat system in Indo-Gangetic plains (Singh *et al.* 2015).

## Three fundamental principles of conservation agriculture

CA principles (**Figure 1**) are universally applicable to all agricultural landscapes and land uses with regionally adapted approaches. Direct-seeding and/or the placement of fertilizer results in the least amount of mechanical soil disturbance and it would reduce soil erosion and preserve organic matter in the soil. Permanent soil cover with residue and/or cover crops helps to maintain a protective layer of vegetation on the soil surface that controls weed growth, shields the soil from the effects of extreme weather patterns, aids in retaining soil moisture, and prevents compaction of the soil. Species diversification through varied crop sequences intended to have a well-designed crop rotation in the field that would help improve soil structure, fosters a diverse range of soil flora and fauna that contributes to nutrient cycling and improved plant nutrition and aids in pest and disease prevention. Overall, external inputs like agrochemicals and plant nutrients of mineral or organic origin are delivered optimally and in ways and quantities that do not interfere with or disrupt the biological processes

## Advantages of conservation agriculture

* Enhanced soil quality, i.e. soil physical, chemical, and biological conditions
* Reduced cost of production
* Increased carbon sequestration and soil organic matter
* Reduced soil erosion and leaching
* Increased water and nutrient-use efficiencies
* Reduced production energy inputs by saving time and fuel
* Reduced labour requirement, considerably
* Greater environmental sustainability
* Increased residue breakdown with legumes in the rotation
* Reduced soil temperature variability
* Opportunities for crop diversification and intensification

## Weed management challenges under CA

Weeds quite often discredit the numerous benefits of CA and pose a significant barrier to its widespread adoption. Tillage manages weeds by uprooting, dismembering, and burying them deeply enough to prevent emergence. Ploughing also moves weed seeds

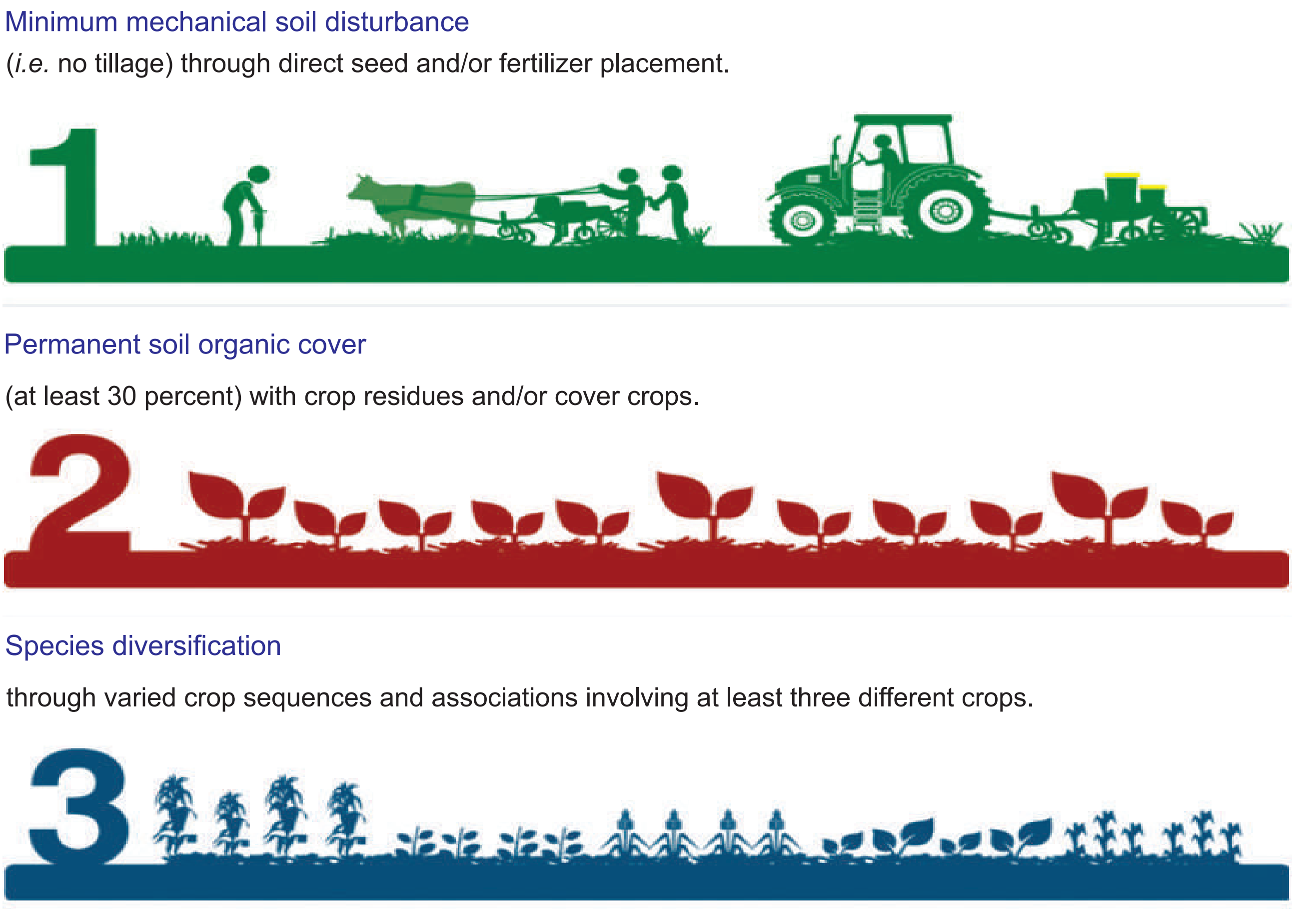



**Figure 1. Three principles of conservation agriculture (Source: www.fao.org/3/cb8350en/cb8350en.pdf)**

both vertically and horizontally and changes the soil environment, promoting or inhibiting weed seed germination and emergence. However, reduced tillage as practiced under CA generally increases weed infestation. When compared to CT, the presence of weed seeds on the soil surface is greater under CA and tends to favour relatively higher weed seed germination. The presence of residue on the soil surface in CA systems may influence soil temperature and moisture regimes, which too affect weed seed germination and emergence patterns throughout the growing season. Weed species composition and relative time of emergence differ between CA and soil-inverting CT systems. Annual weed germination may be suppressed or some weed species may grow more quickly as a result of the changes in the soil microenvironment brought on by surface mulching. Weed management in CA poses a greater challenge due to the absence of weed seed burial and studies indicated crop yield reduction thereof. Preventive measures, cultural practices (tillage, crop residue as mulches, intercropping, cover cropping, and competitive crop cultivars), herbicides, and herbicide-tolerant cultivars are the various approaches used to successfully manage weeds in CA systems. Among different approaches, herbicides are considered as an integral part of weed management in CA system and becoming popular as they are cheaper, require less labour, and allow flexibility in management.

## A survey-based study on weed management under CA

In 2012, ICAR-Directorate of Weed Research (ICAR-DWR) has initiated, the on-farm demonstrations on improved weed management technologies (WMT) under conservation agriculture (CA+WMT) in the Panagar block of Jabalpur, Madhya Pradesh. Initially, 4 farmers (4 acres of land) were targeted. After 5 years of demonstrations in the Panagar block, the Directorate moved to other localities to upscale the technology. After the first year's demonstration, many farmers in the Panagar block came forward to take up the conservation agriculture practice as they gradually realized the added benefit of conservation agriculture along with improved weed management as compared to conventional agriculture. Against this backdrop, a small-scale survey-based study was conducted in the 8 villages of Panagar block to understand the extent of adoption of the technology and the impact thereof. The focus group discussion (FGD) method was used to collect the data from farmers. In each village, a group of farmers and a key informant farmer were assembled in one place for the discussion and likewise, 58 farmers participated across 8 villages. These farmers adopted CA in the rice-wheat-greengram cropping system and they were adopting the same cropping system earlier too, but with conventional tillage. The weed management practices adopted under CA were:

**Figure 2. Wheat and rice crops under conservation agriculture system in Panagar block, Jabalpur**

Pre-emergence application (PE) of pyrazosulfuron 20 g/ha followed by (*fb*) bispyribac-sodium 25 g/ha at 20 days after seeding (DAS) in direct-seeded rice (DSR). The wheat crop was sown with Happy Seeder without tilling (maintaining rice stubbles in the field) along with use of the herbicides clodinafop + metsulfuron at (60 + 4 g/ha) at 25 DAS. Post-emergence application (PoE) of imazethapyr 100 g/ha at 20 DAS was used to control the weeds in greengram (**Figure 2**).

### Adoption status of the weed management technologies under CA

Consequent to the demonstrations by ICAR-DWR, farmers in the Panagar block gradually started to adopt the CA and weed management technologies, and currently most of the villages in the block have taken up the CA+WMT practice of cultivation (**Table 1**) after realizing the potential benefit of the same. Among the 8 studied villages, Baroda village has the highest area coverage under CA+WMT (250 acres) the and second highest percentage of farmers (85%) adopted the technology. Bharda village has the highest percentage (90%) of farmers adopting the technology and it has the second highest acreage of 200 acres with the technology adoption. The CA+WMT was adopted in 920 acres, in total, across the 8 villages in the block. According to the farmers, the demonstrated technology is being spread slowly to all other villages too and the technology adopting acreage may significantly increase in the coming years. One of the main constraints in the farmers' adoption of the technology was the non-availability and unaffordable high cost of Happy Seeder. However, in recent times, large farmers or groups of farmers purchasing the machine and subsequently providing it on rent to their fellow farmers in the village. This initiative brought huge differences in the adoption rate of the technology in all villages.

**Table 1 Extent of adoption of CA+WMT in Panagar block**

| S.N. | Village | Area covered (acres) | % of farmers adopted |
|---|---|---|---|
| 1 | Bharda | 200 | 90 |
| 2 | Padaria | 150 | 60 |
| 3 | Tintani | 30 | 40 |
| 4 | Behra bijora | 90 | 30 |
| 5 | Mudiya | 70 | 20 |
| 6 | Nuniya | 90 | 25 |
| 7 | Baroda | 250 | 85 |
| 8 | Manikwada | 40 | 15 |

### Economic benefits due to weed management technologies under CA

The benefit of CA+WMT technology over farmers' practice was calculated based on the on-farm research data (2020-2021) of ICAR-DWR conducted in the same locality (**Table 2**). Three-year average value of benefit over farmers' practice is taken as benefit per hectare due to the adoption of recommended weed management technologies under conservation agriculture in each of the crop. Obviously, price of the commodity in the respective year also affects the value. Accordingly, greengram crop gave the highest returns (₹ 14,323/ha) over farmers' practice, followed by rice (₹ 10,990/ha) and wheat (₹ 8, 280/ha). Correspondingly, the total economic benefit to the farmers from each crop was calculated. All the adopted farmers have raised rice and wheat in 372.5 ha, while greengram was cultivated in around 149 ha, only. Thus, the highest additional returns were obtained from rice (₹ 40.94 lakhs) followed by wheat (₹ 30.84 lakhs) and greengram (₹ 21.34 lakhs). In total, an additional returns of ₹ 93.12 lakhs was realised from 8 villages of the Panagar block.

The information was collected, during the survey, on the cost of cultivation on each of the agronomic components in each of the crop prior to and during the adoption of CA+WMT approach. Costs incurred for each agronomic component *i.e*, seed, fertilizer, irrigation,

**Table 2. Economic benefit accrued due to adoption of weed management technology under CA**

| S.N. | Crop | Benefit over FP*(Rs/ha) | Total benefit (Rs. lakhs) |
|---|---|---|---|
| 1 | Rice | 10,990 | 40.94 |
| 2 | Wheat | 8,280 | 30.84 |
| 3 | Greengram | 14,323 | 21.34 |

*FP= farmers' practice (conventional tillage and one hand weeding) insecticide, harvesting, *etc.* were collected. In order to arrive at a parallel value for a meaningful comparison, present value of the cost of cultivation has been deflated at constant prices. The cost saving due to the adoption of CA+ WMT in each crop was computed based on collected information. The cost saving was highest in greengram (₹ 14,165/ha) followed by rice (₹ 12,175/ha) and wheat (₹ 9870/ha) (**Figure 3**). The component crops productivity improvement also occurred. The highest additional yield was for wheat (1.48 t/ha) followed by rice (14.24 t/ha) and greengram (0.49 t/ha). The adoption of improved weed management technologies resulted in significant cultivation cost saving. The herbicide use has considerably reduced the labour requirement for the cultivation and also resulted better management of weeds. The farmers saved substantial expenditure due to CA adoption that avoided ploughing operations in the field.

## Conclusion

Conservation Agriculture offers an alternative sustainable production system during the times of resource crunch and climate change. CA is gathering momentum globally as a new paradigm shift in the 21st century. CA helps to improve soil quality, and nutritional status, and reduce input use, soil erosion, and leaching. However, weed problem prevents harnessing the potentiality of the CA system due to yield reduction compared to conventional practices and preventing the widespread adoption of the CA by farmers in spite of their awareness on the benefits of the CA system. The evidence from on-farm demonstrations indicated that proper weed management in the CA system would bring double benefit to the farmers by reducing the input use in cultivation along with yield improvement in all the three crops considered under the rice-wheat-greengram system. In a nutshell, CA with proper weed management would lower the cultivation costs and make agriculture more resource-efficient and sustainable.

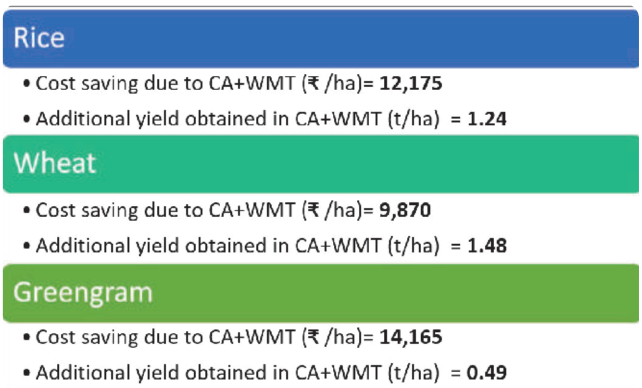



**Figure 3. Cost saving and additional returns under CA+WMT in each crop**

## FURTHER READING


Bajwa AA. 2014. Sustainable weed management in conservation agriculture. *Crop Protection*, *65*, 105–113. https://doi.org/10.1016/j.cropro. 2014.07.014

Bhullar MS, Pandey M, Kumar S and Gill G. 2016. Weed management in conservation agriculture in India. *Indian Journal of Weed Science* **48**(1): 1–12

Cordeau S. 2022. Conservation agriculture and agroecological weed management. *Agronomy*. **12**(4): 867

FAO (Food and Agriculture Organization of the United Nations). 2016. Available online at https://www.fao.org/3/cb8350en/cb8350en.pdf. Accessed on 04.09.22

Friedrich T, Derpsch R and Kassam A. 2017. Sustainable Development of Organic Agriculture. *Sustainable Development of Organic Agriculture* **6**: 0–7.

Rahman MM. 2017. Weed Management in Conservation Agriculture. *Advances in Plants & Agriculture Research* **7**(3), 302–303.

Singh VP, Barman KK, Raghwendra Singh, Singh PK and Sharma AR. 2015. Weed management in conservation agriculture system. 2015. ICAR - Directorate of Weed Research, Jabalpur, India, 60p.

Singh PK, Sondhia S, Dubey RP, Kumar S, Kumar B, Gharde Y and Choudhary VK. 2017. Adoption and impact assessment of weed management technologies in wheat and greengram under conservation agriculture system in central India. *Indian Journal of Weed Science* **49**(1), 23.

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

# Weed management in direct-seeded rice - A success story

**Makhan Singh Bhullar*, Tarundeep Kaur, Manpreet Singh, Jasvir Singh Gill and Pervinder Kaur**
*Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab 141004, India*
**Email: bhullarms@pau.edu*

Direct-seeded rice (DSR) is considered more prone to weed infestation than puddle transplanted rice (PTR). Weed plants compete with crop plants for resources and could reduce DSR yield by 50 to 90% (Bhullar *et al.* 2016). Hence, weed management is critical in DSR for reducing the crop yield losses due to weeds and for enhancing yield and income of the farmers. DSR fields are infested with diverse weed flora including grasses, broad-leaved and sedges (**Table 1**).

In general, rice is directly seeded in dry fields (dry-DSR) followed by irrigation and pre-emergence herbicide application (PE) in a moist field. This is followed by 2-3 more irrigations during the first 15-20 days of sowing for proper germination and establishment of rice seedlings. The frequent irrigations lead to leaching of the applied herbicide which results in higher weed emergence and weed competition even during early crop growth stages. The farmers had to go for repeated post-emergence herbicides application (PoE) to manage the weeds. To tackle the weed management issue, and for higher saving in irrigation water, Punjab Agricultural University (PAU), Ludhiana, developed and recommended a novel DSR technique called '*Tar-wattar* DSR' in 2020 in which rice is direct-seeded in a tar-wattar field (having sufficiently high but workable soil moisture), after pre-sowing irrigation, and the first post-sowing irrigation is applied at 21 days after sowing (DAS) (Gill and Bhullar 2020, Yaduraju *et al.* 2021). Rice seed is sown using Lucky seed drill (a seeding machine designed and developed by PAU), which does sow rice seeds and spray pre-emergence herbicide, simultaneously (**Figure 1**). The use of rice seed drill having press wheel attachment enhances efficacy of applied herbicide and conserves the soil moisture for a longer period. *Tar-wattar* DSR has many advantages over dry-DSR in that the delayed post-sowing irrigation results in higher saving in irrigation water, lesser weed infestation (**Figure 2**), lesser leaching of soil nutrients and lower incidences of nutrient deficiency especially iron. In 2022, PAU recommended DSR on raised beds in *tar-wattar* fields for higher irrigation water saving and better weed management. In this method, 67.5 cm wide shallow beds (bed with 37.5 cm flat top with adjacent 30 cm furrow) are made by bed planter followed by pre-sowing irrigation, in furrows only. When field come to *tar-wattar* conditions, sowing is done with bed planter (fitted with bed compacter) which reshape beds and does simultaneous sowing (2 rows/bed) of hydro-primed and treated seed, and applies pre-emergence herbicide, immediately. In this

**Figure 1. Lucky seed drill does sow rice seeds and spray pre-emergence herbicide simultaneously and provide adequate control of first flush of weeds**

**Figure 2. Delaying first post-sowing irrigation is the key to discourage weed growth in *tar-wattar* DSR**

**Table 1. Major weed flora in DSR fields**

| Grass weeds | Broad-leaved weeds | Sedges |
|---|---|---|
| *Echinochloa crus-galli* (swank)*, Dactyloctenium aegyptium* (madhana)*, Leptochloa chinensis* (chini ghas)*, Echinochloa colona* (chotti swank)*, Digitaria sanguinalis* (takri ghas)*, Eragrostis* sp. (love grass) | *Digera arvensis* (tandla)*, Trianthema portulacastrum* (itsit)*, Amaranthus viridis* (chulai)*, Caesulia axillaris* (ghrilla)*, Sphenoclea zeylanica* (sanni) | *Cyperus iria* (rice motha)*, Cyperus rotundus* (gandi wala motha)*,* |

method also, the first post-sowing irrigation is applied at about 21 days after sowing (DAS) which saves more irrigation water and has less incidence of weeds also.

Before the advent of herbicides, cultural practices (like crop rotation) and tillage were commonly used for weed control in field crops. Currently, herbicides have replaced cultural and tillage methods as herbicides are relatively cost-effective and provide timely and selective control of weeds. The concerns about environmental fate of herbicides and their residues in food commodities, however, demand for their judicious use. For this, realizing the best efficacy from herbicides is important. In this context, to realize the best herbicide efficacy, it is important to have the knowledge, of previous history of the weed flora in the field where herbicide is to be applied before the emergence of weeds and proper identification of associated weed flora in the field, if the herbicide is to be used after emergence of the weeds. The continuous use of any methods of weed control results in the weeds adapting to that method and, under these situations, one or more weed species become dominant over time. To tackle these issues, alternative approaches need to be incorporated in the weed management program, along with herbicides.

In DSR fields, use of herbicides will continue to be the primary method for weed management. However, herbicides alone have not been able to provide long term solution in any crop. Hence, in DSR, cultural practices also play an important role in weed management as their adoption reduces weed incidence and makes it easier to manage weeds. In this context, though herbicides will remain the primary method for weed management in DSR, the integration of herbicide with cultural and mechanical practices called 'integrated weed management', could provide sustainable weed management in DSR farming (Rao and Matsumoto 2017, Bhullar *et al.* 2021). In any case, the weed management must start with the use of non-chemical methods and be integrated with the chemical method. It may be mentioned here that while in case of chemical method, the weed management start after its application while in case of non-chemical approaches it starts much earlier.

The available cultural and mechanical methods and herbicides found effective for sustainable weed management in DSR include:

### Cultural and mechanical methods

Several cultural and mechanical practices are available which prevent/delay the weed emergence, establishment and/or weed seed production. These practices are very helpful especially in reducing early crop-weed competition, as they provide favorable environment to the crop for growth. These practices are:

**Laser levelling the field:** In a laser levelled field there is uniform and higher crop emergence which provides initial edge to the crop over weeds.

**Choice of soil/field:** DSR is always recommended in medium and heavy textured soils. Light textured soils are more prone to iron deficiency and needs more frequent irrigations which leach the herbicide promoting higher weed emergence. Prefer DSR in fields which had been under puddle transplanted rice during previous years as in these fields the weed flora will consist mainly of typical rice weeds like swank (*Echinochloa colona* (L.) Link; *Echinochloa crus-galli* (L.) P.Beauv.), rice motha (*Cyperus iria* L.) which are easier to control. In fields which had been under crops other than rice, the weed flora in DSR would have aerobic weeds like *Dactyloctenium aegyptium, Leptochloa chinensis, Cyperus rotundus,* along with typical rice weeds, which need more herbicide applications.

**Selection of variety:** The adoption of short duration variety, having early vigor and early canopy coverage, provides more smothering effect on weeds than long duration variety having slow growth during early stages.

**Sowing method:** As explained earlier, the shift from 'dry-DSR' to '*tar-wattar* DSR' significantly reduces weed pressure and results in higher irrigation water saving. 'Direct sowing on raised beds under *tar wattar* conditions' enhances irrigation water saving and help in better management of weeds than other two methods.

**Pre-sowing irrigation/stale seedbed:** Pre-sowing irrigation stimulates germination in non-dormant weed seeds present in the upper soil layer and weed seedlings are killed by shallow tillage during seedbed preparation which reduces weed pressure. Weed establishment in the next crop can be decreased drastically if a stale seedbed is used effectively. The reduced population of weeds that emerges after sowing can be controlled more effectively with herbicides. In fields having history of higher weed incidence, one extra pre-sowing irrigation provides better management of weeds.

**Seed priming and treatment:** Hydro-priming (soaking in water) ensures higher and quick emergence and early establishment which provides competitive edge to crop over weeds. Seed treatment provides protection to seed and seedling against seed borne diseases and ensures proper emergence and early establishment.

**Timing of seed bed preparation and sowing:** Field preparation and sowing in the evening or morning hours conserve the soil moisture which is required for proper crop germination and establishment and activation of herbicide. In noon hours, the evaporation loss of water is very high and field dries up quickly when tilled for seedbed preparation that adversely affect germination and crop emergence, and herbicide efficacy will also be lower in a dry field. Hence, it is always advised that field preparation, sowing and herbicide application must be done in the evening or in early morning hours.

**Sowing with Lucky Seed Drill:** Proper moisture is important for activation of pre-emergence herbicide.

Lucky seed drill ensures that herbicide is placed in moist soil which provides better control of weeds. Any delay in herbicide application will reduce its efficacy as surface soil dries up quickly in prevailing hot and dry conditions. In case of sowing with Lucky seed drill (with press wheel attachment), wheels compact surface soil in between crop rows which conserve soil moisture, prevents surface crust formation in case of rainfall before emergence and enhances efficacy of pre-emergence herbicide.

**Timing of first post-sowing irrigation:** As most of the weed germinates from surface soil, the delay in first irrigation to about three weeks reduces weed germination as weeds fail to emerge from dry soil surface. The delay in first irrigation helps maintain herbicide layer in the treated zone which prevent weed germination and weeds will not germinate from dry upper surface layer. It promotes prolific root development also which makes the crop plant more competitive toward weeds.

**Judicious use of fertilizers:** Use of mineral fertilizers, especially nitrogen, also play a role in weed management in DSR. In general, in case of parmal rice, 150 kg N/ha is recommended to be applied in three equal splits at 4, 6 and 9 weeks after sowing and in basmati rice, it is 62 kg applied at 3,6 and 9 weeks after sowing. Early application as starter dose of nitrogenous fertilizer, when actually the crop does not need it, favor weeds, and, if accompanied with frequent irrigations, it makes weed management more difficult. Hence, judicious and timely use of mineral fertilization is desirable for better weed management. Use of higher than recommended dose of nitrogen favor weed plants more than crop plants and must be avoided.

### Chemical method

The herbicides recommended for weed management in DSR are given in **Table 2**. Use of pre-emergence herbicide is mandatory in DSR to provide weed free environment to crop during early growth stages (**Figure 3**). Pendimethalin at 0.75 kg/ha PE in 500 litres of water per ha provide effective control of annual grass weeds like swank, madhana (love grass, chini ghas) and small seeded broad-leaved weeds. It provides weed free conditions to crop during germination and establishment stages. The herbicide must be applied in a moist field, immediately after sowing or along with sowing in case Lucky seed drill is used. It is always advised that field preparation, sowing and herbicide application must be done in the evening or in early morning hours. In noon hours, the evaporation loss of water is very high and field dries up quickly that will adversely affect germination and crop mergence and the herbicide efficacy will also be lower in a dry field. The research studies indicates that tank-mix of pendimethalin with pyrazosulfuron-ethyl provides broad spectrum weed management as compared to use of pendimethalin alone.

The choice of post-emergence herbicide depends on the type of weed flora present in the field (**Table 2**). It must the ensured that herbicide is used in a moist field and moisture must be maintained in the field for a minimum of one week after spray for getting the best efficacy from a post emergence herbicide. The post-emergence herbicides are highly stage specific and provide control of select weed species only. For example, pre-mixes of triafamone + ethoxysulfuron and cyhalofop butyl+ penoxsulam are used early post-emergence when weed plants are at 1-2 leaf stages and can be applied when crop is 10-15 days stage or later but weed plants must be in 1-2 leaf stages. Post-emergence herbicides like bispyribac-sodium, fenoxaprop-p-ethyl and pre-mix of metsulfuron methyl + chlorimuron ethyl provides the best weed control when weed plants are at 2-4 leaf stages and crop is 15-25 days old. Hence, these herbicides must be used at right stage of weed and crop plants.

Half-life of pendimethalin at 1000 g/ha is 38 days in DSR and 26 days in PTR which indicates that herbicide persist longer in DSR than in a PTR field and hence would keep weed under check for a longer period in DSR. Half-lives of triafamone and ethoxysulfuron are also longer in DSR than in PTR fields. In DSR, in the absence of standing water, weed pressure is relatively more than in

**Figure 3. Weed free DSR field during initial stages**

**Table 2. Herbicide options for weed management in DSR**

| Name of herbicide | Dose/ha | Target weed species | Time of application | Weed leaf stage at time of application |
|---|---|---|---|---|
| **Stomp 30 EC (pendimethalin)** | 2500 ml | Grass weeds, small seeded broad-leaved weeds | PE (at sowing) | Before emergence |
| Vivaya 6 OD (penoxsulam 1.02% + cyhalofop 5.1%) | 2250 ml | Swank, chini ghas, broad-leaved weeds, rice motha | EPoE (10-15 DAS) | 1-2 leaf |
| Council activ 30 WG (triafamone 20% + ethoxysulfuron 10%) | 225 g | Swank, chini ghas, broad-leaved weeds, rice motha, gandi wala motha | EPoE (10-15 DAS) | 1-2 leaf |
| Nominee Gold 10 SC (bispyribac-sodium) | 250 ml | Swank, chotti swank, rice motha | PoE (15-25 DAS) | 2-4 leaf |
| Ricestar 6.7 EC (fenoxaprop-p-ethyl) | 1000 ml | madhana, chini ghas, takri ghas, love grass | PoE (15-25 DAS) | 2-4 leaf |
| Almix 20 WP (chlorimuron-ethyl 10% + metsulfuron-methyl 10%) | 20 g | Broad-leaved weeds, rice motha, gandi wala motha | PoE (15-25 DAS) | 2-4 leaf |

DAS: Days after sowing; PE: Pre-emergence; EPoE: Early post-emergence; PoE: Post-emergence

PTR fields. The harvest time residues of pendimethalin, triafamone + ethoxysulfuron, cyhalofop-butyl + penoxsulam, bispyribac-sodium and fenoxaprop-p-ethyl at recommended and double the recommended doses, in rice grains and in soil, were below detection limits (0.01 mg/kg) indicating these herbicides are safe for use in DSR.

### Herbicide spray technology

The adoption of important tips, given below, help in achieving best weed control with herbicides:

**Selection of right herbicide:** The selection of the right herbicide is very important for getting best results. The herbicide selection must always be based on the presence of weed flora in the field. In this context, proper knowledge of identification of weed species is important.

**Herbicide rotation:** The continuous use of the same herbicide/s having similar modes of action results in reduced weed control over years as weed plants evolve resistance against the herbicide. To prevent this, adopt rotational use of herbicides having different mode of action. When herbicide rotation is properly followed, herbicides continue to provide effective control of weeds which otherwise become ineffective/control is reduced if same herbicide is used continuously.

**Herbicide dose**: Always use recommended dose of the herbicide. Use of lower than the recommended dose gives poor weed control while higher dose results in toxicity to the wheat plants.

**Time of application:** Preventive herbicides provide best weed control when applied at or immediately after sowing. Post-emergence herbicides provide best control of weeds when weed plants are in 1-4 leaf stages depending on the herbicide. Large weed plants develop capacity to degrade herbicide which results in poor weed control.

**Soil moisture:** Herbicides provide best weed control when applied in a *wattar* field having good soil moisture. The application in a dry field result in poor control of weeds. Presence of excess soil moisture at the time of herbicide application may cause toxicity to crop plants, poor weed control or both.

**Type of sprayer:** For pre-emergence herbicide, prefer Lucky seed drill fitted with press wheel for getting best herbicide efficacy. Alternatively, hand/battery/power operated sprayers fitted with single or multiple nozzles may be used. 'Rice Transplanter' can be easily converted into boom sprayer for herbicide and other pesticides applications. Do not use 'gun sprayer' as uneven spray application results in poor control of weeds, toxicity to crop plants or both.

**Type of nozzles:** Use flood-jet or flat-fan nozzles for pre-emergence application and flat-fan nozzle for post-emergence applications. Don't use cone type nozzles for herbicide application as it has less coverage area and apply less spray volume per unit area as compared to flood-jet/flat-fan nozzle which results in poor weed control.

**Figure 4. Bumper *tar-wattar* DSR crop at a famer's field in Punjab**

**Spray volume:** Use 500 litres water for pre-emergence and 375 litres per ha for post-emergence applications.

**Herbicide mixture:** Do not use un-recommended herbicide mixtures (mixing of 2 or more herbicides at time of spray) as these often causes toxicity to crop plants, poor weed control or both.

**Irrigations:** Application of light irrigation 2-3 days after application of a post-emergence herbicide enhances weed control efficacy.

### Weed seed harvest

Some weed plants may escape even after adoption of different methods of weed control or germinate at later crop stages. Those weed plants may or may not reduce crop yield but seeds produced from these plants will certainly increase weed problem in next season. Hence, do not allow these weed plants to set seed. To ensure this, uproot these weed plants or cut their heads with sickle or any other means. The proper integration of cultural and mechanical practices with herbicides is advised to manage weeds in DSR and attain optimal rice yield (**Figure 4**).

## FURTHER READING


Bhullar MS, Manpreet Singh and Jasvir Gill. 2020. Weeds in direct seeded rice field? Here lies the solution. *Progressive Farming* **56**(7): 24.

Bhullar MS, Kumar S, Kaur S, Kaur T, Singh J, Yadav R, Chauhan BS and Gill G. 2016. Management of complex weed flora in dry-seeded rice. *Crop Protection* **83**: 20–26.

Gill, Jasvir and M S Bhullar. 2021. *Tar-wattar* direct seeded rice: A novel technique to reduce water footprint in rice cultivation. *Progressive Farming* **57**(5): 14–1.

Rao AN and Matsumoto H. (Eds.). 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.

Yaduraju NT, Rao AN, Bhullar MS, Gill JS and Malik RK. 2021. Direct-seeded rice (DSR) in India: New opportunities for rice production and weed management in post-COVID-19 pandemic period. *Weeds – Journal of Asian-Pacific Weed Science Society* **3**(2): 30-48.

# Integrated weed management in millets

**R.P. Dubey* and J.S. Mishra**
*ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482004, India*
**Email: dubeyrp@gmail.com*

Millets are small seeded coarse grain cereal crops grown for food purposes. Millets have been categorized in two groups, major millets *i.e.*, sorghum (*Sorghum bicolor* L.), pearl millet (*Pennisetum glaucum* L.) and minor or small millets comprising finger millet (*Eleusine coracana* L. Gaertn.), barnyard millet (*Echinochloa frumentacea* L.), little millet (*Panicum sumatrense* Roth ex. Roem. and Schult.), foxtail millet (*Setaria italica* L.), kodo millet (*Paspalum scrobiculatum* L.) and proso millet (*Panicum miliaceum* L.). These crops are mainly cultivated in Africa and Asian regions since ancient times. In India, during the past 50-60 years their cultivation and consumption reduced due to availability of high yielding varieties of rice and wheat. However, in recent years, owing to their high nutritional values, low glycemic index, awareness to millets as nutri-cereals has increased and they are in high demand again. During 2018-19, millets were cultivated on an area of 12.54 million hectares with a production of 13.71 million tonnes and an average yield of 1048 kg/ha (Dayakar Rao *et al*. 2021). The productivity of millets is quite low which needs to be increased through development of better genotypes and management practices. Out of the several biotic constraints, weeds have been considered as the most limiting factor in production of millets (Rao 2021). Besides reduction in yields, many weeds also serve as host for various insect-pests and diseases. The potential benefits of improved technologies will not be realized until appropriate weed management practices are adopted.

## Crop-weed competition and yield losses

Weeds compete with crop for nutrients, soil moisture, space and sunlight when they are limiting, resulting in reduced yields, lower grain quality, increased production costs, and weed seed content of the soil seedbank. The magnitude of losses depends on the crop, cultivar, nature and intensity of weeds, spacing, duration of weed completion, environmental conditions and management practices. Although millets are drought tolerant compared to other cereal crops, the depletion of soil moisture by weeds may create severe water stress condition for millets growth.  There are several grassy weeds in millets like *Echinochloa colona*, *Eleusine indica*, *Panicum repens*, *Setaria glauca*, *Paspalum paspaloides*, *etc*. whose water requirement is less than that of many millets. Millets are poor weed competitors in the early stage of growth due to slow growth and thin seedlings. During rainy season, weeds emerge continuously throughout the crop growth period. It is therefore important to control weeds during the critical period of crop-weed competition which is around 25-40 days after sowing/planting. If not controlled timely these harmful plants reduce the yield of sorghum by15-83%, pearl millet by16-94%, finger millet by 55-61% (Mishra *et al.* 2018) and kodo millet by 46% (Prajapati *et al*. 2007). In central India, the yield loss due to weeds in finger millet was estimated to be 46.6 to 68.1%, in kodo millet 56.6 to 67.3%, in little millet 59.6% and in barnyard millet it was 63.5% (Annual Report, ICAR-DWR 2020 and 2021).


**Figure 1. Unweeded crop of finger millet (left) and sorghum (right)**

## Major weeds infesting millets

Millets are mostly grown in the *Kharif* (rainy) season, hence most of the rainy season weeds of the particular agro-ecological zone infest millet crops (**Figure 2**). Major among grasses are *Echinochloa colona, E. crus-galli, Cynodon dactylon, Dactyloctenium aegyptium, Brachiaria ramosa, Digitaria sanguinalis, Eleusine indica, Panicum reptans, Dinebra retroflexa, Paspalidium flavidum*, *etc.* the major broad-leaved weeds are *Euphorbia geniculata, E. hirta, Alternanthera sessilis, Physalis minima, Digera arvensis, Commelina benghalensis, C. communis, Amaranthus viridis, Trianthema portulacastrum, Ageratum conyzoides, Celosia argentea, Eclipta alba, Mollugo pentaphylla, Phyllanthus niruri, Leucas aspera, Striga asiatica* (a parasitic weed) *etc*. Among sedges *Cyperus rotundus, C. iria and C. esculentus* are the major ones.

## Weed management options

Millets are primarily grown on nutrient-poor soils with inadequate crop management. The agronomic practices like broadcasting method of seed sowing and fertilizer application help in abundant growth of weeds. Weeds in these crops are mostly managed by manual and mechanical weeding once at the early growth stage. Herbicide use is restricted due to non-availability of selective herbicides in millets. Different weed management options in millets are:

**Preventive methods:** As most of the serious grassy weeds of the millets belong to millets family and difficult to control, the crop seed for sowing should be free of grassy weed seeds. The compost used should be well rotten so that weed seeds are killed in the process of composting. The field bunds and irrigation channels should be kept weed free and emphasis should be to remove the weeds before they set seeds for the next generation.

**Stale seed-bed:** This is an effective practice for controlling the first flush of weeds. 10-15 days before sowing the crop, a light irrigation may be given to germinate the weed seeds which are killed by either herbicides or light inter-culture operation. Afterwards crop sowing is done without much disturbing the soil.

**Crop row spacing:** Sowing the crop in rows helps easy removal of weeds by mechanical tools. Narrow row spacing also helps the crop to cover the soil surface quickly thereby reducing the weed germination (**Figure 3**).

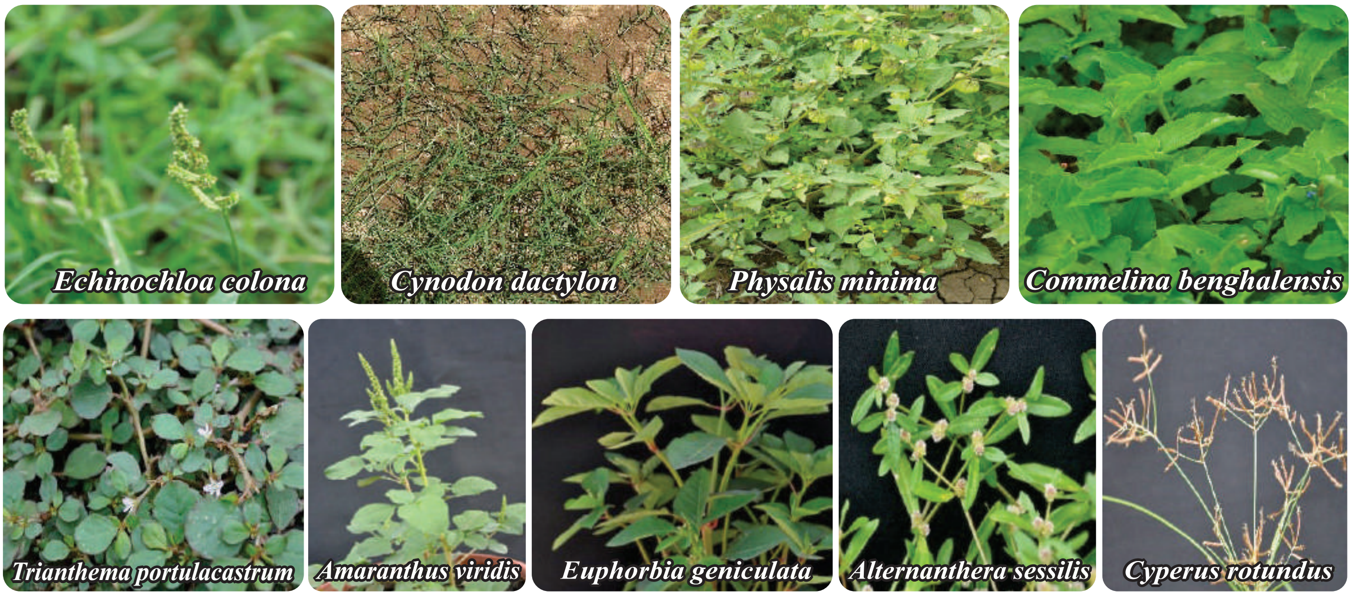



**Figure 2. Major weeds predominant in millet crops**

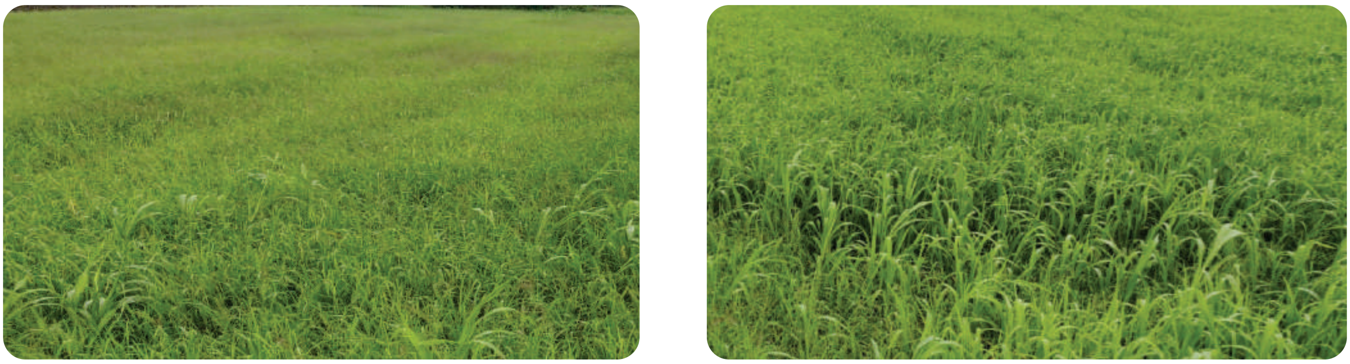


**Figure 3. Compared to finger millet (left), narrow row spaced (22.5 cm) barnyard millet (right) caused better weed suppression**

**Mulching:** Mulches of crop residues may be used to cover the soil surface in between the crop rows (**Figure 4**). This restricts sunlight to reach the soil surface which does not allow weed seeds to germinate.

**Intercropping with legume crops:** Intercropping is an effective tool for weed suppression. The sorghum and pearl millet which are grown in wider rows (45-60 cm) may be intercropped with short statured and quick growing legume crops *viz*. blackgram, greengram, soybean, cowpea, etc. to minimize weed infestation as they cover soil quickly. Small millets may be intercropped with pigeonpea in 6:1 ratio (**Figure 5**).

**Inter-culture/weeding:** Millets are grown at row to row spacing of 30-60 cm, hence suitable weeding tools like wheel hoe, hand hoe can be utilized for weeding purposes at least twice *i.e.*, at 20 and 40 DAS/DAT. Similarly, two hand weedings done at 20 and 40 DAS/DAT are sufficient to contain the weed growth. Stale seed-bed, mulching and herbicide application, is often followed by complementary mechanical or hand weeding.


**Figure 4. Finger millet crop mulched with wheat straw**

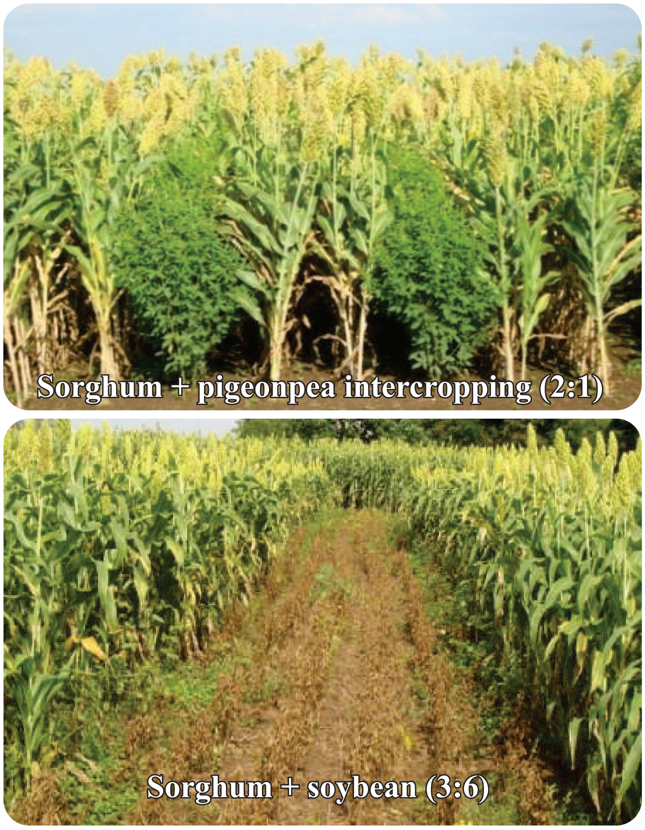



**Figure 5. Millet based intercropping systems**

**Herbicide uses in millets:** Limited herbicide recommendations for weed management in millets are

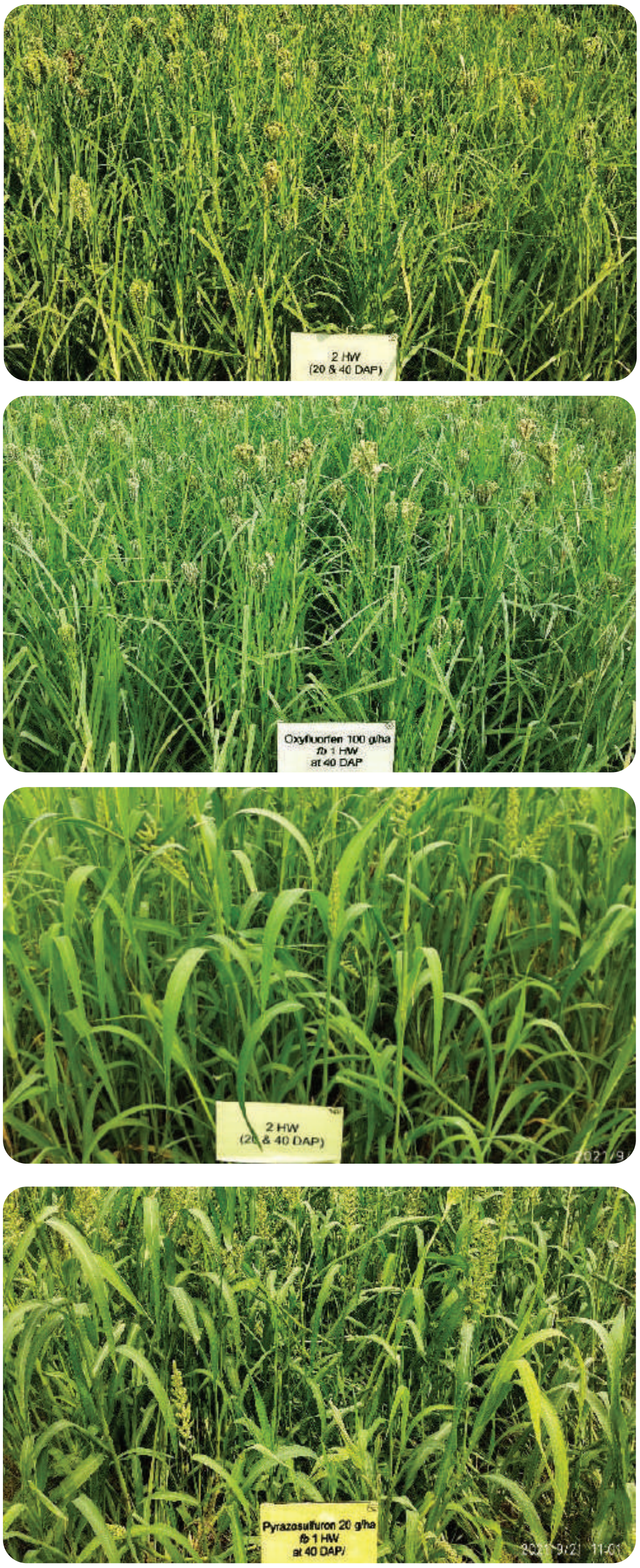



**Figure 6. Components of integrated weed management adopted in finger millet and barnyard millet crops**

**Table 1. Herbicides found suitable for use in millets (ICAR-Directorate of Weed Research, Jabalpur)**

| Millet | Herbicide | Dose (g/ha) and time of application | Weeds controlled | Optional* supplementary management |
|---|---|---|---|---|
| **Sorghum, Pearl millet** | Atrazine | 1000, 1-2 DAS | GR and BL, *Striga* | 1 HW 30 DAS |
| | Pendimethalin | 675, 1-2 DAS | GR and BL | 1 HW 30 DAS |
| | Metolachlor | 500, 1-2 DAS | GR | Under legume intercropping |
| | 2, 4-D | 500, 25 DAS | BL | 1 HW 40 DAS |
| **Finger millet, Barnyard millet, little millet** | Atrazine | 500, 1-2 DAT | GR and BL | 1 HW 30 DAT |
| | Metribuzin | 150, 1-2 DAT | GR and BL | 1 HW 30 DAT |
| | Oxyfluorfen | 100, 1-2 DAT | GR and BL | 1 HW 30 DAT |
| | Pyrazosulfuron | 20, 1-2 DAT | BL, SG and some GR | 1 HW 30 DAT |
| | Metsulfuron | 4, 20 DAT | BL | 1 HW 40 DAT |
| | 2, 4-D | 500, 25 DAT | BL | 1 HW 40 DAT |
| **Kodo millet** | Metribuzin | 150, 1-2 DAT | GR and BL | 1 HW 30 DAT |
| | Pyrazosulfuron | 20, 1-2 DAT | BL, SG and some GR | 1 HW 30 DAT |
| | Pendimethalin | 675, 1-2 DAT | GR and BL | 1 HW 30 DAT |
| | Metsulfuron | 4, 20 DAT | BL | 1 HW 40 DAT |
| | 2, 4-D | 500, 25 DAT | BL | 1 HW 40 DAT |

Note: 25-30 days old seedlings of minor millets may be transplanted without puddling the soil. There should not be water stagnation in the field. GR - grass; BL – broad-leaved; SG – Sedge; HW = hand weeding; * need based; DAS – days after sowing; DAT – days after transplanting

available at present (**Table 1**). In barnyard millet, pre-emergence application (PE) of bensulfuron-methyl 0.6 G + pretilachlor 6 G 495 g/ha (RM) on 3 DAS followed by (*fb)* one hand weeding on 20 days after seeding (DAS) reduced the weed density and biomass, weed index and showed higher weed control efficiency (Thambi *et al*. 2021). Isoproturon 500 g/ha PE *fb* hand weeding at 40 DAS was found effective in reducing the density of weed species in irrigated kodo millet (Vinothini and Murali Arthanari 2017).

## Conclusion

Millets occupy an important place in human diet as nutri-cereals and their cultivation is being promoted to mitigate the problems of malnutrition. Weeds, if not managed can cause severe crop yield loss besides reducing the quality of the produce in millets. Millet crops are poor competitors to weeds during initial phase of growth. Good agronomic practices, which give competitive edge to millet crops against weeds, are key to minimizing weed infestation. Some of the practices like stale seed-bed, mulching, intercropping can be integrated with one hand weeding to achieve better weed control (**Figure 6**). Availability of selective herbicides in millets is limited, hence they should be applied with care and as recommended. Herbicides may be used as a component of integrated weed management along with other components such as hand weeding for effective weed management in millets.

## FURTHER READING


Annual Report. 2021. ICAR-Directorate of Weed Research, Jabalpur. p. 118.

Annual Report. 2020. ICAR-Directorate of Weed Research, Jabalpur. p. 155.

Dayakar Rao B, Raj Bhandari and Tonapi VA 2021. "*White Paper on Millets – A Policy Note on Mainstreaming Millets for Nutrition Security*". ICAR-Indian Institute of Millets Research (IIMR), Rajendranagar, Hyderabad-500030.

Mishra JS, Kumar R, Upadhyay PK and Hans Hansraj. 2018. Weed management in millets. *Indian Farming* **68**(11): 77-79.

Prajapathi BL, Upadhyay VB, Singh RP 2007. Integrated weed management in rainfed kodo millet (*Paspalum-scrobiculatum* L.). *Indian Journal of Agronomy* **52**(1): 67-69.

Rao AN. 2021. Weed management in finger millet in India- an overview. *Indian Journal of Weed Science* **53**(4): 324–335.

Thambi B, Latha KR, Murali Arthanari P and Djanaguiraman M. 2021. Integrated weed management practices in barnyard millet (*Echinochloa frumentacea*) under irrigated condition. *The Pharma Innovation Journal* **10**(10): 1404-1408.

Vinothini G and Murali Arthanari P. 2017. Pre-emergence herbicide application and hand weeding for effective weed management in irrigated kodo millet (*Paspalum scrobiculatum* L.). *International Journal of Chemical Studies* **5**(3): 366-369.

# Management of *Orobanche* in mustard, tomato and brinjal in India

**S.S. Punia[1]* and T. Ram Prakash[2]**
[1]*Retired Principal Scientists, CCS Haryana Agricultural University, Hisar, Haryana 125004, India*
[2]*Principal Scientist, AICRP-Weed Management PJTSAU, Hyderabad, Telangana 500030, India*
**Email: puniasatbir@gmail.com*

*Orobanche* or Broomrape (*Orobanche* spp.) locally known as margoja, rukhri, khumbhi or gulli is a phanerogamic, obligate, troublesome holo root parasite that lack chlorophyll and obtain carbon, nutrients, and water through haustoria which connect the parasites such as rapeseed and mustard, brinjal, tomato, sunflower, tobacco and faba bean allover the world with the host vascular system. Broomrapes are among the most damaging parasitic weeds to agricultural crops and are reported from more than 58 countries including India. Presently, the genus is represented by 13 species in India. Majority of species are facultative or obligate root parasites that subsist on broad-leaf plants, exhausting hosts' nutrients, minerals and water and cause a significant reduction in yield. The most crop destructive and problematic species are branched broomrape (*Orobanche ramose* L.), Egyptian broomrape (*O. aegyptiaca* Pers.), nodding broomrape (*O. cernua*), crenate broomrape (*O. crenata* Loefl.) and small broomrape (*O. minor* James Edward Smith); sunflower broomrape (*O. cumana* Wallr.) and fetid broomrape (*O. foetida* Poir.).

**Losses:** Depending upon the extent of the infestation, environmental conditions, soil fertility, and crops competitiveness, the damage caused by *Orobanche* can range from zero to complete crop failure (Dhanapal and Struik 1996). losses range from 50% in tobacco to more than 80% in solanaceous vegetables are reported (Punia 2014). Worldwide annual crop losses as a result of broomrape infestation are estimated at $1.3 to 2.6 billion. In India, *O. cernua*, *O. cumana* and *Phelipanche aegyptiaca* are occurring on various crops such as tobacco, cumin, mustard, plantago, lentil, potato, brinjal and tomato and cause significant yield losses depending upon the intensity of infestation.

## Geogrphical distribution in India

*Orobanche* is widely distributed in the states of significant yield loss is dependent upon the intensity of the infestation Rajasthan, Haryana, Karnataka, Andhra Pradesh, Telangana, Tamil Nadu, Gujarat, Maharashtra, Madhya Pradesh, Uttar Pradesh and Bihar and is a cause of great concern among the farmers. However, its heavy infestation is localized in northern Rajasthan, Haryana, and North-East Madhya Pradesh, growing rapeseed and mustard in large areas (**Figure 1**). *Orobanche* infests about 90% area under tobacco in Karnataka and causes 50-60%

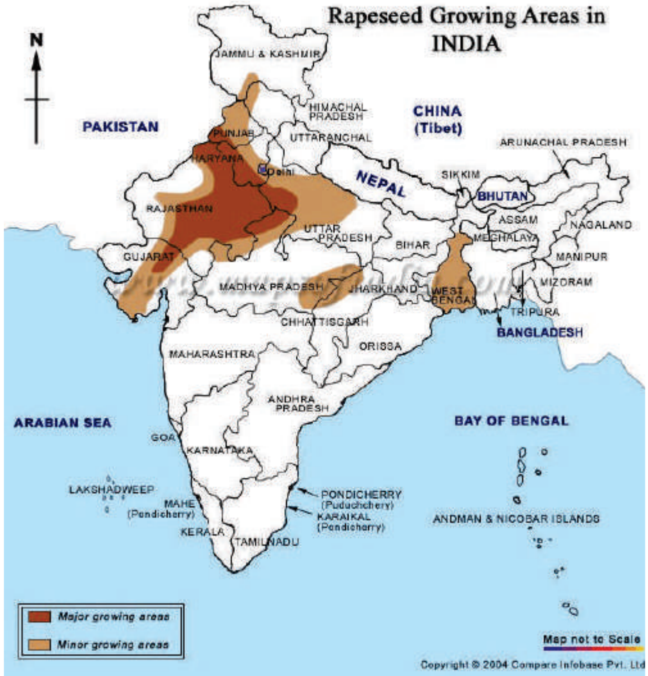



**Figure 1. Mustard cultivation in India**

yield losses in some areas. In the Mewat and Bhiwani districts of Haryana, tomato, brinjal crops have been found infested with *Orobanche* spp. (Punia 2014). Minor infestation is also observed in cauliflower and cabbage crops also. This parasitic weed has the tendency to proliferate well in coarse textured soils with high pH, low in nitrogen status having poor water holding capacity where the crop cultivation is either rainfed or dependent on sprinkler systems for irrigation.

**Life cycle:** In an experiment on weed biology of *Orobanche* at Hisar, it was observed that in mustard crop *Orobanche* panicles appeared above soil on an average 45-54 days after sowing of mustard. Violet cream colored flowers started to appear 11-13 days after panicle emergence of *Orobanche.* The capsule number per shoot varied from 38-45 and a single plant may produce more than one lakh seeds (**Figure 2a**) depending upon species (Punia *et al.* 2019). Seed generally remains viable in soil for 10 to 13 years but the viability can be up to 20 years. Seeds of *Orobanche* generally remain dormant and require a post-harvest ripening period for their germination in

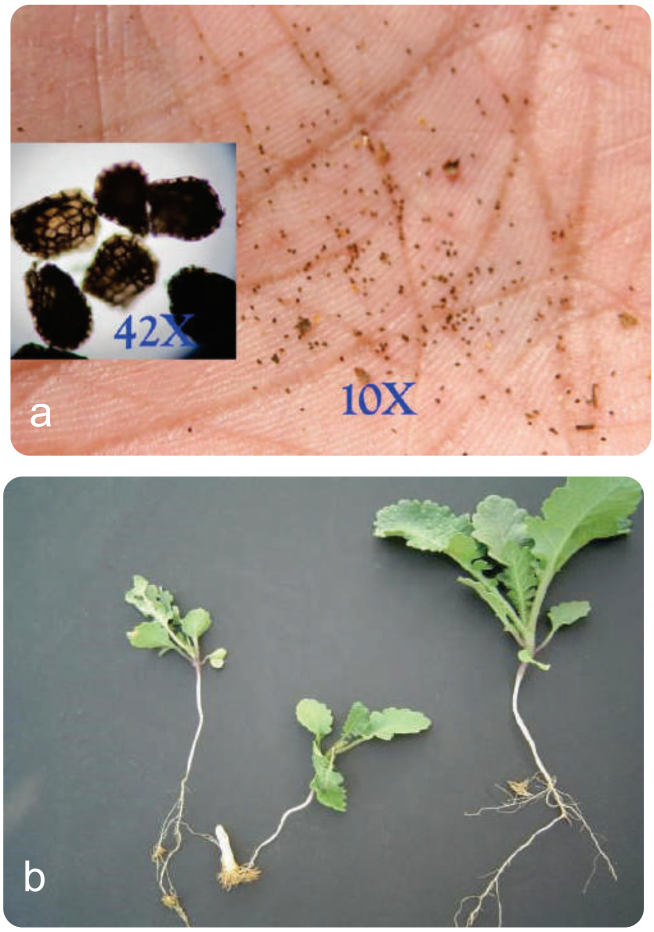



**Figure 2. Minute size of seeds of *Orobanche* (a) enlarged view and emerging tubercle from the root of host plants (b)**

response to chemical stimulation (alectrol/ orobanchol) from the host plant roots. These conditions ensure that only seeds with in the rhizosphere of an appropriate host root will germinate. Suitable temperatures of conditioning of *Orobanche* seeds are between 15-20°C for at least 18 days for maximum germination. Optimum temperatures for conditioning and germination are 18°C for O. crenataand about 23°C for O. ramosa. Following the conditioning phase, germinated seed produces a germ tube or radicle in close proximity to the host plant roots that elongates chemotropically anddevelops an organ of attachment 'the haustorium', which serves as a bridge between the parasitic weed and host plant to drive water, mineral nutrients and carbohydrates from the host plant. The part of the broomrape seedling swells outside the root of host plant to form a tubercle. Within 1-2 weeks, a shoot bud develops on the tubercle producing a flowering spike which elongates, and emerges outside the surface soil surface soil (**Figure 2b**). Within a period of 15-20 days, the parasitic weed completes its life cycle and shed lakhs of seeds per plant.

Most of the damage to the host plant caused by the parasite occurs before the parasite shoot emergence, thus restricting effective control to its underground stages.

## Management

Besides, certain specific characteristics such as host specificity, wide-spread occurrence, competitiveness and aggressiveness, prolific seed production, and prolonged seed viability make *Orobanche* spp very difficult to be controlled by normal weed management practices. Lack of effective control measures of *Orobanche* hastens its spread and makes soil sick over a small period. *Orobanche* species have strong adaptation mechanisms to co-exist with their hosts in the same environment, resulting in strong parasitism.

Different strategies adopted for *Orobanche* spp. control include prevention, cultural methods, physical, biological, biotechnological and chemical in different crops.

## Prevention methods

Spreading of *Orobanche* from infested areas to non-infested areas can be achieved by adopting the preventive measures. Clean crop seed should be used to reduce the spread of parasitic weeds; thourough cleaning of farm implements after working in *Orobanche* infested fields; preventing the transfer of soil from infested area to new area; avoiding grazing of animals infested area; destruction of all the physically removed *Orobanche* plants (especially mature plants); also controlling *Orobanche* growing on wild hosts/weeds with non-selective herbicides to prevent seed production.

Hand weeding and burning of parasite shoots is necessary to prevent seed spread and control of weeds in general during fallow years and before seeding is needed to prevent parasitic weed on wild or weed species.

## Cultural methods

**Crop rotation**: A crop rotation system includes *Orobanche* host crops, trap crops and catch crops and non-host crops. Crop rotation of mustard with non-host crops like wheat, barley, chickpea etc. is the most effective and commonly used management strategy for reducing the weed seed bank in heavily infested areas. The major hinderence in adopting crop rotation in long-run is the longer viability of its seeds and lack of poor irrigation facilities to good alternative crops. Thus, heavy infestations may remain in a field despite absence of host crops for several years. Weed seeds buried in the soil beneath the crop root zone can be brought up to surface soil as a result of subsequent ploughings, germinate and provide competition to the host crop in later years. Frequent planting of susceptible crops on the same field should be avoided and as far as possible grow mustard in alternate years with diverse growing habit genotypes.

**Trap and catch crops**: These crops exude stimulants that induce *Orobanche* seed germination but no viable attachment to the host plant roots is established and the weed seedlings withers away and die up and ultimately their seed bank in the soil gets reduced. In Indian conditions, at Agricultural Research Station, Nepani

(Karnataka), sun hemp and green gram proved to be promising trap crops for *Orobanche cernua* control where bidi tobacco is grown in long growing ( *Kharif* and *Rabi*) seasons (Dhanapal and Struik 1996). Experimental results in Tehran indicated that sesame, brown Indian hemp, Egyptian clover and mungbean increased total biomass of tomato by 71.4, 67.5, 65.5, and 62.5 %, respectively. It was observed that these plants have a great potential to reduce broomrape damage and they can be used in rotation in broomrape infested fields.

An additional cultural method means for reducing *Orobanche* seed bank in the soil is the use of 'catch crops' *i.e.,* planting an *Orobanche* host crop for inducing parasite seed germination and attachment and that will be destroyed later on by means of light tillage practices or residual soil herbicides. But the use of trap and catch crops to manage this weed is somewhat limited due to: (a) enormous amount of *Orobanche* seeds dispersed in the soil and only a small proportion may be exposed to germination stimulants in the rhizosphere. b) feasibility and economics of growing these crops in the existing situations .

**Sowing dates and cropping density**: Delaying the planting date affects *Orobanche* more than its hosts. Late planting of mustard (last week of October-first fortnight of November) in northern part of India is observed to be helpful in reducing the parasitism of *Orobanche* a result of specific weed and host plant differential response to low temperatures in Indian conditions. Moreover, farmers' perception for late sowing is pessimistic owing to limitation of mustard cultivation to conserved moisture conditions and competition for water utilization for pre-sowing irrigation in wheat; therefore, alternation in sowing time seems to be uncommon and unrealistic approach under Indian context

**Water management:** Less infestation of the parasitic weed has been observed in raya/mustard grown under flooded irrigation compared to sprinkler irrigation or on conserved moisture as the seeds of *Orobanche* do not survive an extended period of inundation. Availability of water and undulating topography are again the limiting factors to practice flooding in north India .

**Nutrient management**: Higher *Orobanche* infestation and its parasitism on host plants is generally more in inherently poor fertility soils prevailing in major mustard growing areas of the India. Urea, ammonium nitrate, and ammonium sulfate and the goat manure at 20 and 30 t/ha were found to be most effective in reducing parasitism of *Orobanche* and enhancing growth of tomato plants. To confirm the effect of nitrogen fertilization through different sources on *Orobanche* inhibition in mustard, localized field studies were carried out through farmers' participatory approach in Haryana, India during 2004-2010. Erratic response over the years was observed with respect to weed infestation and population dynamics when nitrogen sources, *viz.* ammonium sulphate, calcium nitrate and urea were evaluated alone or in combination with FYM, poultry manure, castor cake, pressmud or vermicompost. Use of neem cake/vermi-compost/castor cake and increased N fertilization (120 kg/ha) increased/maintained the crop productivity with parasitism of *Orobanche* by sustaining the host plant growth even with depleted fertility status.

**Mechanical and physical methods**

**Hand weeding /hand pulling**: Hand weeding or hand pulling before flowering followed by burning can be an effective and practicable method of checking seed production. Hand weeding though useful under low weed infestation but it is time consuming, labour intensive and costly. Profuse emergence of new inflorescence from below ground plant parts was also observed within a short span of 7-10 days of hand weeding or hoeing therefore, this warrant for frequent repetitive measures.

**Tillage/intercultivation**: Tillage/intercultural operations are not practically and economically feasible due to late emergence of growing shoots and the risk/ uncertainty of crop injury always remains there due to close proximity of the root parasite with the host plant. Deep tillage during summer months causes seed desiccation and places them below the root zone preventing seed germination to some extent, but again the longer viability (up to 20 years) of weed seeds raises a question mark in long run is useful only to prevent seed formation .

**Soil solarization**: Covering moist soil (with or without minimum disturbances at planting) with white or black polyethylene sheet for a month or so can increase the soil temperature by around 10°C (48-57°C) compared to uncovered soil resulting in killing of *Orobanche* seeds that are in the imbibed state; therefore soil must be wet at the time of treatment. Soil solarization has been proven to be the most effective methods in controlling broomrape in open crops fields but high cost of polyethylene, appropriate machinery and cloud-free sunny days may restrict its use on larger scale.

**Biological methods**: Fungi such as *Trichoderma viridae* and *Psuedomona*s inflorescence were tested at farmers' fields of Bhiwani and CCS HAU Hisar during 2010-14, but these were found ineffective against *0robanche* in mustard. More research is needed to develop a reliable biological method under Indian conditions.

**Chemical methods**: Two groups of chemicals *i.e.* soil applied herbicides and post- emergence applied herbicides have been reported to possess potential to control *Orobanche*.

**I. Residual soil applied herbicides**: Seed treatments with sulfonylureas have proven to be effective for controlling *Orobanche* in mustard and tomato crop. The herbicide is incorporated as a coating on the seeds and distributed with them at the time of planting of mustard. Seed coating with chlorsulfuron, triasulfuron or sulfosulfuron at 0.05-0.1 mg/kg of seed proved safe for crop. Results of experiments conducted from 2008-10 under farmers' management practices revealed that seed treatment of mustard with triasulfuron, sulfosulfuron and chlorsulfuron has reduced 55-98% population of *Orobanche,* but the results were inconsistent over the years. Moreover over-dosing of the herbicide seed treatment sometimes caused poor germination and suppression in crop growth (Punia 2016).

**II. Foliar applied herbicides**: Sulfosulfuron and triasulfuron are registered worldwide for pre- and post-emergence application to manage grass and broad-leaf weeds in wheat. Ethoxysulfuron is recommended to control broad-leaved weeds and sedges in rice. These systemic and somewhat persistent herbicides are absorbed through foliage and roots of plants with rapid acropetal and basipetal translocation. Study conducted in Chickballapura district of Karnataka state, India revealed effectiveness of pre-emergence application (PE) of sulfosulfuron at 75 g/ha in controlling *Orobanche* in tomato grown under irrigated conditions (Dinesha and Dhanpal 2014). Based on two years study on *Orobanche* control in tomato in Mewat area of Haryana, Punia *et al*. (2016) reported that post-emergence application (PoE) of ethoxysulfuron / sulfosulfuron at 25 g/ha at 30 DAS followed by its use at 50 g/ha or sulfosulfuron at 50 g/ha at 30 and 60 DAS, respectively, provides 85-90% control of Egyptian broom rape in tomato without any adverse effect on crop with yield increase of 46-58% as compared to untreated check. No herbicide residues were found in tomato fruits and soil at maturity. However residual carry over effect of sulfosulfuron was observed on succeeding sorghum crop depending upon soil type, rainfall during the season and number of irrigations applied to tomato crop. Sulfosulfuron at 20 g/ha PoE at 45 and 90 DAP of eggplant (brinjal) provides effective control of *Orobanche* but with 5-10% crop suppression but with no yield gain as compared to untreated check (Singh *et al*. 2017).

**III. Glyphosate use for control of *Orobanche***: Studies undertaken at CCS HAU Hisar indicated that higher dose of glyphosate at early crop stages sometimes causes localized phytotoxicity on mustard plant viewing marginal leaf chlorosis, slow leaf growth, interveinal leaf bleaching, and/or slight elongation of apical leaves (**Figure 3**) but the crop recovered within 7-10 days after spray with no yield penalty. Glyphosate applied twice at 25 g/ha PoE at 30 DAS followed by 50 g/ha at 55 DAS provided 65-85% control of *Orobanche* even up to harvest (without any crop injury) with yield improvement from 12 to 41% over the traditional farmers' practice in mustard in different years of the study (Punia 2014). Similar findings on the control of *Orobanche* in mustard through herbicide application were also reported by the scientists at Gwalior and Bikaner (DWR 2009). These results were further validated in large scale multi-locational trials conducted at different locations through farmers' participatory approach in Haryana State during the *Rabi* (winter) seasons of 2010-11 to 2016-17. A total of 758 demonstrations were conducted in mustard growing areas of Haryana state covering 1831 ha area and it was observed that overall 76.5% (range 40-95%) reduction in *Orobanche* weed infestation with 21.4% (range 13.9-38.7%) yield superiority was noticed with glyphosate treated plots (25 g/ha at 30 DAS followed by 50 g/ha at 55-60 DAS) when compared with the farmers' practice of one hoeing at 25-30 DAS. This technology has now spread to the most *Orobanche*-infested mustard-growing areas of Haryana and the farmers are fully convinced of the benefits of this low-cost technology. Foliar spray of glyphosate twice; 25 g/ha at 25-30 DAS followed by 50 g/ha at 45-50 DAS may be helpful in reducing the *Orobanche i*nfestation by checking the further increase in weed seed bank without any crop suppression, but at the same time requires certain precautionary measures in its use. Since most of the mustard cultivation in India is limited to light textured soil having inherent poor fertility status and water holding capacity, care should be taken that the crop should not suffer from any moisture stress at the time of foliar spray, therefore, the fields should be irrigated 2-3 days prior to herbicide application.

**Figure 3. Phytotoxicity symptoms of glyphosate (50 g/ha at 30 DAS) on mustard**

**Management *Orobanche* in tobacco:** Studies under taken by Dhanapal (1996) for control of broomrape in tobacoo indicated that 0.5 kg/ha glyphosate 60 DAS and 0.01 kg imazaquin 30 DAS gave best weed reduction (75-80%) and increased the yield of tobacco by 43%. Neem, coconut, sunflower, castor niger and mustard oils killed the buds of *Orobanche* within 3 to 5 days without phytotoxicity to tobacco. They also reported effectiveness of glyphosate at 500 g/ha at 60 days after transplanting (DAT) and imazaquin at 10 g/ha applied at 30 DAT in reducing the number of aboveground broomrape spikes by 75 to 80%, respectively, and increased tobacco yield by 80 to >100% compared to the untreated plots.

## Conclusions

In India, *Orobanhce* is the most important parasitic weed on mustard, tomato, brinjal causing serious economic losses. Area infested by this problematic parasitic weed is increasing year by year and consequently losses caused are also increasing drastically. Eventhough some weed control options are available, individually these options are not a comprehensive solution to minimize losses caused by this weed. This precarious situation at hand necessitates, integration of preventive, cultural, physical, biological/bio-technological and chemical methods in a economical, effective, compatible manner to exhaust parasitic weed seed banks in cropped soils and achieve higher crop yields.

## FURTHER READING


Cartry D, Steinberg C and Gibot-Leclerc S. 2021. Main drivers of broomrape regulation. A review. *Agronomy for Sustainable Development* **41**: 17

Das TK , Ghosh S, Gupta K, Sen S, Behera B and Rishi R. 2020. The weed *Orobanche*: species distribution, diversity, biology and management. *Journal of Research in Weed Science* **3**(2): 162-180

Dhanapal GN and Struik PC. 1996. Broomrape control in a cropping system containing bidi tobacco. *Journal of Crop Science* **177**(4): 225–236.

Dhanapal GN. 1996. Management of broomrape (*Orobanche cernua*) in tobacco (*Nicotiana tabacum*). 183 p.

Dinesha MS and Dhanapal GN. 2014. Broomrape parasitic weed biology and its management with herbicides in naturally infested tomato field. Pp. 303. In: *Extended Summary, Biennial Conference of Indian Society of Weed Science on emerging Challenges of Weed Management*, DWSR, Jabalpur, February 15–16.

DWR. 2009. *Proceedings of AICRPWC Biennial Workshop*. Directorate of Weed Science Research, Feburary 28–March 1, 2009 AAU, Anand **99**: 5–6.

Habimana S, Nduwumuremyi N. and Chinama RJD. 2014. Management of *Orobanche* in field crops- A review. *Journal of Soil Science and Plant Nutrition* **14**(1): 43-62

Kumar S. 2002. Preliminary studies on the control of broomrape in mustard. *Indian Journal of Weed Science* **34**(3&4): 303–304.

Parker C. 2009. Observations on the current status of *Orobanche* and *Striga* problems worldwide. *Pest Management Science* **65**(5): 453-459

Punia SS. 2014. *Orobanche:* Weed biology and control measures. *Indian Journal of Weed Science* **46**(1): 36–51.

Punia SS. 2016. Effectiveness of different measures on control of *Orobanche aegyptiaca* in Indian mustard. *Agriculture Research Journal* **53**(2): 276–279.

Punia SS, Duhan Anil, Yadav Dharam Bir and Sindhu VK. 2016. Use of herbicides against *Orobanche* in tomato and their residual effect on succeeding crop. *Indian Journal of Weed Science* 48(4): 404–409.

Punia SS, Yadav Dharam Bir, Maun Vinod, Manjeet and Punia Todarmal. 2019. Biology and large scale demonstration for management of *Orobanche aegyptiaca* in mustard. *Indian Journal of Weed Science* **51**(3): 266–269.

Singh N, Punia SS and Yadav DB. 2017. Chemical control of *Orobanche aegyptiaca* L. in brinjal. *Abstract published in proceedings of Biennial Conference of the Indian Society of Weed Science on "Doubling Farmers' Income by 2022*: The Role of Weed Science", March 1-3, 2017, Udaipur, India.

# Weed problem in rice-fallows and its management

**J.S. Mishra[1], A.S. Rao[2] and Rakesh Kumar[3]**
[1]*ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482004, India*
[2]*Acharya NG Ranga Agricultural University, Lam, Guntur, Andhra Pradesh, India*
[3]*ICAR Research Complex for Eastern Region, Patna, Bihar 800014, India*
**Email: jsmishra31@gmail.com*

Rice-fallow areas are those *Kharif* (rainy) season rice grown areas that kept fallow in succeeding *Rabi* (winter) season due to lack of irrigation, late harvesting of long-duration high yielding rice varieties, moistures stress at sowing during the *Rabi* crops, water logging and excessive moistures in November/December, and nuisance like stray cattle and blue bulls. This system covers ~11.7 million ha in India and mostly (82%) concentrated in the Eastern states. The peninsular Indian states, *viz*., Andhra Pradesh, Karnataka and Tamil Nadu contributes remaining 18% rice-fallow area. There is large scope in converting rice-fallows into the productive agro-ecosystems through sustainable intensification with suitable crops and varieties, and appropriate management technologies.

Weed menace is one of the major constraints in limiting the crop productivity of rice-fallows. Due to frequent rainfall during the rainy (rice) season, complex weed flora (grasses, broad-leaved and sedges) do emerge in several flushes and complete with rice for nutrients, water, solar radiation and space. Depending up on intensity and nature of weed flora, and crop management practices, weed competition reduces rice yield by 15-100% in direct-seeded conditions and 15-20% in transplanted, valued at ₹ 28,291 crores annually (Gharde *et al*. 2018 ). In most of rice-fallow areas after rice harvest, the subsequent crops are grown on residual soil moisture. In low lying areas with high soil moisture, winter season pulses are grown as *Utera* cropping, where in seeds are broadcasted 10-15 days before rice harvesting. Weeds are a serious problem under *Utera* cropping as there is no land preparation. Hand weeding is a difficult proposition due to fast drying of soil surface. In many areas, *Cuscuta* infestation is also associated with urdbean and greengram (Satyanarayana *et al*. 1997) and lentil, chickpea and linseed (Mishra 2009).

In coastal districts of Andhra Pradesh, cultivation of pulses in rice-fallows is a unique system of cultivation, wherein, sprouted seeds of blackgram, greengram, horsegram *etc*. are directly broadcasted in the standing rice crop prior to its harvest. This practice helps the farmers to harness the residual soil moisture and at the same time increasing nitrogen content in the soil by biological nitrogen fixation. Thus, pulses sown in this system survives entirely on residual soil moisture and fertility only. The time of sowing of blackgram/greengram in this system vary from November to December depending on duration of rice variety grown in *Kharif*. Among different constraints of rice-fallow, pulses cultivation, weed menace receives special attention, as it can reduces crop yield ranging from 31 to 75% depending on the severity of weed infestation (Appanna *et al.* 1998, Rao and Rao 2003). However, in the recent times, area under pulses has declined due to late planting of rice and severe attack of viral diseases and parasitic weed *Cuscuta* (Mishra *et al.* 2009) (**Figure 1**). Due to this problem, much of rice-fallow pulses area has now been converted in to rice-fallow maize and sorghum.

For sustainable weed management strategies in rice-fallows, weeds need to be managed from rice season itself, followed by need-based weed management strategies for succeeding crops. The good agronomic practices of soil management like crop residue retention on the soil surface, minimal soil disturbance, crop diversification, mulching *etc.* need to be incorporated while developing the integrated weed management technologies in rice-fallows.

## Weed management in rice

In rice-fallow ecology, rice is grown as puddled transplanted or direct-seeded (dry/wet). Complex weeds including grasses, broad-leaved and sedges (**Table 1**) do germinate in several flushes, and interfere with rice during growing season, and reduces its productivity and quality. Although, different methods of weed management in rice *viz.* cultural, manual and mechanical are still adopted by the farmers, but effectiveness of these methods is limited. Moreover, availability of manpower for manual weeding and increased labour wages are the other major constraints in manual and mechanical weed management. Use of recommended herbicides (**Table 2**) for weed management in rice is gaining much importance in recent past due to awareness, increased availability, cost-effectiveness and broad-spectrum weed control.

## Weed management in fallow crops

In rice-fallows, lentil, field pea, lathyrus, greengram, blackgram, groundnut, *toria*, mustard, safflower, linseed *etc.* are grown after harvest of rice. In some parts of Jharkhand and Chhattisgarh, cucurbits can also be grown

A. Rice-fallow blackgram infested with Cuscuta campestris

B. Severe infestation of weeds in rice-fallow sorghum

C. Rice-fallow blackgram infested with weeds and yellow mosaic virus

D. Atrazine (0.75 kg/ha) + paraquat (0.50 kg/ha) as pre-emergence

**Figure 1. Weeds in crops grown in rice fallows (A, B, C) and their management (D)**

**Table 1. Major weeds of rice**

| Grasses | Broad-leaved | Sedges |
|---|---|---|
| *Echinochloa crus-galli* | *Commelina diffusa*, *C. communis*, *C. benghalensis* | *Cyperus iria* |
| *E. colona* | *Sphenochlea zeylanica* | *C. difformis* |
| *E. glaberescens* | *Ammannia baccifera* | *C. rotundus* |
| *Leptochloa chinensis* | *Eclipta alba* | *Fimbristylis miliacea* |
| *Dactyloctenium aegyptium* | *Caesulia axillaris* | *Scirpus* spp. |
| *Digitaria sanguinalis* | *Alternanthera philoxeroides* | |
| *Ischaemum rugosum* | *Alternanthera sessilis* | |
| *Elesuine indica* | *Euphorbia hirta* | |
| *Eragrostis tenella* | *Trianthema portulacastrum* | |
| *Paspalum distichum* | *Phyllanthus niruri* | |
| *Brachiaria reptans* | *Physalis minima* | |
| *Eragrostis japonica* | *Monochoria vaginalis* | |
| *Digitaria ciliaris* | *Marsilea quadrifolia* | |
| *Leersia hexandra* | *Ludwigia octovalvis* | |
| *Dinebra retroflexa* | *Ludwigia parviflora* | |
| | *Lindernia* spp. | |
| | *Sagittaria* spp. | |

after rice harvest with proper mulching to conserve the soil moisture. In coastal Andhra Pradesh, area under maize and sorghum are increasing in rice-fallows. Most of these crops are raised on residual soil moisture. In low land ecology of eastern Uttar Pradesh and Bihar, with high soil moisture content after rice harvest, *utera* practice is also common.

Weeds are the major constraint in rice-fallow crops due to lack of tillage operations for field preparation, high soil moisture content, lower plant population due to uneven plant emergence, and problem of existing weeds after rice harvest. The major weeds of fallow crops include; *Chenopodium album, Vicia sativa, V. hirsuta, Lathyrus aphaca, Medicago denticulata*, *Solanum* *nigrum, Coronopus didymis, Anagalis arvensis, Cuscuta campestris* (parasitic weed) *Convolvulus arvensis* (broad-leaved), *Cynodon dactylon* (grassy), and *Cyperus rotundus* (sedge).

### Problems in weed management in *Utera* cropping

- Severe weed problem in absence of no field preparation for sowing.
- Difficulty in manual and mechanical weeding because of presence of rice stubbles. In addition, problem of trampling of crop seedlings in *Utera* cropping as seeds are broadcasted on the soil surface.
- Inter-cultivation is not possible as seeds are broadcasted in *utera*.
- Normal methods of pre-emergence application of herbicide is not possible as blackgram / greengram / lentil seedlings are established at the time of removal of paddy sheaves.
- Already established weeds are there at the time of removal of paddy sheaves.
- Weed management will be further complicated if parasitic weed like *Cuscuta* are there.
- Further, presently farmers are using post-emergence grassy herbicides, like fenoxaprop-ethyl, quizalofop-ethyl *etc.* to control the grassy weeds in rice fallow greengram / blackgram. Therefore, broad-leaf weeds like *Chrozophora rottleri*, *Grangea maderaspetana*, *Ocimum canum, Cardiosperma helicacaba, Cardanthera uliginosa*, *Vicia sativa etc.,* becamea problematic.

### Promising herbicides for weed management in rice-fallow crops

In rice fallow maize in coastal Andhra Pradesh, pre-emergence application (PE) of atrazine at 0.50-1.0 kg/ha, and post-emergence application (PoE) of tembotrione (120 g/ha), topramezone (75.2 g/ha), atrazine + topramezone (500 + 5.2 g/ha) and atrazine + tembotrione (500 + 120 g/ha) provides broad-spectrum weed control. Halosulfuron 67.5 g/ha PoE against sedges and 2, 4-D 0.50 kg/ha PoE for broad-leaved weeds has been found effective. In sorghum, atrazine 0.50 kg/ha PE and 2, 4-D 0.50 kg/ha PoE has been found promising. For weed management in greengram/blackgram, pendimethalin or pendimethalin + imazethapyr at 1.0 kg/ha PE, and imazethapyr at 80-100 g/ha PoE, quizalofop-ethyl 50 g/ha PoE, fomesafen + fluazfop-p-butyl 250 g/ha PoE, propaquizafop + imazethapyr 125 g/ha PoE, imazethapyr + imazamox 70 g/ha PoE, Na-acifluorfen + clodinafop 245 g/ha PoE and imazethypyr + quizalofop 65.6 + 32.8 g/ha PoE has been recommended.

In eastern ecology, pendimethalin 1.0 kg/ha, isoproturon 1.0 kg/ha, oxadiargyl 90 g/ha and quizalofop 50 g/ha in mustard/toria, pendimethalin 1.0 kg/ha, quizalofop 50 g/ha, isoproturon 0.75-1.0 kg/ha and fluazifop-p-butyl 100 g/ha in linseed, pendimethalin 1.0 kg/ha, pendimethalin + imazethapyr 1.0 kg/ha and quizalofop 50 g/ha in chickpea, and pendimethalin 1.0 kg/ha, and quizalofop 50 g/ha in lentil, and pendimethalin 1.0 kg/ha, metribuzin 0.25 kg/ha and quizalofop 50 g/ha in can be used.

In some parts of southern India, groundnut is grown in rice fallows. Pendimethalin + imazethapyr at 1.0 kg/ha PE, pendimethalin 1.0 kg/ha PE followed by imazethapyr 75 g/ha PoE at 18-22 days after sowing, imazethypyr + quizalofop 65.6 + 32.8 g/ha PoE, propaquizafop + imazethapyr 125 g/ha PoE, imazethapyr + imazamox 70 g/ha PoE, and Na-acifluorfen + clodinafop 245 g/ha PoE have been found effective for controlling weeds.

**Weed management in rice-fallow Utera cropping:** Rice-fallow pulses (lentil in eastern India, and blackgram/greengram in coastal region) are mostly grown as *utera* cropping under high moisture conditions. Use of pre-emergence or pre-plant herbicides is not feasible under *utera* system. Since post-emergence herbicides are not commercially available especially for winter-season pulses and inter-cultivation is difficult due to hard soil, hand weeding is the only option during the early stage. However, recent studies suggest that post-emergence (at 3-4 leaf stage of weed) application of imazethapyr at 80-100 g/ha, quizalofop-ethyl at 50 g/ha, Na-acifluorfen + clodinafop 245 g/ha, fomesafen + fluazfop-p-butyl 250 g/ha, propaquizafop + imazethapyr 125 g/ha, imazethapyr + imazamox 70 g/ha has been found quite effective against the seasonal grassy weeds in groundnut, urdbean and greengram. Quizalofop can also be used to check ratooning of rice stubbles to reduce the soil moisture loss.

**Management of parasitic weed *Cuscuta* in rice-fallow pulses:** *Cuscuta* is a parasitic weed and it is very difficult to control by using any single method. Therefore, it is better to follow the integrated approach to reduce its intensity. Possible methods for prevention of spread and control of *Cuscuta* in rice-fallows are:

- Use of *Cuscuta* free crop seed.
- Application of pendimethalin at 1.25-1.5 kg/ha mixed in 50 kg sand and broadcasted uniformly followed by water spray 500 L/ha, immediately after removal of the rice sheaves from fields.
- Spraying of imazethapyr at 50 g/ha at 20 to 25 DAS (crop will be slightly stunted for a week and recover gradually) in greengram and blackgram.
- At 30-35 DAS, *Cuscuta* should be removed and burned as and when observed, or spot treatment with paraquat 24 % SL 5 ml/L of water.
- Crop rotation.

**Management of *Vicia sativa* in rice-fallow pulses**: Common vetch (*Vicia sativa* L.) is a very problematic weed in relay crop of pulses in north coastal districts of Andhra Pradesh. This is weed being leguminous, it is difficult to control even with the selective post-emergence herbicide like imazethapyr and hand weeding is also difficult due to its twining habit, besides presence of the dense stubbles of rice, forcing the farmers sometimes to leave the fields even without harvesting. Following possible methods to manage *V. sativa* have been suggested (Aliveni *et al*. 2017).

**Table 2. List of recommended herbicides for weed control in rice**

| Recommended herbicides | Dose (g/ha) | Application time | Remarks |
|---|---|---|---|
| Pretilachlor | 600 g/ha | Pre-emergence | Excellent control of grasses |
| Pyrazosulfuron | 20 g/ha | Pre-emergence | BLWs and sedges |
| Pretilachlor + pyrazosulfuron | 600 + 15 g/ha | Pre-emergence | Broad-spectrum weed control |
| Pretilachlor + bensulfuron | 600 + 60 g/ha | Pre-emergence | Broad-spectrum weed control |
| Pendimethalin + pyrazosulfuron | 900 + 20 g/ha | Pre-emergence | Broad-spectrum weed control |
| Penoxsulam + butachlor | 820 g/ha | Pre-emergence | Broad-spectrum weed control |
| Bispyribac-Na | 25 g/ha | Post-emergence | Broad-spectrum weed control |
| Penoxsulam | 22.5–25 g/ha | Post-emergence | Broad-spectrum weed control |
| Bentazone | 960 g/ha | Post-emergence | BLWs and sedges |
| Triafamone + ethoxysulfuron | 62.5 g/ha | Post-emergence | Broad spectrum weed control |
| Flucetosulfuron | 25 g/ha | Post-emergence | Broad-spectrum weed control |
| Azimsulfuron | 35 g/ha | Post-emergence | Broad-spectrum weed control |
| Fenoxaprop + safener | 60 g/ha | Post-emergence | Excellent control of grasses |
| Metsulfuron + chlorimuron | 4 g/ha | Post-emergence | BLWs and sedges |
| Cyhalofop | 60 g/ha | Post-emergence | Excellent control of grasses |
| Cyhalofop + penoxsulam | 135 g/ha | Post-emergence | Broad-spectrum weed control |
| Clomazone + 2, 4-D EE | 250–375 g/ha | Post-emergence | Broad-spectrum weed control |

Pre-emergence: 0-3 DAS/DAT; Post-emergence: 18-22 DAS/DAT, BLWs: Broad-leaved weeds

- Selection of pure crop seed free from *Vicia* seeds.
- Sand mix application of pendimethalin 1.5 kg/ha in 50 kg sand/ha immediately after removal of paddy sheaves and this should be followed by water spray at 500 l/ha.
- Acifluorfen + clodinafop-propargyl 0.30 kg/ha PoE at 25-30 days after sowing.
- Avoid cattle grazing in *Vicia* infested fields.
- Crop rotation with crops like rice and maize *etc.*

**Weed management in rice-fallows through conservation agriculture:** The resource conserving technologies (RCTs) such as zero tillage (ZT) and mulching with crop residue help in establishing the fallow crops. Zero tillage helps in conserving in-situ residual soil moisture and facilitates sowing of succeeding crops immediately after rice harvest. Minimal disturbance of soil in ZT also reduces weed seed germination due to less exposure of soil weed seedbank to solar radiation. Most of the weed seeds are accumulated on soil surface in ZT system, and lose their viability due to different biotic (insect-pests, birds, *etc.*) and abiotic stresses (high temperature). Presence of crop residue cover on the soil surface influences weed seed germination and emergence, and weed biomass by changing soil seedbank environment (light interception, physical barrier, soil moisture, allelopathy) (Nichols *et al.* 2015). Retaining the crop residue on soil surface under ZT system suppresses weed seedling emergence, delays the time of emergence, and allows the crop to gain an advantage over weeds (Chauhan and Johnson 2010).

## FURTHER READING


Aliveni A, Rao AS, Ramana AV and Jagannnadham J. 2017. Management of common vetch and other weeds in relay crop of blackgram. *Indian Journal of Weed Science* **48**(3):341-342.

Appanna G, Rao AS, Rao RSN and Ravi Kumar A. 1998. Evaluation of new herbicides for weed management in rice fallow blackgram, *The Andhra Agricultural Journal* **45**(1&2):116-118.

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

Gharde Y, Singh PK, Dubey RP, and Gupta PK. 2018. Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection,* **107**: 12–18.

Mishra JS, Subbarayudu B, Chapke RR and Seetharama N. 2009. Sorghum-a potential high yielder in rice-fallows of Andhra Pradesh. *ICAR NEWS* **15** (4): 8p.

Mishra JS. 2009. Biology and management of *Cuscuta* spp. *Indian Journal of Weed Science* **41**(1&2): 1–11.

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

Rao AS and Rao RSN. 2003. Bio-efficacy of clodinafop-propargyl on *Echinochoa* spp. control in blackgram. *Indian Journal of Weed Science* **35**(3&4):251–252.

Satyanarayana A, Seeniah P, Sudhakara Babu K. and Prasada Rao MP. 1997. Extending pulse area and production in rice fallows. pp 569–588. In: *Recent Advances in Pulses Research,* (Eds. A.N. Asthana and Masood Ali). Indian Institute of Pulses Research, Kanpur, India.

# Weed risk assessment – A tool to assess potential invasiveness of new plants

**M.C. Singh*, V. Celia Chalam, Dhruv Singh[1], D. Sreekanth[2] and Sushilkumar[2]**
*ICAR- National Bureau of Plant Genetic Resources, New Delhi 110 012, India*
*[1]Sardar Vallabhbhai Patel University of Agriculture & Technology, Meerut, Uttar Pradesh 250110, India*
*[2]ICAR-Directorate of Weed Research, Maharajpur, Jabalpur, Madhya Pradesh 482004, India*
**Email: mchsingh@gmail.com*

The implementation of new policy on 'Seed Development' by the Government of India has provided stimulus for the import of seeds of various crops from all over the world. This has increased the risk for the introduction of exotic weeds into India. Weeds have major impacts on economies and natural environments worldwide including India. Many of these weeds have been purposely introduced as new crops or as ornamentals. To counter the threat to agriculture or the environment from new plants, regulatory authorities have a statutory responsibility to ensure that all plants proposed to be imported, which are not already established, be evaluated for their potential to damage the productive capacity or environment of the country. Quarantine in India officially came into operation with the passing of the Destructive Insects & Pests Act (DIP Act) in 1914. Plant Quarantine Order 2003 (regulation of import into India), of the Destructive Insects and Pests Act (1914) provides a legislative framework for the application of measures to prevent the introduction or spread of insect, disease and weed pests affecting plants. Effective plant quarantine is important for the protection of the biodiversity of the natural environment and agricultural productivity. Infestation of agricultural system has the potential not only to incur costs in controlling pests and losses in production, but also to restrict access to export markets, if the pest has the potential to contaminate the marketable product. There are many approaches to predicting weed potential (Mack 1996), but there is an urgent need of an objective, credible and publicly acceptable risk assessment system to predict the weediness of the new plant introductions.

An acceptable weed risk assessment system should satisfy a number of requirements. It should be calibrated and validated against a large number of plants already present in the recipient country and representing the full spectrum of plants likely to be encountered as imports into that country. It must discriminate between weeds and non-weeds, such that the majority of weeds are not accepted, non-weeds are not rejected, and the proportion of plants requiring further evaluation is kept to a minimum. As international trade agreements require that prohibited plant should fit in the definition of a quarantine pest before they can be excluded by quarantine regulations (Singh *et al.* 2005), the system must be passed on explicit assumption and scientific principles so that country can not be accused of applying unjustified non-tariff trade barriers. Ideally, the system should be capable of identifying which land use system the plant is likely to invade, to assist in an economic evaluation of its potential impacts. Finally, the system must be cost effective. This 'weed risk assessment' (WRA) system for India is designed in consultation with the weed scientists of Australia, University of Queensland, Brisbane.

## Methodology of weed risk assessment

The Weed Risk Assessment (WRA) process is a science-based biosecurity risk analysis tool for determining the weed potential of any plant. It is designed to run on Microsoft Excel 2007 in MS Windows operating system. The basis of the WRA is to answers 49 questions (**Table 1**) based on the main attributes and impacts of weeds. These are combined into scoring system which in the absence of any evidence to the contrary, gives an equal weight to nearly all questions (**Table 2**). These cover a range of weedy attributes in order to screen for plants that are likely to become weeds of an environment and/or agriculture. The questions are divided into three sections producing identifiable scores that contribute to the total score (**Table 2**). Most questions are answered, as yes, no or don't know. Biogeography consists the documented distribution, climate preferences, history of cultivation, and weediness of a plant elsewhere in the world, *i.e.* apart from the proposed recipient country. Weediness elsewhere is a good predictor of a plant becoming a weed in new areas with similar environmental conditions (Forcella and Wood 1984). The questions concerning the history of cultivation recognizes the important human component of propagule pressure (Williamson and Fitter 1996), but such data are obviously never available for the proposed new country. The global distribution and climate preferences, where these are available, are used to predict a potential distribution in the recipient country. Undesirable attributes are characteristics such as toxic fruits and unpalatibility, or invasive behavior, such as a climbing or smothering growth habit, or the ability to survive in dense shade. Biology and ecology are the attributes that enable a plant to reproduce, spread and persist (Noble 1989) such as whether the plant is wind dispersed or animal dispersed, and whether the seeds

**Table 1. Questionnaire for weed risk analysis**

| | | | |
|---|---|---|---|
| | Botanical name: | Outcome: | |
| | Common name: | Score: | |
| | Family name | Your name: | |
| | | **History/Biogeography** | |
| A | **1** *Domestication cultivation* | 1.01 Is the species highly domesticated. If answer is 'no' got to question 2.01 | |
| C | | 1.02 Has the species become naturalised were grown | |
| C | | 1.03 Does the species have weedy races | |
| | **2** *Climate and Distribution* | 2.01 Species suited to Indian climates (0-low; 1-intermediate; 2-high) | 2 |
| | | 2.02 Quality of climate match data (0-low; 1-intermediate; 2-high) | 2 |
| C | | 2.03 Broad climate suitability (environmental versatility) | |
| C | | 2.04 Native or naturalised in regions with extended dry periods | |
| | | 2.05 Does the species have a history of repeated introductions outside its natural range | |
| C | **3** *Weed elsewhere* | 3.01 Naturalised beyond native range | |
| E | | 3.02 Garden/amenity/disturbance weed | |
| A | | 3.03 Weed of agriculture/horticulture/forestry | |
| E | | 3.04 Environmental weed | |
| | | 3.05 Congeneric weed | |
| | | **Biology/Ecology** | |
| A | **4** *Undesirable traits* | 4.01 Produces spines, thorns or burrs | |
| C | | 4.02 Allelopathic | |
| C | | 4.03 Parasitic | |
| A | | 4.04 Unpalatable to grazing animals | |
| C | | 4.05 Toxic to animals | |
| C | | 4.06 Host for recognised pests and pathogens | |
| C | | 4.07 Causes allergies or is otherwise toxic to humans | |
| E | | 4.08 Creates a fire hazard in natural ecosystems | |
| E | | 4.09 Is a shade tolerant plant at some stage of its life cycle | |
| E | | 4.10 Grows on infertile soils | |
| E | | 4.11 Climbing or smothering growth habit | |
| E | | 4.12 Forms dense thickets | |
| E | **5** *Plant type* | 5.01 Aquatic | |
| C | | 5.02 Grass | |
| E | | 5.03 Nitrogen fixing woody plant | |
| C | | 5.04 Geophyte | |
| C | **6** *Reproduction* | 6.01 Evidence of substantial reproductive failure in native habitat | |
| C | | 6.02 Produces viable seed | |
| C | | 6.03 Hybridises naturally | |
| C | | 6.04 Self-fertilisation | |
| C | | 6.05 Requires specialist pollinators | |
| C | | 6.06 Reproduction by vegetative propagation | |
| C | | 6.07 Minimum generative time (years) | 1 |
| A | **7** *Dispersal mechanisms* | 7.01 Propagules likely to be dispersed unintentionally | |
| C | | 7.02 Propagules dispersed intentionally by people | |
| A | | 7.03 Propagules likely to disperse as a produce contaminant | |
| C | | 7.04 Propagules adapted to wind dispersal | |
| E | | 7.05 Propagules buoyant | |
| E | | 7.06 Propagules bird dispersed | |

**Table 2. Weed risk assessment scoring sheet**

| | | a | b | c | d | e |
|---|---|---|---|---|---|---|
| Section | | Question | Response [1] | Score | N score | Y score |
| A | C | 1.01 | | | 0 | -3 |
| | C | 1.02 | | | -1 | 1 |
| | C | 1.03 | | | -1 | 1 |
| | | 2.01 | | The response for these questions is 2 unless a climate analysis is done | | |
| | | 2.02 | | | | |
| | C | 2.03 | | | 0 | 1 |
| | C | 2.04 | | | 0 | 1 |
| | | 2.05 | | | | |
| | | | | | | |
| | C | 3.01 | | | Refer to lookup table | |
| | E | 3.02 | | | | |
| | A | 3.03 | | | | |
| | E | 3.04 | | | | |
| | C | 3.05 | | | | |
| B | C | 4.01 | | | 0 | 1 |
| | C | 4.02 | | | 0 | 1 |
| | C | 4.03 | | | 0 | 1 |
| | A | 4.04 | | | -1 | 1 |
| | C | 4.05 | | | 0 | 1 |
| | C | 4.06 | | | 0 | 1 |
| | C | 4.07 | | | 0 | 1 |
| | E | 4.08 | | | 0 | 1 |
| | E | 4.09 | | | 0 | 1 |
| | E | 4.10 | | | 0 | 1 |
| | E | 4.11 | | | 0 | 1 |
| | C | 4.12 | | | 0 | 1 |
| C | E | 5.01 | | | 0 | 5 |
| | C | 5.02 | | | 0 | 1 |
| | E | 5.03 | | | 0 | 1 |
| | C | 5.04 | | | 0 | 1 |
| | C | 6.01 | | | 0 | 1 |
| | C | 6.02 | | | -1 | 1 |
| | A | 6.03 | | | -1 | 1 |
| | C | 6.04 | | | -1 | 1 |
| | C | 6.05 | | | 0 | -1 |
| | A | 6.06 | | | -1 | 1 |
| | C | 6.07 | | | | |
| | A | 7.01 | | | -1 | 1 |
| | C | 7.02 | | | -1 | 1 |
| | A | 7.03 | | | -1 | 1 |
| | C | 7.04 | | | -1 | 1 |
| | E | 7.05 | | | -1 | 1 |
| | E | 7.06 | | | -1 | 1 |
| | C | 7.07 | | | -1 | 1 |
| | C | 7.08 | | | -1 | 1 |
| | C | 8.01 | | | -1 | 1 |
| | C | 8.02 | | | -1 | 1 |
| | A | 8.03 | | | 1 | -1 |
| | A | 8.04 | | | -1 | 1 |
| | C | 8.05 | | | 1 | -1 |
| | | **Total score** [3] | | | | |
| | | **Outcome** [4] | | | | |
| | | Agricultural score [6] | | | | |
| | | Environmental [6] | | | | |

Only score 1.02 and 1.03 if you answered yes to 1.01

| Lookup table for section 3. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Locate value of inputs and lookup output for each question | | | | | | | | | | |
| | | ***Yes*** to questions 3.01 - 3.05 | | | | | | | | **default** |
| Inputs | 2.01 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 2 | **2** |
| | 2.02 | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | **2** |
| Results | 3.01 | 2 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | **2** |
| | 3.02 | 2 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | **2** |
| | 3.03 | 3 | 2 | 1 | 4 | 3 | 2 | 4 | 4 | **4** |
| | 3.04 | 3 | 2 | 1 | 4 | 3 | 2 | 4 | 4 | **4** |
| | 3.05 | 2 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | **2** |
| | | ***No*** to questions 3.01 - 3.05 | | | | | | | | |
| Input | 2.05 | ? | N | Y | | | | | | |
| Results | 3.01 | -1 | 0 | -2 | | | | | | |
| | 3.02-3.05 | 0 | 0 | 0 | | | | | | |

**Procedure for scoring assessment**

1. Record appropriate responses in column b.
2. Look up score in columns d & e and record result in column c.
3. Calculate total score.
4. Lookup and record recommendation.
5. Verify that minimum number of questions from each section are answered.
6. Compute Agricultural (A&C) and Environmental (E&C) scores: if either score is less than 1, the outcome pertains to the other sector.

| Lookup table for 6.07 | | | |
|---|---|---|---|
| years | 1 | 2 | 4 |
| score | 1 | 0 | -1 |

| Score | Outcome |
|---|---|
| < 1 | Accept |
| 1-6 | Evaluate |
| > 6 | Reject |

| Section | Minimum # questions [5] |
|---|---|
| A | 2 |
| B | 2 |
| C | 6 |
| Total | 10 |

The WRA compares the total score for a species to the critical values to determine the recommendation for the species. The threshold values for the system are shown as follows:

| **Scores** | **Recommendation** |
|---|---|
| If the plant scores less than 1 | Accept the plant |
| If the plant scores greater than 6 | Reject the plant |
| If the plant scores between 1 to 6 | Plant requires further evaluation |

would survive through passage of an animal's gut. Availability of information is often very limited for new species which can restrain the utility of screening systems. To ensure that at least some questions were answered for each section, the WRA system requires the answer to two questions in Section-A, two in Section- B and six in Section-C before it will give an evaluation and recommendation. The recommendation can be compared with the number of questions, answered as an indication of its reliability which obviously improves as more questions are answered.

| Reproduction | Scores |
|---|---|
| < 1 to 2 years | 1 |
| Between 2 to 4 years | 0 |
| Greater than or equal to 4 years | -1 |

Answers to the questions provide a potential total score ranging from -14 (benign plant) to 29 (maximum weediness) for each plant. The total score is partitioned between answers to questions considered to relate primarily to agriculture, to the environment, or common to both (**Table 1**). The total scores are converted to one of the three possible recommendations by two critical score settings. The lower critical scores 0, separates 'acceptable' plants from those requiring 'evaluation', and the higher critical score, 6, separates plants requiring 'evaluation' from those that should be 'rejected'. Evaluation could mean either obtaining more data or re-running the system, or undertaking further investigations such as field trails (Mack 1996). The model was run to assess the weed potential of plants ranging from beneficial plants to serious weeds.

## Interference of results of WRA

The answer to most of the questions in WRA is yes (y), no (n) or don't know (leave blank or?). The system translates these responses into a numerical score. A typical score for a question is Yes=1 point, No= -1 or 0 and don't know/? =0 The questions in Sections- 2 and -3 (climate and weed elsewhere) of the questionnaires differ from the typical scoring in that they generate a score by a weighting system. The score given for questions 2.01 and 2.02 is used to weight the scores for 'yes' answers in the weed elsewhere questions (3.01 to 3.05). The quality of climate data greatly affects the climate match. A good climate match increases the probability that a weedy species will behave the same way in India as it does overseas. The weediness score also increases if the information used to produce the climate match is not comprehensive, due to the greater uncertainty introduced by this data.

## Two other questions do not fit into the standard scoring system

1) A score of 'no' for question 3.01, whether a plant has naturalized overseas, is modified by the score to question 2.05, its history of repeated export species with repeated introductions outside of their native range that have not established are a lower risk.

2) Questions 6.07, the minimum generative time, require the input of a numerical score. This generative time is standardized by the use of correlation factor as shown in table.

## Interpretation of the questions in the WRA system?

The Weed Risk Assessment system consists of 49 questions. A description of each question has been developed. Users of the WRA should try to follow these descriptions so that all users of the system answer the questions consistently.

## History/Biogeography

### 1 Domestication / cultivation

1.01 ***Is the species highly domesticated? If answer is `no" go to Question 2.01***

The taxon must have been cultivated and subjected to substantial human selection for at least 20 generations. Domestication generally reduces the weediness of a species by breeding out noxious characteristics.

1.02 ***Has the species become naturalised where grown?*** Is a domesticated plant, which has introduced from another region, growing, reproducing and maintaining itself in the area in which it is growing. A `yes' answer to question 1.01 will be modified by the response to this question.

1.03 ***Does the species have weedy races?***

Only answer this question if the species you are assessing is a sub-species, cultivar or registered variety of a domesticated species. If the taxon is a less weedy subspecies, variety or cultivar, then there must be good evidence that it does not retain the capacity to revert to a weedy form. A `yes' answer to question 1.01 will be modified by the response to this question.

### 2 Climate and distribution

2.01 ***Species suited to Indian climates (0-low; 1-intermediate; 2-high)***

This question applies to any one Indian climate type, or more than one. Ideally, base the climate matching on an approved computer prediction system such as CLIMEX , BIOCLIM or Climate. If no computer analysis is carried out then assign the maximum score (2).

2.02 ***Quality of climate match data (0-low; 1-intermediate; 2-high)***

The score for this question is an indication of the quality of the data used to generate the climate analysis. Reliable specific data scores 2, general climate references scores 1, broad climate or distribution data scores 0. If a computer analysis was not carried out assign the maximum score of 2.

2.03 ***Broad climate suitability (environmental versatility)*** Score `yes' for this question if the species is found to grow in a broad range of climate types. Output from the climate matching program may be used for this question. Otherwise base the response on the natural occurrence of the species in 3 or more distinct climate categories. Use the map of climatic regions provided or one available in a comprehensive atlas.

2.04 ***Native or naturalised in regions with extended dry periods*** The species is able to grow in areas with rainfall in the driest quarter less than 25 mm. Plants from this group may potentially grow and survive in arid Australian conditions.

2.05 ***Does the species have a history of repeated introductions outside its natural range?***

This history should be well documented. A potential weed must have opportunities to show its potential. A score for Question 2.05 will modify the score for a `no' answer to Question 3.01. Species with repeated introductions that have not established are a lower risk.

### 3 Weed elsewhere

3.01 ***Naturalised beyond native range***

A naturalised species will be cited in floras of localities which are clearly outside of the native range. If the native range is uncertain and the known extent of the naturally growing plants is within the area of uncertainty then the answer is `don't know.'

3.02 ***Garden/amenity/disturbance weed***

The plant is generally an intrusive weed of gardens, parklands, roadsides, quarries, *etc.* This question carries less weight than 3.03 or 3.04. If a plant is listed as a weed in relevant references but the type of weed is uncertain or it is a minor weed - score `yes' for 3.02.

3.03 ***Weed of agriculture/horticulture/forestry***

The plant is generally a weed of agriculture /horticulture/ forestry and causes productivity losses and/or costs due to control. This question carries more weight than 3.02. If a plant is listed as a weed in relevant references but the type of weed is uncertain or it is a minor weed - score `yes' for 3.02.

3.04 ***Environmental weed***

The plant is documented to alter the structure or normal activity of a natural ecosystem. This question carries more weight than 3.02. If a plant is listed as a weed in relevant references but the type of weed is uncertain or it is a minor weed - score `yes' for 3.02.

3.05 ***Congeneric weed***

Documented evidence that one or more species, with similar biology, within the genus of the species being evaluated are weed.

## Biology/Ecology

### 4 Undesirable traits

4.01 ***Produces spines, thorns or burrs***

The plant possesses a structure on the plant known to cause fouling, discomfort or pain to animals or man. If the taxon is a thornless subspecies, variety or cultivar, then there must be good evidence that it does not retain the capacity to revert to a thorny form.

4.02 ***Allelopathic***

The plant is well documented as a potential suppressor of the growth of other species by chemical (eg. hormonal) means. Such evidence is rare throughout the whole plant kingdom.

4.03 ***Parasitic***

The parasite must have a detrimental effect on the host and the potential hosts must be present in Australia. This question includes wholly and semi-parasitic plants. Such plants are rare.

4.04 ***Unpalatable to grazing animals***

Consider the plant with respect to where the plant has the potential to grow and if the herbivores present could keep it under control. This trait may be found at any stage during the lifecycle of the plant and/or over periods of the growing season.

4.05 ***Toxic to animals***

There must be a reasonable likelihood that the toxic agent will reach the animal, by grazing or contact. Some species are mildly toxic but very palatable and could cause problems if heavily grazed.

4.06 ***Host for recognised pests and pathogens***

The main concerns are plants that are hosts of toxic pathogens and alternate or alternative hosts of crop pests and diseases. Where suitable alternative or alternate hosts are already widespread in cropping or natural systems the answer should be `no' unless the species will affect the current control strategies for the pathogen or pest. Apply a reasonable level of specificity; a pathogen of an entire family, such as takeall, should not be the basis for answering `yes' for an individual species.

4.07 ***Causes allergies or is otherwise toxic to humans***

This condition must be well documented and likely to occur under normal circumstances. For example by physical contact or inhalation of pollen from the species.

4.08 ***Creates a fire hazard in natural ecosystems***

This question applies to species that have a documented growth habit that leads to the rapid accumulation of fuel for fires when growing in natural or unmanaged ecosystems.

4.09 ***Is a shade tolerant plant at some stage of its life cycle***

Shade tolerance can enhance the invasive potential of a species.

4.10 ***Grows on infertile soils***

Species that tolerate low nutrient levels could potentially grow well here. Legumes, tolerant of low soil phosphorus, are a particular concern since they would also modify the soil environment.

4.11 ***Climbing or smothering growth habit***

This trait includes fast growing vines and ivy's that cover and kill or suppress the growth of the supporting vegetation. Plants that rapidly produce large rosettes could also score for this question.

4.12 ***Forms dense thickets***

The thickets produced should obstruct passage or access, or exclude other species. Woody perennials are the most likely candidates, but this question may include densely growing grasses.

### 5 Plant type

5.01 ***Aquatic***

The question includes any plants normally found growing on rivers, lakes and ponds. These species have the potential to choke waterways and starve the system of light, oxygen and nutrients. Consequently, the score is high (5).

5.02 ***Grass***

A large proportion of the grass family (Poaceae) are weeds in some context. As with congeneric weed species, there is a high probability that a species from this family will be a weed.

5.03 ***Nitrogen fixing woody plant***

A large proportion of woody legumes (Family Leguminosae/Fabaceae) are weeds, particularly of conservation areas. As with congeneric weed species, there is a high probability that a species from this family will be a weed.

5.04 ***Geophyte***

Perennial plants with tubers, corms or bulbs. This question is specifically to deal with plants that have specialised organs and should not include plants merely with rhizomes/stolons (see 6.06). Plants from this group can be particularly difficult to eradicate from a site.

### 6 Reproduction

6.01 ***Evidence of substantial reproductive failure in native habitat***

Predators and other factors present (eg. disease) in the native habitat can cause substantial reductions in reproductive capacity. The reproductive output of a species may greatly increase when the plant grows in areas without these factors.

6.02 ***Produces viable seed***

If the taxon is a subspecies, variety or cultivar, it must be indisputably sterile. The male plants of a dioecious species are regarded as seed producers.

6.03 ***Hybridises naturally***

A `yes' answer for this question requires documented evidence of interspecific hybrids occurring, without assistance, under natural conditions.

6.04 ***Self-fertilisation***

Species capable of self-seeding, can spread from seed produced by an isolated plant.

6.05 ***Requires specialist pollinators***

The invasive potential of the plant is reduced if the species requires specialist pollinating agents that are not present or rare in Australia.

6.06 ***Reproduction by vegetative propagation***

The plant must be capable of increasing its numbers by vegetative means. This may include reproduction by: rhizomes, stolons or root fragments, suckers or division.

6.07 ***Minimum generative time (years)***

This is the time from germination to production of viable seed, or the time taken for a vegetatively reproduced plant to duplicate itself. The shorter the timespan, the more-weedy a plant is likely to be. The score for this trait uses the correlation factor (1 year score 1, 2-3 years score 0, greater than or equal to 4 years score -1).

### 7 Dispersal mechanisms

7.01 ***Propagules likely to be dispersed unintentionally***

Propagules (any structure, sexual or asexual, which serves as a means of reproduction), unintentionally dispersed resulting from human activity. An example is plants growing in heavily trafficked areas such as farm paddocks or roadsides.

7.02 ***Propagules dispersed intentionally by people***

The plant has properties that make it attractive or desirable, such as an edible fruit, an ornamental or curiosity. The species is readily collected as a cutting or seed. This group includes most horticultural plants.

7.03 ***Propagules likely to disperse as contaminants of produce***

Produce is the economic output from any agricultural, forestry or horticultural activity. An example is grain shipments that contain seeds of weed species.

7.04 ***Propagules adapted to wind dispersal***

Documented evidence that wind significantly increases the dispersal range of the propagule. An example is an achene with a pappus. This group includes tumbling plants and plants with seeds contained within an explosive capsule or pod. 7.

05 ***Propagules buoyant***

This question includes any structure containing the propagule that typically becomes detached from the plant and is buoyant. An example is a pod of a legume. This is a limited method of distribution of land plants.

7.06 ***Propagules bird dispersed***

Any propagule that may be transported and/or consumed by birds, and will grow after defecation. An example is small red berries with indigestible seeds.

7.07 ***Propagules dispersed by other animals (externally)***

The plant has adaptations, such as burrs, and/or grows in situations that make it likely that propagules become temporarily attached to the animal. This can include the spread of plants parts on clothing. This dispersal group includes seeds with an oily or fat-rich outgrowth that aids in ant seed dispersal.

7.08 ***Propagules dispersed by other animals (internally)***

The propagules are eaten by animals, dispersed and will grow after defecation.

### 8 Persistence attributes

8.01 ***Prolific seed production***

The level of seed production must be met under natural conditions and applies only to viable seed. For grasses and annual species this rate should be (>5000-10000/$m^2$/yr), for woody annual a rate of (>500/$m^2$/yr) would be considered high. Specific data on this attribute may be unavailable, however, an estimate can be made from the seed/plant and the average size of the plant.

8.02 ***Evidence that a persistent propagule bank is formed (>1 yr)***

Greater than 1% of the seed should remain viable after more than one year in the soil. This bank may include both canopy and soil seed banks. Long seed viability increases a plants invasive potential.

8.03 ***Well controlled by herbicides***

Documented evidence is required for good chemical control of the plant. This control must be acceptable in the situations in which it is likely to be found. The chemical management should be safe for other desirable plants that are likely to be present. This information will be poorly documented for most non-agricultural plants.

8.04 ***Tolerates or benefits from mutilation, cultivation or fire***

Plants that tolerate or benefit from such disturbance may out-compete other species. This question does not apply to seed banks.

8.05 ***Effective natural enemies present in India***

A known, effective, natural enemy of the plant may or may not be present in Australia. The answer is 'don't know' unless a specific enemy/enemies are known.

The species used for the calibration of the system ranged from severe agricultural and environmental weeds to benign and beneficial plants. The WRA tallies the number of questions answered in each section. The WRA allows for a minimum number of questions in each of its three different categories. The minimum number of questions for each section is: 2 for Section- A, 2 for Section- B and 6 for Section- C. When using the; Excel Spreadsheet', if the minimum number of questions is not completed, a message that more information is required is posted by the system. The WRA has some capacity to suggest the type of ecosystem likely to be affected by the plant assessed. The WRA indicates if the plant is more likely to be a specific weed of agriculture or the general environment, once it has assessed the plants potential to become a weed in India. A species may be assessed to be a weed of both categories. The partitioning helps to identify areas most at risk from the characters assessed for the species. The assessment method was tested against 170 plants representing both weeds and useful plants from agriculture and environment. The method was judged on its ability to correctly reject weeds and accept non weeds. A total of 40% plants were classified as serious weeds, 30% as common weeds and remaining 30% were non weeds.

The system identifies a wide range of weeds, and does not accept plants known to be major weeds in India. By splitting the total scores, the model also allows an estimate of whether the weed is more likely to impact on agricultural or natural environment systems, which may assist regulatory authorities in making a recommendation. These features suggest that the system could be altered and still be expected to produce satisfactory results in other bio-climatic regions of the globe where protocols are lacking (Ruesink *et al.* 1995). As the system is simple and spreadsheet based, it can be used by lay people who wish to import plants and it has an educational role because it shows the effect of individual questions on the total score. The system distinguishes between many useful and non-useful plants, but some useful plants can be rejected. This is to be expected, because planned introductions are chosen for their ability to survive (Ruesink *et al.* 1995), and the questions asked by the system are based primarily on biological and ecological criteria which identify attributes common to both useful agricultural plants and weeds (Lonsdale 1994). These may differ only in a small number of characteristics within any single life from (Perrins *et al.* 1992). Where a plant may have significant economic benefits, a further evaluation of its weediness potential may include experimental studies (Williamson 1993, Scott and Panetta 1993). Economic value should be scored in a transparently separate exercise and balanced against weediness in appropriate risk assessment evaluations (Singh *et al.* 2005).

## Conclusion

Seeds and planting materials of different plant species are being imported into India. Many of these plants have the potential to become agricultural or environmental weeds and this risk needs to be assessed before allowing their entry. Weed risk assessment is a question based scoring system, containing 49 questions about the species. The assessment method was tested against 170 plants representing both weeds and useful plants from agriculture and environment. The method was judged on its ability to correctly reject weeds and accept non weeds. A total of 40% plants were classified as serious weeds, 30% as common weeds and remaining 30% were non weeds. The system is designed to be operated by plant quarantine officers.

It is concluded that the Weed Risk Assessment System with explicit scoring of biological, ecological and geographical attributes is a useful tool for detecting potentially invasive weeds in other parts of the world and should be used in Indian Plant Quarantine to assess the plants before issue of the Import Permit.

## FURTHER READING


Downey PO, Holloway S and Plumb N. 2022. A new post-border weed biosecurity risk management system. Pp. 200-203. In: *Proceedings of the 22nd Australian Weeds Conference*. (Eds. Brodie C, Emms J, Feuerherdt L, Ivory S, Melland R. and Potter S.), 25-29 September 2022, Adelaide. Weed Management Society of South Australia Inc. Adelaide.

Gordon DR, Gantz CA, Jerde CL, Chadderton WL, Keller RP, et al. 2012 Weed risk assessment for aquatic plants: Modification of a New Zealand System for the United States. *PLoS ONE* **7**(7): e40031.

Gordon DR, Mitterdorfer B, Pheloung PC, Ansari S, Buddenhagen C, *et al*. 2010. Guidance for addressing the Australian Weed Risk Assessment questions. *Plant Protection Quarterly* **25**(2): 56 – 74

Forcella F and Wood TJ. 1984. Colonization potentials of alien weeds are related to their native distribution- implications for plant quarantine. *Journal of Australian Institute of Agricultural Science* **50**: 35–41.

Lonsdale WM. 1994. Inviting trouble: introduced pasture species in northern Australia. *Australian Journal of Ecology* **19**: 345–354.

Mack RN. 1996. Predicting the identity and fate of plant invaders: emergent and emerging approaches. *Biological Conservation* **78**: 107–121.

Noble IR. 1989. Attributes of invaders and the invading process: terrestrial and vascular plants. Pp. 301-310. In: *Biological Invasions: A Global Perspective*, (Eds. JA Drake, HA Mooney, FD Castri, RH Groves, FJ Kruger, M Rejmanek and M Williamson). Chichester: John Wiley.

Perrins J, Williamson M and Fitter A. 1992. A survey of differing views of weed classification: implifications for regulating introductions. *Biological Conservation* **60**: 47–76.

Pheloung PC, Williams PA, Halloy SR. 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. *Journal of Environmental Management* 57: 239–251.

Ruesink JL, Parker IM, Groom MJ and Kareiva PM. 1995. Reducing the risks of nonindigenous species introductions. *Bioscience* **45:** 465–477.

Scott JK and Panetta FD. 1993. Predicting the Australian weed status of southern African plants. *Journal of Biogeography* **20**: 87–93.

Sreekanth D, Pawar D, Chethan CR, Singh PK, Sondhia S, Chander S and Singh MC. 2022. Indian quarantine weeds invasiveness assessment using bio-security tool: Weed Risk Assessment. *Indian Journal of Weed Science* **54**(2): 110 – 115

Singh MC, Gnansambandham S and Chandurkar PS. 2005. Weeds as quarantine pests. *Plant Protection Bulletin* **57**: 1–3.

Williamson M. 1993. Invaders, weeds and the risk from genetically manipulated organisms. *Experimentia* **49**: 219-224.

Williamson M and FitterX FD. 1996. The characteristics of successful invaders. *Biological Conservation* **78:** 163–170.

# Practical weed management in conservation agriculture systems

T.K. Das[1*] and A.R. Sharma[2]
[1]Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi 110012, India
[2]Rani Lakshmi Bai Central Agricultural University, Jhansi, Uttar Pradesh 284003, India
*Email: tkdas64@gmail.com

Conservation agriculture is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. It can enhance natural and biological processes above and below the ground. It involves a paradigm shift in crop production from conventional agriculture. CA is believed to have potential to achieve acceptable profits, high and sustained production levels, and conservation of the environment. CA can help in adaptation and mitigation of the climate change effects. It has the potential to reduce, reverse and counteract many adverse effects of conventional agriculture such as declining factors (water, nutrient, energy, labour, pesticide) productivity, stagnating trends of crop yield and farm income, deteriorating soil health (organic matter decline, soil structural degradation, reduced infiltration, compaction), higher surface runoff and erosion, secondary salinization and sodicity problems, higher biotic interferences and declining biodiversity (natural and agro-ecosystems), susceptibility to climatic variability and global warming, and air and ground water pollution. Good agricultural practices (GAPs) like quality seeds, integrated pest, nutrient and water management should be integrated with CA to sustain higher crop productivity, soil and environmental health and conserve natural resource base.

## Adoption of CA

CA is a fastest growing technology in the world, adopted on a majority in dryland rainfed agricultural situations. CA was adopted in less than 1.0 million ha (M ha) in 8 countries in 1970, which has now covered more than 205 M ha in 102 countries. It is about 15% of the world's cropland area, which is the highest under any given technology practice. Argentina, Australia, Brazil, Canada, Paraguay, South Africa, Uruguay and USA have adopted CA in >50% of their cropped area. From 1990 to 2009, CA has globally spread 5.2 M ha per year, and reached to ~100 M ha in 2008, after which it has spread at double that rate (~10.5 M ha per year. In India, CA-based management is adopted on about 2.5 M ha.

## CA and weeds

CA is based on the practical application of three interlinked principles: continuous zero or minimum mechanical soil disturbance by direct planting, permanent vegetative soil cover or mulch to protect the soil surface, and diversification of cropping systems including legumes. These principles have tremendous effects on weed seed bank enrichment, weed spread and dynamics (**Table 1**). Thus, CA systems require a total paradigm shift from conventional agriculture with regard to management of crops, soil, water, nutrients, weeds, and farm machinery.

## Weed dynamics under CA

CA changes the crop microclimate that leads to a paradigm shift in weed germination and emergence. Some weeds are favoured by the changes in microclimate and emerge profusely than others under continuous ZT system. This results in weed shift, particularly towards perennials under CA systems, which are better adopted under less-disturbed soils. Also, herbicides are not effective against most perennial weeds, which reproduce, mainly, through vegetative means. Perennial monocots like *Cyperus rotundus* (Purple nutsedge), *Saccharum spontaneum* (Tiger grass), *Cynodon dactylon* (Bermuda grass) and *Sorghum halepense* (Johnson grass) reproduce from

**Table 1. Effect of CA principles on weeds**

| Conservation tillage | Crop residue | Crop rotation |
|---|---|---|
| Weed seed bank (size of seedbank, vertical distribution, germination, predation, viability of weed seeds) | Weed seed bank (Germination, predation, pathogens attack and viability) | Weed seed bank (size of seedbank, germination, predation of weed seeds) |
| Growth and establishment of germinated weeds | Growth and establishment of germinated weed seeds | Establishment, seed setting, and dispersal |
| Production, dispersal, and recruitment of weed seed | Seed production, dispersal, and recruitment of weed seed | |
| Weed community composition and diversity (perennial vs annual) | | Weed community composition and diversity of weed species |

underground vegetative structures, tubers, rhizomes, stolon, corms *etc*. *Euphorbia microphylla* after wheat harvest also became dominant in CA-based rice-wheat system (**Figure 1**). The infestation of *Cyperus esculentus* increased tremendously in different in different CA-based systems after 8 years (**Table 2**).

Perennial dicots weeds such as *Polygonum plebejum* (Indian knotweed) and *Alternanthera philoxeroides* (Alligator weed) have been observed in continuously CA plots under rice-wheat system, and *Sonchus arvensis* (Perennial Sow thistle) under CA-based rice-mustard system. Annual weed shifts towards small-seeded ones is generally observed under CA. But, *Phalaris minor* although has small seeds, is reduced gradually under ZT compared to CT system in the Indo-Gangetic Plains (IGPs). This may be attributed to: (i) higher soil strength in ZT because of crust development in the absence of tillage, which can impede seedling emergence, (ii) less soil temperature fluctuation under ZT, and (iii) relatively lower levels of light stimuli, N mineralization and gas exchange under ZT.

## Weed management options

### Prevention of weed seed rains

Preventive methods of weed control are equally or even more important than curative measures under CA. Several ways to reduce seed rains, which add to the seed bank are: (i) use of certified seeds or clean seeds free of weeds; (ii) minimize the weed entry and establishment in a new area; (iii) prevent invasive and alien weeds; (iv) cleaning of farm implements and machineries before and after use; (v) application of well rotten compost, and (vi) cleaning of farm bunds. Even after practicing weed control, some weeds escape and can produce a large number of seeds with variable dormancies, which can further reduce yields or increase weed management costs in subsequent years. It is also essential to prevent seed production from weeds growing during the fallow period (between harvesting and seeding of next crop), and on bunds and channels. Harvest weed seed control targets weed seed during grain harvest operations to minimize fresh seed inputs to the seedbank.

**Table 2. *Cyperus esculentus* infestation (no./$m^2$) after 8 years of CA in different cropping systems at New Delhi**

| Treatment | Cotton-wheat | Pigeonpea-wheat | Maize-wheat |
|---|---|---|---|
| Conventional tillage | 900 | 208 | 568 |
| Permanent narrow-bed + residue | 769 | 51 | 526 |
| Permanent broad-bed + residue | 140 | 21 | 257 |
| Permanent flat-bed + residue | 849 | 16 | 188 |

*Cyperus esculentus* in maize under CA-based maize-wheat system

*Cyperus esculentus* in cotton under CA-based cotton-wheat system

*Euphorbia microphylla* after wheat harvest under CA-based rice-wheat system

*Cyperus esculentus* after wheat harvest under CA-based rice-wheat system

**Figure 1. *Cyperus esculentus* infestation in different CA-based cropping systems and *E. microphylla* infestations in CA-based rice-wheat system**

### Stale seedbed technique

In this technique, weed seeds are encouraged to germinate and then are killed by either a non-selective herbicide (paraquat, glyphosate, or glufosinate) or by shallow tillage before sowing (under conventional agriculture). This technique is effective not only in reducing weed emergence during the crop season but also in reducing the weed seed bank. This technique is most effective against: (i) weed seeds pre sent in top soil, (ii) weeds having low initial dormancy, and (iii) weed seeds requiring light to germinate. The susceptible weed species include: *Cyperus iria, Digitaria ciliaris, Eclipta prostrata, Leptochloa chinensis* and *Ludwigia hyssopifolia*.

### Proper sowing time

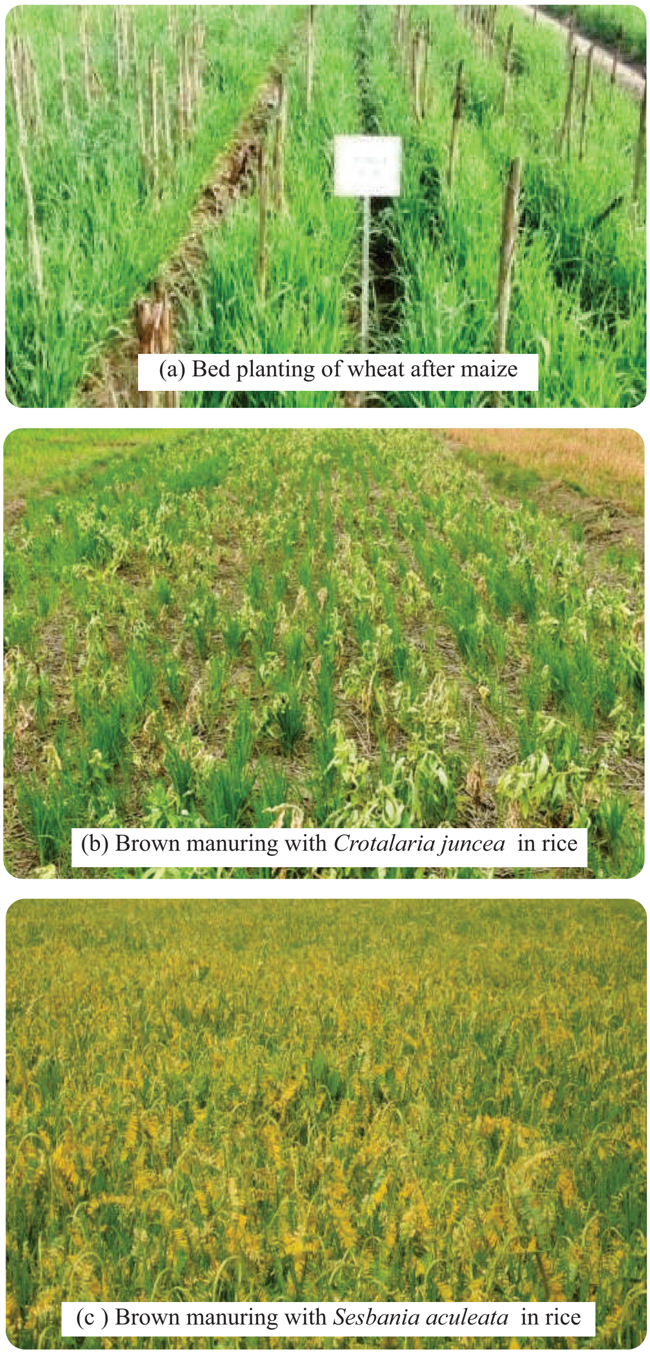
Due to dormancy, many weeds germinate during specific seasons. If the approximate date of emergence is known for problem weeds, sowing time can be adjusted so that either (i) the crop emerges before the weeds for a competitive advantage, or (ii) weeds are allowed to germinate and are controlled before or during crop planting. Planting earlier by even a few days can give the crop a significant competitive advantage over weeds. The potential weed suppression offered by early sowing of wheat is demonstrated by the case of *Phalaris minor* in rice-wheat systems. Adoption of ZT permitted wheat sowing 1–2 weeks earlier, allows the crop to establish before emergence of dormant *Phalaris minor*.

### Bed planting with residue

Bed planting is growing of crops on the raised-beds alternated by furrows for conserving inputs like seed, fertilizer, water *etc.* Beds are usually made at 0.6-1.2 m apart, and 2-3 rows of crops are sown on the beds and irrigation water is applied in the furrows. Close growing of crops, particularly wheat on the beds reduces weed emergence and competition. The height of beds is maintained at about 15-20 cm and having a width of about 40-70 cm depending on the crops. In case of wheat around 40 cm bed width is maintained and generally 2-3 rows are sown. The bed planting conserves resources and reduces cost of cultivation, saves water by 20-30%, increases fertilizer-use efficiency, leads to better management of weeds like *Phalaris minor,* and increases yield by 10-20% (**Figure 2a**).

### Crop varieties

The varieties of crops for CA should be quick-growing in nature so that they have early seedlings establishment to smother weeds. They should be more competitive with weeds by virtue of their plant architectures. Designing breeding programs to select for competitive ability under CA is challenging due to the complexity of characteristics and large variation between location and year. Two wheat varieties (*HDCSW 18* and *HDCSW 16*) have been developed at IARI for CA-based cropping systems. Herbicide-tolerant crops (HTCs) under ZT practices could be better options for some crops. Non-selective herbicides glyphosate and glufosinate-AM can provide complete weed control in these crops by one or more application across crop growth stages. If at all required, a selective pre-emergence herbicide may also be applied in HTCs for better weed control. Non-transgenics or gene-mutated imazethapyr-tolerant varieties of rice like *Pusa Basmati 1979* and *Pusa Basmati 1985* have been released recently from IARI. Such varieties are on the anvil for wheat and maize, which will be of immense use to combat perennial weed shift in CA.



(a) Bed planting of wheat after maize

(b) Brown manuring with *Crotalaria juncea* in rice

(c ) Brown manuring with *Sesbania aculeata* in rice

**Figure 2. Bed planting and brown manuring weed management methods in conservation agriculture**

### Brown manuring

Another approach that has shown promise for suppressing weeds in ZT is brown manuring (**Figure 2b, c**). In this system, the main crop of rice or maize and *Sesbania* are sown together and allowed to grow for 25-30 days. Then, co-culture *Sesbania* crop is knocked down with 2,4 D at 500 g/ha in both maize and rice, and bispyribac-Na 20 g/ha in rice. There is reduction of 70-80% in broad-leaved weeds and 20-30% in grassy weeds with this practice compared with sole rice crop. Brown manuring also reduces the infestation of problematic *Cyperus rotundus* considerably. *Crotalaria juncea* can also be used as brown manure crop in rice to combat nematodes.

### Crop rotations

Rotating crops having dissimilar life cycles or cultural conditions so as to break the cycle of the weeds is among the most effective of all weed control methods. Rice-fallow-sugarcane-ratoon sugarcane-sunflower-rice-wheat-sugarcane is a 4-year rotation, common in the north-eastern districts of Haryana. This rotation offers little opportunity for *Phalaris minor* to proliferate. Other rotations include rice-potato-sunflower, rice-mustard-sugarcane and rice-potato-onion. Inclusion of berseem in the rice-wheat cropping system helps to reduce seed bank of *Phalaris minor* within a lesser period of time because the emerged plants of *Phalaris minor* are cut with each cutting of berseem and these do not get any opportunity to set and shed seeds in field. In central India, chickpea, lentil and mustard are infested with broad-leaved weeds, for which there is no suitable post-emergence herbicide. In such situations, it is suggested to grow wheat and control the broad-leaved weeds with available herbicides like 2,4 D, metsulfuron and carfentrazone to minimize the seedbank of such weeds.

### Herbicides

CA system is dependent on herbicides and associated good agronomic practices for controlling weeds. Usually, less persistent, non-selective herbicides like glyphosate, paraquat or glufosinate-AM are recommended before crop sowing for ensuring weed-free conditions for crop germination. Besides, a pre-emergence herbicidal treatment is required to control flushes of annual weeds coming up with the germination of crops. Selective post-emergence herbicides, if available may be applied depending on the weed intensity. In order to reduce the herbicide residue build-up in CA systems, non-chemical options must also be integrated with herbicides with an emphasis on increasing the competitiveness of crop against weeds. The use of herbicides for managing weeds is becoming popular because they are cheaper than traditional weeding methods, require less labour, tackle difficult-to-control weeds, and allow flexibility in weed management. Pre-emergence herbicides are not be as efficient in controlling weeds in CA systems due to the presence of crop residues, which can bind to soil-applied herbicides and favour the weed seedlings to escape the applied herbicides. To overcome such problems, the following tactics may be adopted:

- Use of high-volume rate at pre-emergence sprays
- Use of higher dose of herbicide than normal to increase efficacy
- Use of granular herbicide formulation for soil application
- Use of broad-spectrum and non-selective herbicide during off-season to control perennial weeds
- Post-emergence herbicides are preferred than pre-emergence.

Weed management is a science as well as an art. The chemistry of herbicide and the art of application of herbicide play role on the overall efficacy that can be achieved due to herbicide application. Like "4R Stewardship" in nutrients management, the "5R Stewardship" should be followed for higher weed control efficacy with no phytotoxicity to crops and little implications to environment. These are:

**Right choice:** Herbicide should be selected based on the spectrum of prevalent weed to be controlled, time of application, and crop selectivity.

**Right source:** Herbicide should be procured from authentic sources /companies / brands for ensuring that the required active ingredient labeled is present and the herbicide is within the expiry date.

**Right dose:** Herbicides should be applied at the doses recommended for crops considering the time of application, crop selectivity and soil conditions.

**Right time of application:** Herbicide should be applied at appropriate time, pre-planting, pre-emergence or post-emergence, and the weed emergence and their growth stages should be considered upon post-emergence applications.

**Right method of application:** Herbicides should always be applied by using a sprayer, preferably a knapsack sprayer with flat fan or flood jet nozzle, proper pressure for delivery of spray droplets, and proper volume rate of water.

Several selective pre-emergence and post-emergence herbicides, some of which are low-dose and high-potency molecules are now available to effectively manage weeds in major field crops like rice, wheat, soybean, cotton, sugarcane, pulses and oilseeds under CA (**Table 3**).

### Integrated weed management

A single isolated approach cannot be a fool-proof strategy for achieving desired level of weed control under CA systems. IWM is not meant to replace selective, safe and efficient herbicides but is a sound strategy to encourage judicious use of herbicides along with other safe, effective, economical and eco-friendly control measures. In fact, the three CA principles are interlinked and interactive enough to counter weed problems in course of time. It is essential that approaches such as stale

**Table 3. Promising herbicides for weed control in different field crops under CA**

| Crop/herbicide | Dose (g/ha) | Time of application |
|---|---|---|
| *Rice* | | |
| Pendimethalin | 1000–1500 | 2-3 DAS/DAT |
| Oxadiargyl | 80-90 | PE (3-5 DAS/DAT) or early PoE (15-20 DAT) |
| Pretilachlor (S) | 750 | PE (3-5 DAS) |
| Pyrazosulfuron-ethyl | 25–30 | 20–25 DAS/DAT |
| Azimsulfuron | 35 | 20 DAS/DAT |
| Bispyribac-Na | 25 | 15–25 DAS/DAT |
| Cyhalofop-butyl | 100 | PoE (20-30 DAS) |
| Chlorimuron-ethyl + metsulfuron-methyl (ready-mix) | 4 | 15–20 DAS/DAT |
| 2,4-D | 750 | 20–25 DAS/DAT |
| Ethoxysulfuron | 20-22 | PE (3-5 DAT) or early PoE (15-20 DAT) |
| *Wheat* | | |
| Pendimethalin | 1000–1250 | 0–3 DAS |
| Clodinafop-propargyl | 60 | 30-35 DAS |
| Sulfosulfuron | 25 | PoE (30-35 DAS) |
| Clodinafop-propargyl + metsulfuron-methyl (ready-mix) | 60 + 5 | PoE (30-35 DAS) |
| Clodinafop-propargyl+ carfentrazone-ethyl (ready-mix) | 60+20 | PoE (30-35 DAS) |
| Sulfosulfuron + metsulfuron (ready-mix) | 25 + 2 | 25–30 DAS |
| Mesosulfuron + idosulfuron (ready-mix) | 12 + 24 | 20–25 DAS |
| Isoproturon + metsulfuron (ready-mix) | 1000 + 4 | 20–25 DAS |
| 2,4-D | 500–750 | 20–25 DAS |
| *Maize* | | |
| Atrazine | 1000-1500 | PE (1-2 DAS) or early PoE (15-20 DAS) |
| Pendimethalin | 1000-1500 | PE (1-2 DAS) |
| Metolachlor | 1000-1500 | PE (1-2 DAS) |
| Atrazine + pendimethalin (tank-mix) | 750+750 | PE (1-2 DAS) |
| Atrazine + metolachlor (tank-mix) | 1000+1000 | PE (1-2 DAS) |
| Atrazine *fb* tembotrione | 1000 &100 (resp.) | PE (1-2 DAS) + PoE (20-25 DAS) |
| Atrazine *fb* topramezone | 1000 &70 (resp.) | PE (1-2 DAS) + PoE (20-25 DAS) |
| 2,4-D | 750 | PoE (30-35 DAS) |
| Bentazon | 1000-2000 | PoE (15-20 DAS) |
| *Soybean* | | |
| Pendimethalin | 1000 | PE (1-2 DAS) |
| Metribuzin | 300-400 | PE (1-2 DAS) |
| Imazethapyr | 100 | 20–25 DAS |
| Pendimethalin+ imazethapyr (tank-mix) | 750+100 | PE (1-2 DAS) |
| Pendimethalin *fb* imazethapyr | 750 & 100 (resp.) | Pendi as PE (1-2 DAS) *fb* imazethapyr PoE (20-25 DAS) |
| Pendimethalin *fb* quizalofop-ethyl | 750 & 50 (resp.) | Pendi as PE (1-2 DAS) *fb* quizalo PoE (20-25 DAS) |
| Chlorimuron-ethyl | 9-12 | 15–20 DAS |
| Fenoxaprop | 80–100 | 20–25 DAS |
| Fenoxaprop + chlorimuron | 80 + 9 | 20–25 DAS |
| *Pigeonpea / mungbean* | | |
| Pendimethalin | 1000-1500 | PE (1-2 DAS) |
| Pendimethalin *fb* imazethapyr | 750 & 100 (resp.) | Pendi as PE (1-2 DAS) *fb* imazethapyr PoE (25-30 DAS) |
| Pendimethalin *fb* quizalofop-ethyl | 750 & 50 (resp.) | Pendi as PE (1-2 DAS) *fb* quizalofop PoE (25-30 DAS) |
| *Groundnut / Sunflower* | | |
| Pendimethalin | 1000 | PE (1-2 DAS) |
| Imazethapyr (groundnut) | 100 | PoE (20-25 DAS) |
| Oxadiazon (for sunflower) | 500-1000 | PE (1-2 DAS) |
| *Sugarcane* | | |
| Atrazine | 2000 | PE (1-2 DAT) |
| Metribuzin | 1000-1500 | PE (1-2 DAT) |
| Halosulfuron-ethyl | 90 | PoE (25-30 DAS) |
| 2,4-D | 1000 | PoE (35-40 DAT) |
| *Chickpea/ lentil / pea* | | |
| Pendimethalin | 1000-1500 | PE (1-2 DAS) |
| Pendimethalin *fb* quizalofop-ethyl | 750 & 50 (resp.) | Pendimethalin as PE (1-2 DAS) *fb* quizalofop PoE (20-25 DAS) |
| *Cotton* | | |
| Pendimethalin | 1000-1500 | PE (1-2 DAS) |
| Pendimethalin *fb* quizalofop-ethyl | 750 & 50 (resp.) | Pendimethalin as PE (1-2 DAS) *fb* quizalofop PoE (25-30 DAS) |
| Pendimethalin *fb* pyrithiobac-Na | 750 and 62 (resp.) | Pendimethalin as pre-em (1-2 DAS) *fb* pyrithiobac-Na PoE (25-30 DAS) |
| *Rapeseed and mustard* | | |
| Pendimethalin | 1000 | PE (1-2 DAS) |
| Isoproturon | 750-1000 | PE (1-2 DAS) |
| Oxadiazon | 500 | PE (1-2 DAS) |
| Oxyfluorfen | 200-250 | PE (1-2 DAS) |

Non-selective herbicides like paraquat and glyphosate should be applied prior to sowing to kill existing weeds; PE: Pre-emergence; PoE: Post-emergence; DAS = days after seeding seedbed, uniform and dense crop establishment, cover crops, crop residues as mulch, crop rotations, and practices for enhanced crop competitiveness with a combination of pre- and post-emergence herbicides are integrated to develop sustainable and effective weed management strategies under CA systems. Therefore, a combination of different weed management strategies is needed to widen the weed control spectrum and efficacy for sustainable crop production.

## Tips for efficient weed management under CA

CA works well when all the required principles along with best management practices are followed. In fact, it is a controversial subject for some researchers and other stakeholders who discount it as not being relevant in Indian conditions, primarily because of weed infestation. The following tips will ensure effective weed control and lead to the success of CA.

### Dos

- Season-long weed control is needed, not just during the critical period of crop–weed competition.
- Kill all the existing weeds before sowing with blanket spray of a non-selective herbicide.
- Ensure perfect levelling of the field for uniform sowing and irrigation.
- Ensure good initial crop stand and vigour, which in fact is the best weed management practice.
- Maintain optimum soil moisture at sowing – sow under residual moisture and apply light irrigation if needed.
- Uniform and adequate amounts of crop residues and other biomass as mulch to prevent light penetration.
- Placement of seed at the desired soil depth, and fertilizer close to the seed to make it less available to the weeds.
- Spray need-based herbicide as per the specific weed flora present in the field.
- Focus on minimization of the weed seed bank – prevent weed plants from flowering and setting weeds.
- Follow sporadic manual weeding for the control of left-over weeds after the main growth period of crop.
- Top dressing of N fertilizer should be made after weed control in cereal and other crops.
- Start CA with winter-season crops, when weed infestations are less and are also easy to control. After gaining experience, opt for summer- and rainy-season crops.
- Follow a cropping system approach, and include a cover crop, preferably a legume in the system.
- Follow CA in all crops in the sequence and dynamic rotations for maximum benefits.

### Don'ts

- Do not follow ZT without mulch of crop residues or any other biomass.
- Do not broadcast basally applied fertilizer on the soil surface as it may benefit weeds.
- Do not use a conventional seed drill for sowing as it opens wide furrows and exposes the weed seeds.
- Do not keep land fallow or uncovered at any time of the year as weeds will proliferate.
- Do not allow the perennial weeds to establish – keep a check and nip them in the bud.
- Do not use the same herbicide repeatedly.
- Do not break the CA cycle as benefits multiply and weed infestations decrease over successive cropping cycles.

## Research needs

There is lack of research on weed management under CA. Studies on weed, disease and pest scenarios under a long-term CA system are of paramount importance. Microbial research towards weed seedbank exhaustion, C, N and other nutrients dynamics, and rhizosphere environment under CA also need to be strengthened. Crop residue allelopathy and weed management may be studied more through residue characterization and quantification on long-term basis. Allelopathic crop cultivars to weeds could be a strategy to avoid development of herbicide resistance in the CA systems. Biotechnological tools may help to unveil allelopathic traits of plants, and a breeding programme to transfer allelopathic genes into modern cultivars to enhance their allelopathic activity for weed suppression may help to reduce over-reliance on herbicides in CA systems. Herbicides cannot be eliminated from CA systems, and therefore, herbicide residue, persistence and degradation pathways are to be studied periodically, particularly where same herbicides are being used over a long period.

## Conclusions

Conservation Agriculture (CA) is a fastest growing technology adopted globally on more than 200 million ha in 102 countries. The CA leads to changes in weed species composition and dynamics over time. There happens a shift towards perennial weeds, and weed diversity gets gradually narrowed down to a few weeds or single weed dominance over time. Continuous residue cover, minimal soil disturbance, and cropping system under CA are mainly responsible for the changes in weed flora. There is an urgent need of selective post-emergence herbicides for efficient crop diversification. Long-term effects of a given herbicide, impact on soil biota, pollution of water bodies, persistence in the soil, resistance by certain weeds to a specific herbicide are of concern and continuous research. A dynamic integrated weed management (IWM) programme is essential involving tillage, residue, cover crops, intercrops and herbicides in CA system.

## FURTHER READING

Rodenburg J, Büchi L and Haggar J. 2021. Adoption by adaptation: moving from Conservation Agriculture to conservation practices. *International Journal of Agricultural Sustainability* **19**(5-6): 437-455.

Sims B, Corsi S, Gbehounou G, Kienzle J, Taguchi M and Friedrich T. 2018. Sustainable weed management for conservation agriculture: Options for small-holder farmers. *Agriculture* **8**: 0; doi:10.3390/agriculture 8080000.

Somasundaram J, Sinha NK, Dalal, RC, Lal R, Mohanty M, Naorem AK, Hati KM, Chaudhary RS, Biswas AK, Patra AK and Chaudhari SK. 2020. No-Till Farming and Conservation Agriculture in South Asia – Issues, Challenges, Prospects and Benefits. *Critical Reviews in Plant Sciences*. **39**(3): 236-279.

# Weed management in seed spices

**V.J. Patel*, D.D. Chaudhari, H.K. Patel and B.D. Patel**
*AICRPWM, B.A. College of Agriculture, Anand Agricultural University, Anand, Gujarat 388110, India*
**Email: avjpatel28@aau.in*

In India, the part of arid and semi-arid region is well known as seed spices bowl particularly Rajasthan and Gujarat which contribute more than 80% of total seed spices production. The number of spices and culinary herbs is very large - although only 109 spices are notified in the International Organisation for Standardisation (ISO) list. Of these, 63 spices are grown in India and out of which 20 are being classified as seed spices. Among seed spices, cumin (*Cuminum cyminum* L.) followed by coriander (*Coriandrum sativum* L.), fennel (*Foeniculum vulgare* Mill.), fenugreek (*Trigonella foenum-graecum* L.), ajwain (*Trachyspermum ammi* (L.) Sprague ex Turrill) and dill seed (*Anethum graveolens* L.) are grown in large area in India. On the contrary, fennel was listed in the Randall's 'Global Compendium of Weeds' as an "agricultural weed, casual alien, cultivation escape, environmental weed, garden thug, naturalised, noxious weed, and is known to be invasive (mostly in natural habitats rather than agricultural land) in California, New Zealand, significant parts of Australia and in a number of locations in the Pacific.

Seed spices play an important role in development of national economy mainly due to its huge domestic consumption besides growing demand for export. During 2020-21, despite the COVID-19 pandemic and the consequent recession in the global economy, spices export from India crossed the milestone of US $3.6 billion mark for the first time in the history of spices export. The estimated export during 2020-21 has been 15,65,000 tonnes valued ₹ 27,193.20 crores (US $3624.76 million) against 12,08,400 tonnes valued ₹ 22,062.80 crores (US $3110.20 million) achieved during the previous financial year. The spices export during 2020-21 attained an all-time record in terms of both volume and value. Compared to 2019-20, the export has shown an increase of 30% in quantity and 23% in value hence, there has been ever increasing demand of seed spices and importing countries look at India for quality produce of seed spices. Among various constrains faced by the spices for their yield potentiality and quality, weeds interfere with the main crops to utilize space, nutrient and soil moisture which eventually withholds the plant growth, reduces yield and quality of seed spices. Slow germination and initial moderate growth habit of seed spices leads to a critical competition of crop and weed which in turn reduces growth and production up-to 91.40%.

## Critical period of crop-weed competition and yield losses

The critical period of crop-weed competition is the period from the time of sowing up to, which the crop is to be maintained in a weed free environment to get the highest economical yield. The critical period of crop-weed competition was observed between 15 to 60 DAS in cumin. Investigations have revealed a loss of 80-90% in the seed yield of cumin due to weed infestation depending upon the intensity and type of weed flora. Weed-free environment throughout crop season produced the maximum oil and protein content and was significantly higher compared to weedy check at Rajasthan. If weeds are not controlled in weedy check, reduced the seed yield of fennel to the tune of 50%. Delayed germination and initial slow growth rate of ajwain (*T. ammi*) increases weed problem during early stage of growth, resulting in yield reduction to the tune of 70-78%. Uncontrolled weeds reduced coriander seed yield by 82%. Fenugreek also faces severe competition from weeds causing yield reductions from 14.2 to 69.0% depending upon density and duration of competition.

## Weed flora

Weed flora in the seed spices vary depending upon the season, agro-climatic situation and soil type. The dominant weed flora observed in seed spices across the country are as under (**Table 1**).

## Methods of weed management

### Preventive measures

It is necessary to avoid the invasion of new species through the use of clean planting material and to prevent seed dispersal on the irrigation water, implements and machines. Another aspect is to impede perennial weed dispersal (or parasitic weeds) through the appropriate use of treatments and tillage and the use of drainage to prevent propagation of some species that need high moisture levels. It is also necessary to scout the field edges to prevent invasions. Need to prevent the grazing of animals in the fallow field to reduce spread of obnoxious weeds.

### Crop rotation

Crop rotation is a key method to reduce weed infestation of crop bound weeds in seed spices. Crop rotation was considered for a long time to be a basic

**Table 1. Major weed flora in seed spices in India**

| Scientific name | Common name | Family |
|---|---|---|
| **Monocot weeds** | | |
| *Asphodelus tenuifolius* Cav. | Wild onion | Asphodelaceae |
| *Indigofera glandulosa* Wendl. | Three leaf indigo | Fabaceae |
| *Echinochloa colona* L. | Barnyard grass | Poaceae |
| *Dactyloctenium aegyptium* L. | Crow foot grass | Poaceae |
| *Eleusine indica* L. | Indian goose grass | Poaceae |
| *Commelina benghalensis* L. | Benghal dayflower | Commelinaceae |
| *Eragrostis major* L. | Love grass | Poaceae |
| **Dicot weeds** | | |
| *Chenopodium album* L. | Lambs quarters | Amaranthaceae |
| *Chenopodium murale* L. | Nettle leaf goose foot | Amaranthaceae |
| *Digera arvensis* L. | False amaranth | Amaranthaceae |
| *Amaranthus viridis* L. | Spineless amaranth | Amaranthaceae |
| *Portulaca oleracea* L. | Purslane | Portulaceae |
| *Physalis minima* L. | Ground cherry | Solanaceae |
| *Euphorbia hirta* L. | Common spurge | Euphorbiaceae |
| *Plantago pumila* L. | Fleaworts | Plantaginaceae |
| *Melilotus alba* L. | White sweet clover | Fabaceae |
| *Argemone mexicana* L. | Mexican poppy | Papaveraceae |
| *Leucas aspera* L. | Thumbai | Lamiaceae |
| *Launaea asplenifolia* L. | Creeping Launaea | Asteraceae |
| *Rumex dentatus* L. | Aegean dock | Polygonaceae |
| **Parasitic weed** | | |
| *Cuscuta* spp. | Dodder | Convolvulaceae |
| *Orobanche* spp. | Broom rape | Orobanchaceae |
| **Sedges** | | |
| *Cyperus rotundus* L. | Purple nutsedge | Cyperaceae |
| *Cyperus iria* L. | Rice flat sedge | Cyperaceae |

practice for obtaining healthy crops and good yields. Introducing a fallow in the rotation is essential for the control of difficult weeds particularly perennial weed. Crop rotation positively reduce the pressure of weeds in crops. This may be due to difference in cultural practices used with different crops and also differed in life cycle or growth habits. In the field condition, rotating the crops based on the demand adds diversity to the cropping system and also increase in sustainability of the system. Crop rotation allows to rotate the other aspects of the crop production system which include type of tillage, seed rate, time of sowing, selection of herbicide, irrigation and fertilizer application.

## Chemical weed control

Management of weeds in seed spices through use of herbicide is gaining popularity due to awareness and paucity of labour in time. Morphological similar weeds are unable to control through mechanical or manual method of weed control. High-density plantings and injury during weeding leads crops susceptible to disease, which limit the use of mechanical cultivation and make hand removal expensive. Under such circumstances use of herbicide ensure the effective control of such type of weeds. Several herbicides were identified for usage to manage weeds in seed spices (**Table 2**).

Maximum plant height at all the growth stages, number of branches/plant, yield attributes like number of umbels/plant, number of umbellates/umbel, number of seeds/umbellate, seed and straw yields of fennel were recorded with pre-emergence application (PE) of oxadiargyl 75 g/ha followed by (*fb*) hand weeding (HW) at 45 days after seeding (DAS) which being at par with pendimethalin 1.0 kg/ha PE *fb* hand weeding at 45 DAS. Further, pendimethalin 1.0 kg/ha PE *fb* post-emergence application (PoE) of quizalofop-ethyl 40 g/ha caused better growth and yield of fennel. Higher plant height, number of umbels/plant and seed yield of fennel was recorded with paddy straw mulch 10 t/ha *fb* HW at 30 and 60 days after transplanting (DATP) and it was at par with paddy straw mulch 5 t/ha *fb* HW at 30 and 60 DATP and inter cultivation (IC) *fb* HW at 30 and 60 DATP *fb* earthing-up at 75 DATP.

Pre-plant incorporation (PPI) of pendimethalin 1.0 kg/ha recorded higher seed yield of cumin but was at par with hand weeding twice at 30 and 45 DAS. Weed free, pendimethalin 900 g/ha PE *fb* HW at 45 DAS and oxadiargyl 75 g/ha applied at 7 DAS *fb* HW at 45 DAS significantly enhanced growth and yield attributes, seed yield of cumin compared to unweeded check. Higher seed yield of cumin, straw yield and harvest index was observed

**Table 2. Herbicides for effective weed management in seed spices**

| Crop | Herbicide a.i./ha | Application time | Types of weeds controlled | Herbicide, commercial formulation, required / 10 litres of water |
|---|---|---|---|---|
| **Cumin** *(Cuminum cyminum)* | Pendimethalin 30% EC 750-1000 g/ha | Pre-emergence | Grassy and broad-leaved weeds | 50-67 mL |
| | Oxyfluorfen 23.5% EC 120 g/ha | Pre-emergence | | 10.2 mL |
| | Oxadiargyl 6% EC 60-75 g/ha | Pre-emergence and Early post emergence | | 20-25 mL |
| | Quizalofop-ethyl 5% EC 50 g/ha | Post emergence 15-20 DAS | Grassy weeds | 20 mL |
| **Dill seed** *(Anethum graveolens)* | Pendimethalin 30% EC 750-1000 g/ha | Pre-emergence | Grassy and broad-leaved weeds | 50-67 mL |
| | Oxyfluorfen 23.5% EC 120 g/ha | Pre-emergence | | 10.2 mL |
| | Oxadiargyl 6% EC 60-75 g/ha | Pre-emergence | | 20-25 mL |
| **Coriander** *(Coriandrum sativum)* | Pendimethalin 30% EC 750-1000 g/ha | Pre-emergence | Grassy and broad-leaved weeds | 50-67 mL |
| | Oxyfluorfen 23.5% EC 120 g/ha | Pre-emergence | | 10.2 mL |
| | Oxadiargyl 6% EC 60-75 g/ha | Pre-emergence | | 20-25 mL |
| **Fennel** *(Foeniculum vulgare)* | Pendimethalin 30% EC 750-1000 g/ha | Pre-emergence | Grassy and broad-leaved weeds | 50-67 mL |
| | Oxyfluorfen 23.5% EC 120 g/ha | Pre-emergence | | 10.2 mL |
| | Oxadiargyl 6% EC 60-75 g/ha | Pre-emergence | | 20-25 mL |
| **Ajwain** *(Trachyspermum ammi)* | Pendimethalin 30% EC 750-1000 g/ha | Pre-emergence | l Grassy and broad-leaved weeds | 50-67 mL |
| | Oxyfluorfen 23.5% EC 120 g/ha | Pre-emergence | | 10.2 mL |
| | Oxadiargyl 6% EC 60-75 g/ha | Pre-emergence | | 20-25 mL |
| **Fenugreek** *(Trigonella foenum-graecum)* | Pendimethalin 30% EC 500-750 g/ha | Pre-emergence | Grassy and broad-leaved weeds | 33-50 mL |
| | Imazethapyr 10% EC 50-70 g/ha | Post emergence 15-20 DAS | | 10-14 mL |
| | Quizalofop-ethyl 5% EC 50 g/ha | Post emergence 15-20 DAS | Control grassy weeds | 20 mL |
| | Quizalofop-ethyl 7.5% +Imazethapyr 15% w/w EC (PM) 32.81+66.625 g/ha | Post emergence 15-20 DAS | Grassy, broad leaved weeds and sedges | 8.8 mL |
| | Propaquizafop 2.5%+Imazethapyr 3.75% w/w ME (PM) 93.75-125 g/ha | Post emergence 15-20 DAS | | 30-40 mL |

with oxadiargyl 60 g/ha PE *fb* hand weeding twice at 40 and 60 DAS.

Oxyfluorfen 120 g/ha PE *fb* quizalofop-p-ethyl 50 g/ha PoE at 20 DAS proved efficient in recording higher weed control efficiency (72.68%), seed (1,019 kg/ha) and haulm (1,222 kg/ha) yields of ajwain with better weed index (11.77) but was closely followed by oxyfluorfen 120 g/ha PE *fb* HW at 40 DAS which recorded a seed yield of 959 kg/ha with a weed index of 16.97.

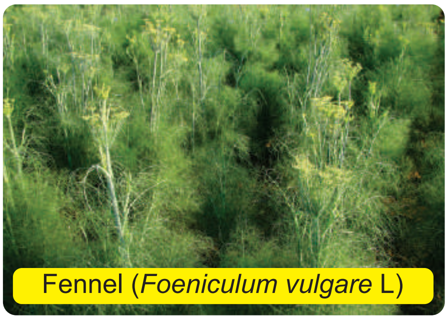
In coriander, for effective and economical weed management, adoption of either interculturing *fb* hand weeding twice at 25 and 40 DAS or pendimethalin 1.0 kg/ha PE was found beneficial. Oxadiargyl 75 g/ha PE *fb* HW at 45 DAS resulted into significantly higher vegetative growth and seed yield of coriander followed by pendimethalin 1.0 kg/ha PE *fb* HW at 45 DAS. Pendimethalin 1.0 kg/ha PE *fb* quizalofop ethyl 40 g/ha PoE at 20 DAS was found most effective in reducing weeds biomass in coriander.

Adoption of integrated approach was found to be better and was statistically similar to weed free crop condition for managing the weed intensity wherein, maximum seed yield with the highest net profit from dill seed was recorded with weed free crop condition followed by pendimethalin 1.0 kg/ha PE *fb* interculturing and hand weeding at 35 DAS in Gujarat. Higher seed yield of dill seed was recorded with oxadiargyl 75 g/ha PE *fb* HW at 40 DAS or IC *fb* HW at 20 and 40 DAS due to effective weed management in dill seed crop grown in sub-humid regions of southern Rajasthan.

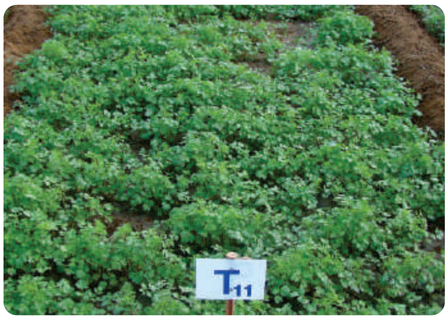

Coriander (*Coriandrum sativum* L.)


Cumin (*Cuminum cyminum* L.)


Dillseed (*Anethum graveolens* L.)


Fennel (*Foeniculum vulgare* L)


Fenugreek (*Trigonella foenum-graecum* L.)


The highest weed control efficiency was attained with hand weeding at 20 and 40 DAS and pendimethalin 0.75 kg/ha PE *fb* interculturing at 40 days after sowing in fenugreek. Pendimethalin 1.0 kg/ha PE and imazethapyr 55 g/ha at 2-4 trifoliate leaf stage was found effective for weed management and recorded higher seed yield and net return in fenugreek.

## Conclusion

Seed spices play a significant role in Indian national economy. There is wide gap between the potential and attained productivity of many seed spices. Majority of seed spices are slow growing during initial stage and weeds pose severe competition for available resources causing significant yield reduction which is much higher in seed species compared to other crops. There are several options available for control of weeds as components of integrated weed management during critical period of competition and realize optimal yield of seed spices.

## FURTHER READING

Anonymous (2021). *Annual Report*. Spices board. Ministry of Commerce & Industry, Govt. of India.

Mali AL. and Suwalka SN. 1987. Studies on weed control in fenugreek (*Trigonella foenum-graecum* L.). *Indian Journal of Agronomy* **32**(2):188-189.

Gohil BS, Mathukia RK, Dobariya VK and Chhodavadia SK. 2014. Weed management and dynamics of weed seed bank in fennel. *Indian Journal of Weed Science* **46**(4): 399-400.

Mehriya ML, Yadav RS, Jangir RP and Poonia BL. 2007. Effect of Crop-Weed Competition on Seed Yield and Quality of Cumin (*Cuminum cyminum* L.) *Indian Journal of Weed Science* **39**(1&2): 104-108.

# Management of *Striga* in sugarcane

C. Chinnusamy*[1] and P. Jones Nirmalnath[2]
[1]School of Agriculture and BioSciences, Karunya Institute of Technology and Sciences (Deemed University), Coimbatore, Tamil Nadu 641114, India
[2]AICRP on Weed Management (Volunteer Centre), University of Agricultural Sciences, Dharwad, Karnataka 580005, India
*Email: chinnusamyc@gmail.com

*Striga* is commonly called as "witch weed" because it attaches itself to the roots and robs the host of water and nutrients, commonly parasitizes on crops like sorghum, sugarcane, maize, pearl millet and rainfed rice. Witch weed establishes contact directly with the vascular system of the host plant and sucks water and nutrients from the host resulting in a crop yield loss of maximum 75%. *Striga* is mainly distributed in tropical arid and semiarid zones with 400 to 1000 mm of annual rain. Of the 40 species of *Striga* reported worldwide, only three *Striga asiatica* (*S. lutea*), *Striga gesnerioides* and *S. hermonthica* are considered notorious. In India, Barber (1901) first reported the occurrence of *Striga* in sugarcane. It is known to occur in almost all states where sugarcane is grown in India.

## Description of *Striga* spp.

A typical witch weed (*S. asiatica*) is an annual plant; 15-20 cm tall. The stem is green, square in cross-section and 1-2.5 mm in diameter. The leaves are opposite, each pair borne at right angles to the preceding one. The flowers, variously coloured according to species and of typical Scrophulariaceous form, are borne in opposite pairs or alternately in a terminal leafy inflorescence. There are at least two morphotypes of *S. asiatica* occurring in Asia. White flowered *S. asiatica* is reported from India, Pakistan and yellow flowered is reported from Thailand and Indonesia. However, it was reported that yellow flowered types of *S. asiatica* occur in the main tract of Karnataka, India. The underground part of the stem is purple, cylindrical, and somewhat thicker than the aerial part and 2.5-7.5 cm long. The roots are white and closely attached to the host roots by haustoria. *S. hermonthica* is strikingly a larger plant (up to 60 cm), with large showy flowers. *S. gesnerioides*, a full parasite, is purplish or brownish in colour, branched, with leaves reduced to scales and the root swollen to a tuber.

*Striga* reproduce by seeds. The seeds are very small and difficult to detect from seed lots. Microscopic examination is needed to identify them. Seeds elliptic, ovate, oblong, occasionally D-shaped, triangular, rhombic, or irregular; often twisted or angled from crowding or position in capsule; tiny, dust like, 0.2-0.6 mm long, 0.1-0.3 wide and thick. They are orange to golden-brown or light to dark brown or gray to blackish in surface color; sometimes sparkling with colored light at high magnification. Due to their minute size, they are easily dispersed by wind, water, animals, *etc.* Under agricultural conditions, the seeds (and fruit capsules containing them) can contaminate the harvested product, or be moved in soil by machinery or implements.

Germination in the field starts about 10 days after the beginning of the rainy season when the host plant has already established. *Striga* seeds will germinate in 1 to 2 days after exposure to the host root exudate. The germ tube elongates in the absence of a host root until the food reserves of the seed are depleted. The young plants are entirely parasitic on the host until they emerge. After living underground as a complete parasite for 3 to 4 weeks, *Striga* seedlings emerges through the soil as a green plant and depend on its host only for water and mineral nutrients and grow as a semi parasite. After emerging above the soil surface the parasite starts to flower and produce seeds after another short period of time. Flowering occurs within 6 weeks of emergence and is day neutral. Some *Striga* spp. are primarily self-pollinating, for instance, *S. asiatica*, while others are primarily outcrossers like *S. hermonthica*. *Striga* fruits (capsules) contain mature seeds in as early as 2 weeks after pollination. Seed production is prodigious; up to 100, 000 or even more seeds can be produced by a single plant and lead to a re-infestation of the field.

## Effect of *Striga* sp. on crops

The greatest damage is done in the first month of vegetative growth, when the fully parasitic young *Striga* may not have emerged yet. The host plant wilts, its growth is stunted and it may shrivel and die. It was observed that symptoms on host plants occur early in the development and are characterized by stunted growth and yellowing of foliage (**Figure 1**). In case of sever infestation substantial yield reductions occur and that severely affected clones characteristically exhibited leaf burn, wilting, stunted growth and small pointed leaves, which contributed to poor, canopy formation and tiller mortality.

**Competition for water, nutrients and minerals:** Host parasitized by *S. asiatica* lost less water than non-parasitised host, indicating reduced water supply to hosts. Partial plugging of the host xylem cells may interfere with water transport to the host shoot. *Striga* plants transpire much more water than is normal for other plants, even under moisture stress, thus maximizing the flow of water and nutrients from the host. *Striga* infested crops showed wilting symptoms even though the soil contained enough moisture and removal of water from host is probable since *Striga* has essentially no root hairs. The competitive success of *Striga* is usually described to it having a greater osmotic pressure than its host and a low stomatal resistance, which results in high transpiration rates.

About 35% of the carbon for *Striga* plant growth comes from the host photosynthates. Analyses of emerged *Striga* shoots show that the presence of large amounts of potassium and magnesium. The amounts of iron, manganese and calcium are similar to those of its host while its nitrogen content is somewhat higher. Zinc content of *Striga* was found to be appreciably lower than that of sorghum, whereas the potassium / calcium ratio of *Striga* was higher than that of its host.

**Yield reduction:** Cane yield reduction of up to 36 per cent has been reported due to *Striga* spp. causing damage in both main and ratoon crops but the damage to ratoon crop was reportedly high.

### Management of *Striga* sp. in sugarcane

### 1. Preventive approach

One of the most important control methods is to prevent the distribution of parasite seeds from one field to another and from infested to *Striga* free areas. Farmers should use clean planting material and clean land preparation implements. Uprooting and burning *Striga* before flowering is needed to avoid its further distribution. Grazing in *Striga* infested fields should not be allowed.

### 2. Non-chemical management

**Deep ploghing:** Deep ploughing can reduce the infestation, if the topsoil layer is properly turned to the bottom. Where equipment is available and soil permits, this technique can form a useful part of an integrated control management. Seedling of *Striga* that are just germinated will be killed, when buried in the soil.

**Soil Solarization:** Solarization is a method of heating the moist soil using clear polyethylene sheet and natural sunlight. During hot weather, moist soil is covered by transparent PE sheets to increase soil temperature. The mode of action on seed during solarization is a combined effect of increased temperature, high moisture and modified gas composition in soil and microroganisms attacking the parasite seeds. The soil solarization was proven effective in reducing several soil borne pests including *Striga*.

**Crop rotation:** Severe infestation by *Striga* builds-up only where crop rotation is such that susceptible crops come frequently at short intervals. Therefore, rotation with non-host crops especially with trap crops is of great advantage. Rotation with cotton was reported to be effective in reducing *Striga* infestation and cotton might reduce the amount of *Striga* four times as many as *Striga* plants being recorded from sugarcane after sugarcane than sugarcane after cotton. Rotation with crops such as cotton, sunflower, groundnut and some other legumes not only reduced the *Striga* seed reservoir in the soil but also increase yields sugarcane because of beneficial rotation effects.

**Trap cropping:** Cotton, groundnut, pigeonpea, sunflower, castor bean, sunhemp, linseed soybean, and cowpea are considered to be the trap crops for striga. According to Parker (1965) use of "false hosts" in reducing *Striga* seed reserves in soil was termed as trap cropping. Trap crops are plants which stimulate the germination of parasitic weed seeds and get not infested by them. False host controls the *Striga* by causing it to germinate but do not support its growth (suicidal germination). In this way trap crops reduce the seed bank in the soil and cause a decrease in infestation. Cotton, sunhemp, pigeon pea, greengram or blackgram, lucerne, sunflower and sesamum are some of the trap crops which produce chemical stimulant necessary for *Striga* seed germination but not parasitised by the *Striga* and can be used in rotation with catch crops like sorghum, maize and millets in reducing *Striga* infestation.

**Mulching:** Enhanced yields and reduced *Striga* infestation were observed due to trash mulching. Pre-emergence application of metribuzin or atrazine both at 1.0 kg/ha followed by trash mulching at 3-5 t/ha in between the rows in sugarcane at 60 DAP provided

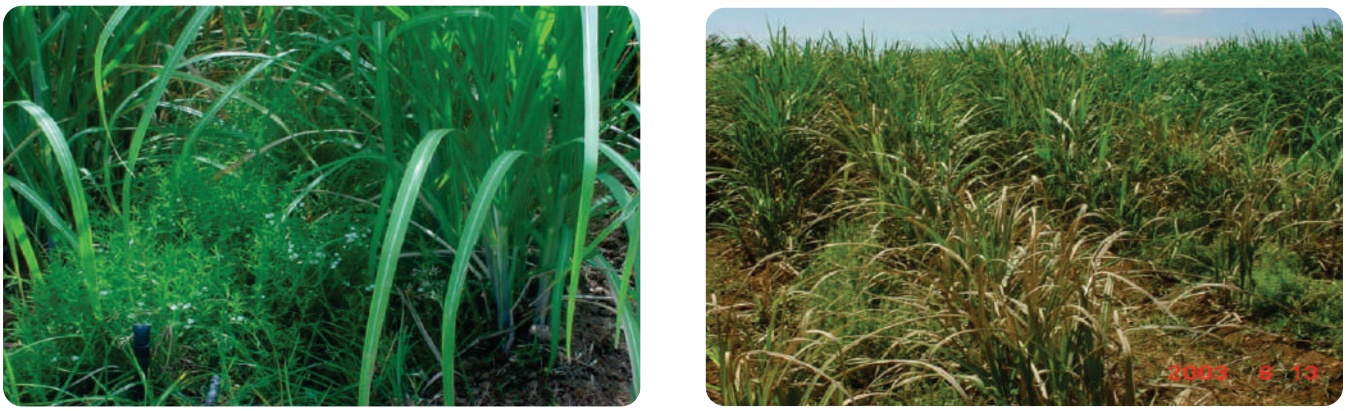


**Figure 1. Intensity and impact of *Striga asiatica* infestation in sugarcane fields**

effective control of *Striga* with higher cane yield compared to pre- and post-emergence herbicide applications.

**Hand weeding / hand pulling:** Weeding of parasitic weeds is one option open to all farmers. Weeding is time-consuming, but in combination with other methods it can reduce the seed bank very efficiently and therefore weeding is economical only on a longer-term basis. Hand pulling is valuable where *Striga* plants in the crop field are few, and it is useless exercise in a heavily infested field. *Striga* could continue to survive, mature and set seed for several weeks after the death of the host shoot. It was recommended that once the crop is harvested, pulling the crop stubble would prevent the further growth of *Striga*.

### 3. Chemical approach

Various herbicides applied either at pre-emergence or post-emergence have been tried to control *Striga* sp.

**Pre-emergence application (PE):** Fenac (2, 3, 6-tri chlorophenyl acetic acid) developed in USA was said to be the most effective herbicide available to control *Striga asiatica* in sugarcane. A group of herbicides 'dinitroanilines' which had been found effective in the control of *Striga* before it emerges above ground. Diphenyl ethers were effective group of pre-emergent herbicides against *Striga*. The most effective member of this family of compounds to control *Striga* is oxyfluorfen

**Post-emergence application (PoE):** 2,4-D at 1.0 to 2.0 kg /ha at flowering to just before seed set was found effective in controlling *Striga* in Africa, USA and India. Application of paraquat at 1.25 liters/ha, with wetting agent, gave excellent control of *Striga* and other weeds including grasses (**Figure 2**). Application of 2, 4-D or paraquat at 90 days after sowing was equally effective in controlling this weed. Bromoxynil, ioxynil, bentazone and pyridate are potent inhibitors of photosynthesis in *S. hermonthica*, while they do not affect the hosts. Linuron also used, but it may affect these crops according to the rate applied. All these herbicides were used to prevent *Striga* seed production. Spraying of imazapyr at 15 g/ha gave 70 to 90 per cent suppression of *Striga* capsule formation, whereas no capsules appeared at 30 g/ha.

**Ethylene in Striga control:** Suicidal seed germination by the exogenous application of ethylene has contributed to the control of *Striga* sp. in infested areas of the USA. Even in the presence of a host, the probability of *Striga* making a successful attachment after ethylene stimulation was rare. Thus, the ethylene-induced germination of *Striga* seeds is suicidal; Research indicated that a single ethylene treatment could rid the soil of up to 90% of the viable pre-conditioned *Striga* seeds. Ethylene gas is extensively used in the USA, but the technique has not yet been developed for use elsewhere.

### 4. Biological control

Biological control of *Striga*, especially by means of mycorrhizal fungi has gained considerable attention in recent years and appears to be a promising biotic tool in enhancing the crop yield benefit under *Striga* stressed soil conditions.

When plants are subjected to a shortage in the available phosphate, the production and release of strigolactones into the rhizosphere is increased. AM fungi

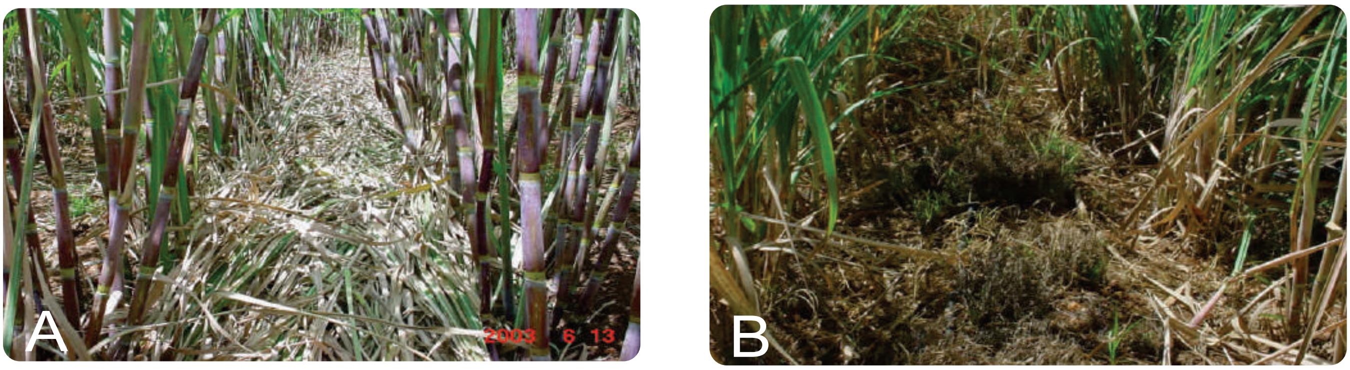



**Figure 2. Management of *Striga asiatica*. A. Suppression by trash mulching; B. Quick knock down by paraquat**

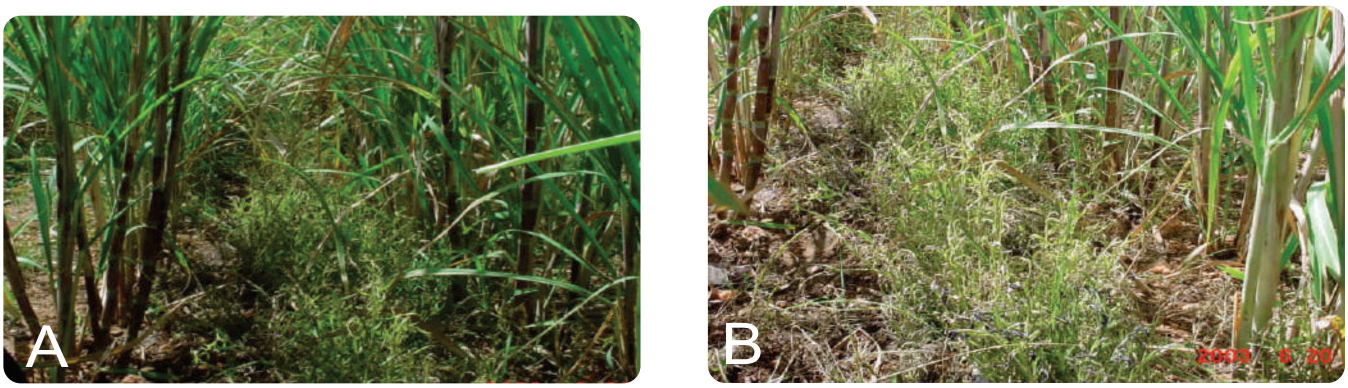



**Figure 3. Efficacy of 2,4-D in managing *Striga asiatica*. A. 2,4-D Na salt; B. 2,4-D Na salt + urea**

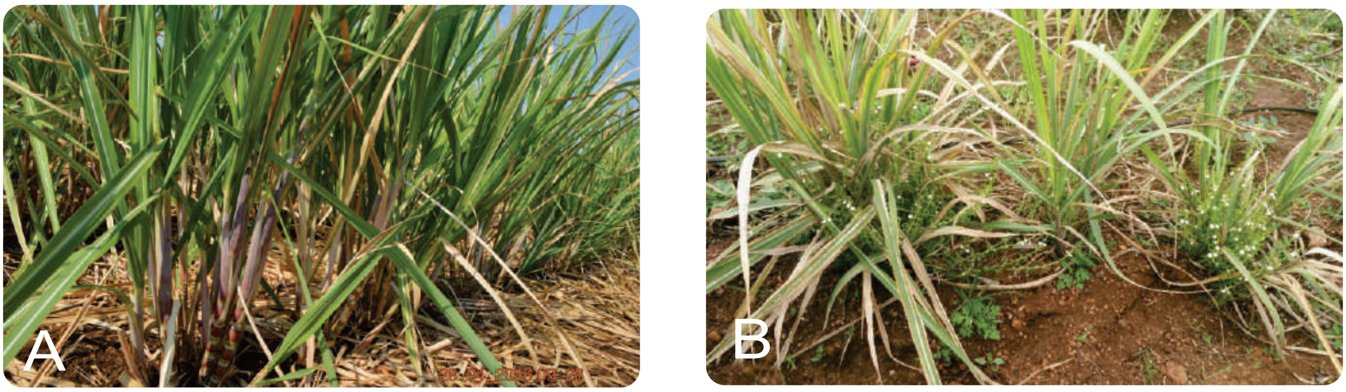



**Figure 4. UASD Mycorrhizal consortium application impact on *Striga asiatica.* A. UASD mycorrhiza consortium applied; B. Non Mycorrhized (UIC)**

perceive this signal and respond with extensive hyphal branching. This process increases the chance of encountering the roots of the host plant and hence assists in establishing the symbiosis. The parasitic *Striga* has likely evolved a mechanism to hijack this communication signal and turn it into a germination inducing signal to respond in the presence of a suitable host. Recent studies have shown that AM fungal colonization is likely to induce resistance to plant parasitism by converting strigolactones into mycoradicin, which is accumulated in mycorrhized roots and thereby reduces availability of strigolactones for *Striga* to germinate (Walter *et al.* 2010).

The field validation has indicated that the mycorrhizal consortium of native arbuscular mycorrhizal fungi spp. developed at University of Agricultural Sciences, Dharwad (UASD) was effective in suppression *Striga* emergence and facilitated the sugarcane plants to grow vigorously under stressful conditions by leading to enhanced growth promotion, photosynthetic rate, stomatal conductance and transpiration rate, which ultimately resulted in sugarcane stem girth, root biomass, total dry matter and cane yield in the mycorrhized plants (Shubha *et al.* 2018; Manjunath *et al.* 2018). Mycorrhizal fungi offer multifaceted advantages as biocontrol agents, they are non-pathogenic to any crop plant, and they provide important additional benefits such as improved water and mineral nutrition uptake. Hence, their use as biocontrol agents offers an attractive complementary approach in the management *Striga* – a parasitic weed.

## Conclusion

Despite the vast number of possible control options, only a few have been adopted by farmers for *Striga* control. For effective management of *Striga* in sugarcane, integrated management with atrazine at 1.00 kg/ha PE followed by earthing up on 65 to 70 days after planting, 2,4-D Na salt PoE at 1.25 kg/ha + urea 20 gm per liter of water at 90 days after planting and sugarcane trash mulching at 5.00 tons/ha on 120 days after planting, is recommended (**Figure 3**). Soil application of UASD mycorrhizal consortium (20 kg) along with 500 kg of compost / ha at the time of planting in the furrows, resulted in suppression of *Striga* emergence (**Figure 4**) to a tune 38.00%, while increased the sugarcane yield up to 13.50% with a BC ratio of 2.51.

## FURTHER READING

Dor E and Goldwasser Y. (Eds.). 2022. Parasitic weeds: Biology and control. Printed Edition of the Special Issue Published in *Plants*. MDPI, Basel. (Available at: https://www.mdpi.com/journal/plants/special issues/parasitic weeds)

Naidu VSGR and Mishra JS 2014. *Parasitic Weeds: Biology and Management*. Today and Tomorrow's Printers and Publishers, New Delhi, India

Parker C and Riches CR. 1993. *Parasitic Weeds of the World: Biology and Control*. CAB International Wallingford UK. 332 pp.

Shubha C, Nirmalnath J P, Sagarkar M A, Babu R, Jagadeesh KS. 2018. Isolation, screening and selection of efficient native arbuscular mycorrhizal fungi for suppression of *Striga,* a parasitic weed in sugarcane. *Indian Journal of Weed Science* **50**(1): 51-55.

Manjunath HP, Jones Nirmalnath P, Chandranath HT, Shiney Ammanna and Jagadeesh KS. 2018. Field evaluation of native arbuscular mycorrhizal fungi in the management of *Striga* in sugarcane. *Journal of Pharmacognosy and Phytochemistry* **7**(2): 2496–2525.

TNAU AICRP WM. 2012. Compendium on "*25 Years of Research on Weed Science in Tamil Nadu*". TNAU Press Coimbatore.

Walter MH, Floss DS and Strack D. 2010. Apocarotenoids: hormones, mycorrhizal metabolites and aroma volatiles. *Planta* **232**(1): 1–17.

# Chemical weed management in different crops

V.K. Choudhary*, M.P. Sahu and J.S. Mishra
*ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482004, India*
**Email: ind_vc@rediffmail.com*

Weeds compete with crops for various natural resources, yet, weeds are relatively underestimated crop pests. Out of the total loss of biotic stresses in India, weeds share is highest at 37% followed by insects at 29% and disease at 22%, and other pests at 12% (**Figure 1**). Globally, weeds are major yield reducers (34%) followed by animals (18%) and pathogens (16%). A study conducted at ICAR-DWR, Jabalpur estimated that in ten major field crops, the yield loss due to weeds are 11 billion US $. Losses caused by weeds will be far more higher, if other crops and cropping systems and indirect effect are also considered. Weed competes with crops for nutrients (N, $P_2O_5$ and $K_2O$), which became a costly input to farming community. Weeds also deplete the available soil moisture from the soil profile with significant competition. It has been stated that 'weeds eat the food of about 1 billion inhabitants.

## Chemical weed management

Currently, herbicides are being used extensively for weed management. In the crop protection market, globally, herbicide consumption contributes 53% followed by fungicides (23%), insecticides (17%) and others (7%), but in India, the share of herbicides is much lower by 17% than the insecticides (44%) and fungicides (37%) consumption of the total pesticides. India stands fourth in manufacturing pesticides in the world. The consumption of pesticides in India is much lower (<500 g/ha) than that of Japan (10-12 kg/ha) and the consumption of herbicides is still lower by 40 g/ha over 675-1350 g/ha consumed in developed countries. The use of herbicides is however increasing in the last decade in India at a much faster rate of 15-20%, but the overall herbicide consumption in terms of volume may not increase due to introduction of low-dose high-potency herbicides. Presently, rice and wheat are major crops followed by plantation crops in terms of herbicide consumption in India.

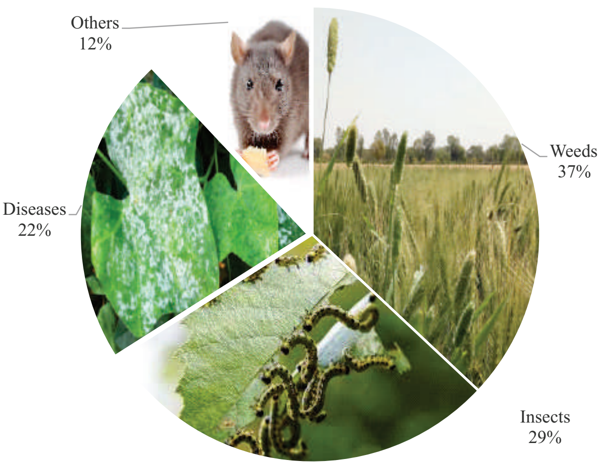



**Figure 1. Yield loss (%) due to biotic stressors**

Herbicides have advantages in managing weeds as they are easy to apply, can be used in close space crops, provide broad-spectrum weed control, and one-time application provides a long-time weed-free environment. Herbicides work fast and are relatively cheaper than manual weeding.

## Advantages

- Herbicide can be recommended for adverse soil and climatic conditions, as manual weeding is highly impossible during monsoon season.
- Herbicides can control weeds even before they emerge from the soil so that crops can germinate and grow in a completely weed-free environment at early stages. It is usually not possible with physical weed control.
- Weeds, which resemble a crop in the vegetative phase, may escape in manual weeding. However, these weeds are controlled by herbicides.
- Herbicide is highly suitable for broadcasted and closely spaced crops.
- Controls the weeds without any injury to the root system of the associated standing crop, especially in plantation crops like Tea and Coffee.
- Reduces the need for pre-planting tillage
- Controls many perennial weed species
- Herbicides control the weed in the field itself or in-situ controlling whereas mechanical methods may lead to the dispersal of weed species through seed
- It is profitable where labour is scarce and expensive
- Suited for minimum tillage adoption
- Highly economical

## Limitations

- Pollutes the environment
- Affects the soil microbes if the dose exceeds
- Herbicide causes drift effect to the adjoining field
- It requires a certain amount of minimum technical knowledge for calibration
- Leaves residual effects

- Some herbicide is highly costlier
- Suitable herbicides are not available for mixed and inter-cropping systems.

## Weed control methods in different crops

Herbicides were researched and recommended for the common usage to manage weeds in *Kharif* (rainy) crops (**Table 1**), *Rabi* (winter) crops (**Table 2**), millets (**Table 3**) and vegetable crops (**Table 4**).

## Instructions for safe handling and use of herbicide

- Adopt good practices during the use of herbicides
- Periodically monitoring of field to know the major and important weed flora present.
- Herbicide should be applied at recommended crop and weed growth stage
- Procurement of herbicide from the right source.
- Selection of suitable herbicide, dosage, spray volume etc.
- Follow the instruction given on the product label.
- Avoid spraying during high wind speed, temperature, and rain.
- Wear all safety precautions/protection items before spraying herbicide.
- Apply herbicide at right time, correct dose, and calibrated spraying tools (sprayer and nozzle).
- Need-based application of herbicide on bands or patches to reduce the cost and be environmentally safe.
- Avoid spills, drift, and respect the edges, waterways, and sensitive areas.
- Wash empty containers or cans at least thrice and do not use them for storing food items.
- Don't rely on a single herbicide for long time, based on availability rotate them.

## Herbicide resistance in weeds

Herbicide-led weed management is becoming increasingly popular among crop growers mainly due to faster action, high potency, selectivity, lower cost and higher efficacy. Still, over-reliance and indiscriminate use of herbicides are related to the evolution of herbicide-resistant weeds. In the last two decades, herbicide resistance (an inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide that would normally be lethal to the wild plant) cases in weeds are gradually increasing. Resistance occurs with the repeated application of the same herbicide or herbicides with similar modes of action on a weed population.

Currently, there are 515 unique cases (species × site of action) of herbicide-resistant weeds globally, with 267 species (154 dicots and 113 monocots). Weeds have evolved resistance to 21 of 31 known herbicide sites of action and to 165 different herbicides http://www.weedscience.org/ accessed on 31 October 2022). Herbicide-resistant weeds have been reported in 97 crops in 72 countries. In India, *Phalaris minor* Retz. has developed multiple-herbicide resistance to PSII, ACCase and ALS inhibitors. Likewise, *Rumex dentatus* L. has evolved resistance against metsulfuron (ALS inhibitor) and cross-resistance to mesosulfuron + iodosulfuron, pyroxsulam, halauxifen + florasulam, while *Polypogon monspeliensis* (L.) Desf. has developed resistance against sulfosulfuron, mesosulfuron and pyroxasulam. In soybean, *Echinochloa colona* (L.) Link and *Commelina communis* L. became resistant to imazethapyr (an ALS inhibitor). In the same way, *Echinochloa crus-galli* and *Cyperus difformis* became resistant to bispyribac-sodium (an ALS inhibitor) in rice. In India, weed management will be more herbicide-driven in the coming years, and the occurrence of herbicide-resistant weeds in the farmer's field makes weed management more difficult. Hence, understanding herbicide-resistance development and accordingly development of best management practices to minimize herbicide-resistance development is of foremost importance.

## Herbicide-tolerant crops

Herbicide-tolerant crops have been developed to tolerate specific broad-spectrum herbicides, which kill the weeds without harming the cultivated crop. The herbicide-tolerant crops occupied (87.5 million ha or 45% of the 191.7 million ha of total biotech crops planted worldwide in 2018). The most common herbicide-tolerant crops are the glyphosate and glufosinate-tolerant varieties of soybean, corn, cotton (*Gossypium hirsutum* L.) and canola (*Brassica napus* subsp. *Napus*). Although several herbicide-tolerant crop varieties both transgenic (glyphosate resistance) and non-transgenic [(mutation breeding) imidazolinone resistance] have been developed and released in many countries in the past few years for commercial cultivation, this technology is in its initial stage of field evaluation in India. Certain pesticide and seed industries have developed non-genetic modified traits for herbicide tolerance and it is incorporated in several different crop species including canola, sunflower and rice which is 'Clearfield' technology. It requires the use of a non-ionic surfactant (NIS at 0.25% v/v) with at least 80% active load with an imidazolinone group of herbicides along with nitrogenous fertilizer. Similarly, 'Provisia' rice production system is comprised of Provisia seed containing the Provisia trait, which allows growers to safely apply Provisia herbicide. The broad-spectrum control of Provisia herbicide works hard to protect crop from weeds like red rice, barnyardgrass, volunteer rice and many more problematic weeds. The rotational use of Provisia rice followed by Clearfield rice followed by soybeans gives the flexibility to grow more rice over multiple seasons while rotating different herbicide modes of action (ALS inhibitors, ACCase inhibitors) for sustainable management of all resistant rice types and annual grasses. Given severe weed problems in direct-seeded rice, an EMS-induced rice mutant, HTM-22', exhibited tolerance to a broad-spectrum herbicide 'imazethapyr', and identified the mutations imparting tolerance to the herbicide. At the ICAR-Indian Agricultural Research Institute, New Delhi, successfully

**Table 1. List of recommended herbicides for weed control in *Kharif* (rainy) crops (pre-emergence: 0-3 DAS; post-emergence: 18-22 DAS)**

| Crops | Recommended herbicides | |
|---|---|---|
| ***Kharif* crops** | Pre-emergence | Post-emergence |
| **Rice** | **Transplanted rice (TPR) and wet-seeded rice**<br>Pretilachlor 600 g/ha<br>Pyrazosulfuron 20 g/ha<br>Pretilachlor+ pyrazosulfuron 600+15 g/ha<br>Pretilachlor+ bensulfuron 600+60 g/ha<br>Pendimethalin+ pyrazosulfuron 900+20 g/ha<br>Penoxsulfuron + butachlor 820 g/ha<br><br>**Direct-seeded rice (DSR)**<br>Pendimethalin 1.0 kg/ha, Pendimethalin+ pyrazosulfuron 900+20 g/ha,<br>Pretilachlor+ pyrazosulfuron 600+15 g/ha<br>Pendimethalin+ penoxsulam 725 g/ha | Bispyribac-Na 25 g/ha, Penoxsulam 25 g/ha, Bentazone 960 g/ha, Triafamone + ethoxysulfuron 67.5 g/ha, Fenoxaprop + safener 67 g/ha, metsulfuron + chlorimuron 4 g/ha, cyhalofop + penoxsulam 135 g/ha, clomazone+2,4-D EE 250-375 g/ha |
| **Maize** | Atrazine 0.5-1.0 kg/ha, Pyroxasulfone 127.5 g/ha | Tembotrione 120 g/ha, Topramezone 25.2 g/ha, Atrazine + mesotrione 875 g/ha, Halosulfuron 67.5 g/ha, 2,4-D 500 g/ha |
| **Soybean** | Sulfentrazone 560 g/ha, Pendimethalin 1.0 kg/ha, Metolachlor 500 g/ha, Diclosulam 28 g/ha, Metribuzin 350-500 g/ha, Pyroxasulfone 127.5 g/ha, Flumioxazin 125 g/ha, Pendimethalin + imazethapyr 1.0 kg/ha, Sulfentrazone + clomazone 350 + 375 g/ha | Chlorimuron 9 g/ha, Imazethapyr 100 g/ha, Fluazifop-butyl 100 g/ha, Quizalofop-ethyl 50 g/ha, Propaquizafop 50–75 g/ha, Haloxyfop 135 g/ha, Fomesafen 150 g/ha, Bentazone 960 g/ha, Fomesafen + fluazifop-p-butyl 250 g/ha, Fomesafen + quizalofop 180+45 g/ha, Propaquizafop + imazethapyr 125 g/ha, Imazethapyr + imazamox 70 g/ha, Na-acifluorfen + clodinafop 245 g/ha |
| **Groundnut** | Pendimethalin 1.0 kg/ha, Diclosulam 28 g/ha, Pendimethalin + imazethapyr 1.0 kg/ha | Imazethapyr 100 g/ha, Fluazifop-butyl 125 g/ha, Quizalofop-ethyl 50 g/ha, Fomesafen + fluazifop-p-butyl 250 g/ha, Propaquizafop + imazethapyr 125 g/ha, Imazethapyr + imazamox 70 g/ha, Na-acifluorfen + clodinafop 245 g/ha, Imazethapyr + quizalofop 65.6 + 32.8 g/ha |
| **Sesame/niger** | Pendimethalin 1.0 kg/ha, | Quizalofop-ethyl 50 g/ha, Clodinafop 60 g/ha |
| **Greengram/ blackgram (summer)** | Pendimethalin 1.0 kg/ha, Pendimethalin + imazethapyr 1.0 kg/ha | Imazethapyr 80–100 g/ha, Na-acifluorfen + clodinafop 245 g/ha, Quizalofop-ethyl 50 g/ha, Fomesafen + fluazifop-p-butyl 250 g/ha, Propaquizafop + imazethapyr 125 g/ha, Imazethapyr + imazamox 70 g/ha |
| **Pigeonpea** | Pendimethalin 1.0 kg/ Pendimethalin + imazethapyr 1.0 kg/ha | Imazethapyr 100 g/ha, Propaquizafop + imazethapyr 125 g/ha, Imazethapyr + imazamox 70 g/ha |
| **Cotton** | Pendimethalin 1.0 kg/ha, Diuron 0.75-1.5 kg/ha | Quizalofop-ethyl 50 g/ha, Pyrithiobac sodium 62.5 g/ha, Fenoxaprop-p-ethyl 100 g/ha, Pyrithiobac sodium + quizalofop 125 g/ha |
| **Sugarcane** | Atrazine 0.5-2.0 kg/ha, Amytrin 2.0 kg/ha, Metribuzin 1.0–2.0 kg/ha, Sulfentrazone 720 g/ha, Amytrine + trifloxysulfuron 937.5–1125 g/ha, Sulfentrazone + clomazone 700 + 750 g/ha | Halosulfuron 67.5 g/ha, 2, 4-D 2.0–3.5 kg/ha, Metribuzin 1.0–1.4 kg/ha, Metsulfuron methyl 6 g/ha, Topramezone + atrazine 25.2 + 500 g/ha, Tembotrione + atrazine 120 + 500 g/ha |

**Table 2. Recommended herbicides for weed control in *Rabi* (winter) crops (pre-emergence: 0-3 DAS; post-emergence: 18-22 DAS, in wheat: 30-35 DAS)**

| Rabi | Pre-emergence | Post-emergence |
|---|---|---|
| **Wheat** | Pendimethalin 1.0 kg/ha, Pyroxasulfone 127.5 g/ha, Sulfentrazone 560 g/ha | Clodinafop 60 g/ha, Pinoxaden 45 g/ha, Sulfosulfuron 25 g/ha, Metsulfuron 4 g/ha, 2, 4 -D 500 g/ha, Metribuzin 175 -210 g/ha, Carfentrazone 20 g/ha, Metsulfuron + carfentrazone 4+20 g/ha, Mesosulfuron + iodosulfuron 12+2.4 g/ha, Sulfosulfuron + metsulfuron 30+2 g/ha, Clodinafop + metsulfuron 60+4 g/ha, Metribuzin + clodinafop 210+60 g/ha, Fenoxaprop + metribuzin 100+175 g/ha |
| **Barley** | Pendimethalin 1.0 kg/ha | Pinoxaden 50 g/ha, Isoproturon 1.0 kg/ha, Metsulfuron 4 g/ha, 2,4 -D 500 g/ha, Carfentrazone 20 g/ha |
| **Chickpea** | Pendimethalin 1.0 kg/ha, Pendimethalin + imazethapyr 1.0 kg/ha | Quizalofop-ethyl 50 g/ha |
| **Pea** | Pendimethalin 1.0 kg/ha, Metribuzin 250 g/ha, Pendimethalin + imazethapyr 1.0 kg/ha | Imazethapyr 100 g/ha, Quizalofop-ethyl 50 g/ha |
| **Lentil** | Pendimethalin 1.0 kg/ha | Quizalofop-ethyl 50 g/ha, Fenoxaprop-p-ethyl 80 g/ha |
| **Mustard** | Pendimethalin 1.0 kg/ha, Oxadiargyl 90 g/ha | Isoproturon 1.0 kg/ha, Quizalofop 50 g/ha, Clodinafop 60 g/ha |
| **Sunflower** | Pendimethalin 1.0 kg/ha | Quizalofop-ethyl 50 g/ha, Clodinafop 60 g/ha |
| **Linseed** | Pendimethalin 1.0 kg/ha | Clodinafop 60 g/ha, Fluazifop-P-butyl 100 g/ha, Isoproturon 750–1,000 g/ha, Imazethapyr 75–80 g/ha |

**Table 3. Recommended herbicides for weed control in millet crops in unpuddled transplanting (pre-emergence: 0-3 DAS; post-emergence: 18-22 DAS)**

| Millets | Pre-emergence | Post-emergence |
|---|---|---|
| **Pearl millet & Sorghum** | Atrazine 500 g/ha, Pendimethalin 1.0 kg/ha, Metolachlor 500 g/ha | Atrazine 500 g/ha, 2,4-D 500 g/ha |
| **In transplanted Finger millet, Barnyard millet, and little millet** | Atrazine 500 g/ha, Oxyfluorfen 100 g/ha, Pyrazosulfuron 20 g/ha | Metsulfuron 4 g/ha (20 DAS/T) |
| **In transplanted Kodo millet** | Pyrazosulfuron 20 g/ha, Pendimethalin 600 g/ha | Metsulfuron 4 g/ha |

**Table 4. Recommended herbicides for weed control in *Rabi* vegetable crops [pre-plant incorporation (before sowing) pre-emergence: 0-3 DAS; post-emergence: 18-22 DAS]**

| Vegetables* | Pre-emergence | Post-emergence |
|---|---|---|
| **Garlic** | Fluchloralin 950 g/ha (PPI), Pendimethalin 750-125 g/ha, Oxyfluorfen 125-240 g/ha, Metolachlor 1000-1500 g/ha, Oxadiazon 10000-1500 g/ha, | Oxyfluorfen 125-240 g/ha, Quizalofop 50 g/ha, Fenoxaprop-p-ethyl 75 g/ha |
| **Carrot, Radish** | Pendimethalin 750-125 g/ha, Alachlor 1250-2500 g/ha, Oxyfluorfen 100-150 g/ha, Metolachlor 1000 g/ha, | Sethoxydim 800 g/ha, Fluazifop-butyl 150 g/ha |
| **Potato** | Metribuzin 525 g/ha, Oxyfluorfen 100–200 g/ha | Paraquat (Early post-emergence at 5–10% potato emergence) |
| **Brinjal** | Pendimethalin 1000-1250 g/ha, Butachlor 1000 g/ha, Oxadiazon 1250 g/ha, Metolachlor 1000 g/ha, | Quizalofop 40 g/ha, |
| **Cabbage** | Pendimethalin 750-2000 g/ha, Alachlor 1000 g/ha, Oxadiazon 1000 g/ha, | Sethoxydim 1500 g/ha, |
| **Cauliflower** | Fluchloralin 840-1500 g/ha, Alachlor 2000 g/ha, Pendimethalin 500-1000 g/ha | |
| **Onion and Garlic** | Pendimethalin 1.0 kg/ha, Oxyfluorfen 100–200 g/ha | Oxyfluorfen100-200 g/ha, Quizalofop-ethyl 50 g/ha, Propaquizafop 62.5 g/ha, Propaquizafop + oxyfluorfen 148.75 g/ha, Quizalofop + oxyfluorfen 100 g/ha |
| **Chilli** | Pendimethalin 580-677 g/ha, Fluchloralin 1000 g/ha, Oxyfluorfen 100-125 g/ha, Alachlor 3000 g/ha, Oxadiazon 1000 g/ha | |
| **Capsicum** | Pendimethalin + oxyfluorfen 1000+150 g/ha (PPI) | |
| **Tomato** | Pendimethalin 560-1000 g/ha (pre-transplant), Metribuzin 525 g/ha, Isoproturon 620-1250 g/ha (pre-transplant), Sulfosulfuron 750 g/ha | |
| **Okra** | Pendimethalin 500-750 g/ha, Alachlor 25000 g/ha, Metolachlor 750 g/ha Oxyfluorfen 150 g/ha) | |

*Compiled based on the information available, however growers are suggested to preliminary test for selectivity of herbicides before applying on the crop.

developed herbicide-tolerant near isogenic lines (NILs) in the genetic background of popular basmati rice variety, '*PB 1121*' by introgression of mutated *AHAS* allele. This was the first report on the development of HT basmati rice.

## Weed-flora shift

Weed species diversity is influenced by crop-establishment techniques, crop rotations and crop management (including weed management) strategies. Adoption of conventional tillage in rice–wheat cropping system for a longer period favoured the severity of grassy weeds *Echinochloa colona* in rice and *Phalaris minor* in wheat. Continuous use of herbicides with a similar mode of action leads to shift in weed flora and evolved into the dominant weeds over time. For example, due to continuous use of single herbicide to control the *E. colona* in rice has led to the emergence of hardy grassy weeds like *Leptochloa chinensis, Cynodon dactylon, Ischaemum rugosum,* and *Paspalum distichum* L.; sedges like *Cyperus* sp., *Scirpus* sp., *Fimbristylis* sp., *Eleocaris* sp. etc. Similarly, with the successful control of grassy weed *Phalaris minor* in wheat, broad-leaf weeds like *Lathyrus sativus* L., *Convolvulus arvensis* L., *Rumex dentatus* L., *Melilotus alba* Medik., *M. indica* (L.) All, *Medicago polymorpha.* L., M. *denticulata* Willd., *Cichorium intybus* L. and *Cirsium arvense* (L.) Scop., are gaining importance. A shift from puddle transplant rice to direct-seeding (DSR) is favoured by the dominance of grassy weeds like weedy rice, *Digitaria sanguinalis* (L.) Scop., *Leptochloa chinensis* (L.) Nees, *Dactyloctenium aegyptium* (L.) Willd., *E. colona* (L.) Link., *Dinebra retroflexa* (Vahl.) Panz., *Eleusine indica* (L.) Gaernt. and *Cyperus* spp. Habitat vacancies were produced when sensitive weeds were controlled, the habitats of resistant weeds were altered, the balance in the original climax community was disrupted, and the competitive exclusion and compensation principles of the weed community composition were followed. For example, Gramineae weeds greatly decreased over time in the haloxyfop-P-treated plots, and almost no Gramineae weeds were observed in the fourth year. The occurrence of the broad-leaved weeds rapidly rose as Gramineae weeds were controlled. In contrast, acetochlor treatment could significantly control weed occurrence, but the occurrence frequency of residual weeds, especially broad-leaved weeds, increased over time. A long-term single application of herbicides, such as fluralin and pendimethalin, to control annual Gramineae weeds and certain broad-leaved weeds resulted in a decrease in the occurrence of Gramineae weeds, such as *D. sanguinalis* and *E. indica* while the population dominance of certain broad-leaved weeds, such as *Solanum nigrum* L. and *Convolvulus arvensis* L., obviously increased, and the weed community succession process in farmlands was accelerated. These examples indicate that the existing herbicides though efficient, cannot solve all the problems and therefore, new herbicides, herbicide mixtures and rotations, and their integration with other crop-management practices are needed to solve the emerging weed problems.

## Herbicide rotation and mixtures

The practice of following a systematic, rotational sequence of herbicides used in the same field to prevent or control the formation of herbicide-resistant weeds. In a rotational, a soil-applied or foliage-applied herbicide or both are used in a sequence to take care of annual as well as perennial weeds. The choice of herbicide depends on the tolerance of crops to particular herbicides, type of weed spectrum, the intensity of weed infestation, soil and climatic factors etc. The application of tank mix or ready-mix herbicides provides broad-spectrum weed control and also has a prolonged weed-free period in crops like rice, wheat, soybean and maize. Likewise, the application of herbicide in sequence also has a broad spectrum effect and prolonged weed control in various crops. Likewise, in orchard alleys, the lowest weed biomass was obtained from the sequential application of glyphosate followed by paraquat. The WCE was highest in glyphosate followed by paraquat (86%) > 83.8% (glyphosate) > 73.2%(paraquat) > 69.6% (paraquat followed by glyphosate) > 58.8% (hand slashing) > 0% (no weeding). This suggests that the use of glyphosate-based herbicide in later rotation with a contact post-emergence herbicide reduced weed density, weed biomass and increased weed control efficiency. Herbicide rotation and mixtures or sequential application helps in preventing the emergence of tolerant weed species; reduces the quantities of herbicide required for optimum weed control over the years; provides the most effective weed control for the duration of crop growth; reduces the building up of herbicide residue problems and it offers high cumulative cost-benefit ratio over the years.

## Conclusion

Due to labour scarcity and higher labour wages, the chemical weed management is considered to be one of the best options to manage weeds in different crops. However, herbicide use has its limitations, therefore, the integration of other measures like preventive, agronomic measures, and mechanical measures is essential while designing weed management programs to minimize the negative impact of exclusive chemical weed management. It is also suggested not to use continuously similar herbicides with the same mode of action and to follow tank-mix application of compatible herbicides, and premix/ready-mix herbicides, in rotation, to avert many weed-related problems in crops and cropping systems.

## FURTHER READING

Choudhury PP, Singh R, Ghosh D and Sharma AR. 2016 *Herbicide Use in Indian Agriculture*. ICAR - Directorate of Weed Research, Jabalpur, Madhya Pradesh, 110 p

Rao AN and Chauhan BS. 2015. Weeds and weed management in India – A Review. Pp. 87-118. In: Weed Science in the Asian-Pacific Region. (Eds. Rao VS, Yaduraju NT, Chandrasena NR, Hassan G. and Sharma AR). Indian Society of Weed Science, Jabalpur, India

Matzrafi M, Peleg Z and Lati R. 2021. Herbicide resistance in weed management. *Agronomy* 11: 280.

Mishra JS, Rao AN, Singh VP and Kumar R. 2016. Weed management in major field crops. Pp. 1-20, In: *Advances in Weed Management*, (Eds. Yaduraju NT. *et al*.). Indian Society of Weed Science, Jabalpur, M.P., India

# Weed management in plantation crops

**P. Prameela*, Savitha Antony and V.R. Krishna**
*Department of Agronomy Kerala Agricultural University KAU, Thrissur, Kerala 680 656, India*
**Email: weedsvka@kau.in*

Plantation crops are an integral part of Indian agricultural economy and a major force behind the advancement and growth of the agrarian economies of several countries. The export potential and the magnitude of direct and indirect employment generation provided by the sector make its role crucial in the Indian economy. The history of plantation crop cultivation in India is equally diverse and rich, with each crop having a unique historical and economic context of development. The major plantation crops in the country include coconut (*Cocos nucifera* L.), arecanut (*Areca catechu* L.), oil palm (*Elaeis guineensis* Jacq.), rubber (*Hevea brasiliensis* Mull. Arg.), cocoa (*Theobroma cacao* L.), cashew (*Anacardium occidentale* L.), tea (*Camellia sinensis* (L.) Kuntze.), and coffee (*Coffea arabica* L.).

In India, plantation crops are cultivated in an area of 4.2 million hectares, out of the total net cultivated area of 139.4 Mha (India Statistics, 2020-21). Among different states, Karnataka, Kerala and Tamil Nadu are major producers. In India, there was a steady increase in area over years, however after 2017-18 a slight decline in production is recorded, which is attributed to the effects of climate change, rising labour and input prices, stagnation in productivity, and the prevalence of pests and diseases.

Being long-term crops, weed competition is a major problem in the initial years of establishment. The weed infestation in plantations in later stages of growth is also a concern and is a major hindrance to harvesting and cultural operations (**Figure 1** and **2**). Weed management strategies in plantation crops are different from that in field crops due to differences in growth habits, extent of competition depending on growth stage, canopy coverage leading to differences in light infiltration, specific land husbandry and crop husbandry practices, topography *etc.* Also, perennial shrubby weeds are a major concern in many plantations rather than understory weeds that often do not compete with trees dueto spatial differences in requirement of growth factors and they actually serve the purpose of a live mulch. There are no crop associated weeds in plantations contrary to field crops. Although weed management is an expensive operation, it is done as a routine practice due to many advantages apart from reducing actual weed competition, like facilitating easy movement, harvest, irrigation, plant protection and other special operations like pruning or training.

## Floristic composition of weeds in plantation crops

The weed flora is almost common in many plantation crops and is decided mainly by the climate and altitude rather than the crop (**Table 1**). Factors like the ecological requirements of weeds, microclimate, agronomic practices, age of the plantation, cropping systems in the adjoining area and altitude influence the type of weed and extent of competition. Typically, weeds tolerant to shaded situations persist in plantations due to thick canopy coverage by crops. Rapid multiplication, adaptations to varying edaphic factors, tolerance to

**Figure 1. Weed infestation in mature coconut plantation**

Figure 2. Weed infestation in sole crop of arecanut

adverse conditions, response to control measures and higher competition ability makes many weeds noxious and very difficult to manage. Shade tolerance is a major adaptation that enables weeds to persist in plantations. Efficient competitors common in plantations include shade loving plants like aroids, ferns, some climbers and other dicots adapted to filtered light.

Understory weed management is very critical in newly established/replanted or young plantations because of the chances of luxurious weed growth due to copious availability of growth resources, and the loss can vary depending on the extent of the weed infestation. Generally, in mature plantations, yield loss is more in

**Table 1. Common weeds associated with major plantation crops**

| Sl. No. | Common name | Scientific name | Annual/ Perennial | Mode of propagation |
|---|---|---|---|---|
| **Grasses** | | | | |
| **1** | Guinea grass | *Panicum maximum* | Perennial | Seeds and vegetative |
| **2** | Torpedo grass | *Panicum repens* | Perennial | Vegetative |
| **3** | Deenanath grass | *Pennisetum pedicellatum* | Perennial | Seeds |
| **4** | Corn grass | *Setaria barbata* | Annual | |
| **5** | Blanket grass | *Axonopus compressus* | Perennial | Seeds and vegetative |
| **6** | Bermuda grass | *Cynodon dactylon* | Perennial | Seeds and vegetative |
| **7** | Hairy crab grass | *Digitaria sanguinalis* | Annual | Seeds |
| **8** | Toco grass | *Ischaemum indicum* | Annual | |
| **9** | Wrinkle grass | *Ischaemum rugosum* | Annual | Seeds |
| **10** | Basket grass | *Oplismenus hirtells* | Annual | Seeds |
| **11** | Goose grass | *Eleusine indica* | Annual | Seeds |
| **12** | Crowfoot grass | *Dactyloctenium aegyptium* | Annual | Seeds and vegetative |
| **13** | Tee grass | *Paspalum* sp. | Annual | Seeds |
| **14** | Cori grass | *Brachiaria* sp. | Perennial | Seeds and vegetative |
| **Sedges** | | | | |
| **1** | Purple nut sedge | *Cyperus rotundus* | Perennial | Seeds and vegetative |
| **Broad leaved weeds** | | | | |
| **1** | Goat weed | *Ageratum conyzoides* | Annual herb | Seeds |
| **2** | Sessile joyweed | *Alternanthera sessilis* | Annual or perennial herb | Seeds and vegetative |
| **3** | Calico plant | *Alternanthera bettzickiana* | Annual or perennial herb | Seeds and vegetative |
| **4** | Button weed | *Borreria hispida* | Annual herb | seed |
| **5** | Siam weed | *Chromolaena odorata* | Perennial shrub | Seeds and vegetative |
| **6** | Hill glory bower | *Clerodendrum infortunatum* | Perennial shrub | Seeds and vegetative |
| **7** | Pagoda flower | *Clerodendrum paniculatum* | Perennial shrub | Seeds and vegetative |
| **8** | Asiatic day flower | *Commelina benghalensis* | Annual or perennial herb | Seeds and vegetative |
| **9** | Pasture weed | *Cyathula prostrata* | Annual to short lived perennial herb | Seeds |
| **10** | Wild poinsettia | *Euphorbia geniculata* | Annual | Seeds |
| **11** | Asthma weed | *Euphorbia hirta* | Annual | Seeds |
| **12** | Wild sage | *Lantana camara* | Perennial | Seeds and vegetative |
| **13** | Mile-a-minute | *Mikania micrantha* | Perennial creeping climber | Seeds |
| **14** | Sensitive plant | *Mimosa* sp. | Annual or perennial | Seeds |
| **15** | Singapore daisy | *Sphagneticola trilobata* | Perennial | Vegetative |
| **16** | Cinderella weed | *Synedrella nodifloara* | Annual | Seeds |
| **17** | Red oat grass | *Themeda triandra* | Perennial | Seeds and vegetative |
| **Major broad leaved weeds of tea and coffee** | | | | |
| **18** | Crofton weed | *Ageratina adenophora* | Perennial | Seeds |
| **19** | Canadian horseweed | *Erigeron canadensis* | Annual | Seeds |
| **20** | Blueweed | *Ageratum houstonianum* | Annual | Seeds and vegetative |
| **21** | Redflower ragleaf | *Crassocephalum crepidioides* | Annual | Seeds |
| **22** | Black jack weed | *Bidens pilosa* | Annual | Seeds |
| **23** | Woodland strawberry | *Fragaria vesca* | Perennial | Seeds and vegetative |
| **24** | Gallant soldier | *Galinsoga parviflora* | Annual | Seeds |
| **25** | Broadleaf woodsorrel | *Oxalis latifolia* | Perennial | Seeds and vegetative |
| **26** | Chinese bur | *Triumfetta rhomboidea* | Annual | Seeds |

**Figure 3. Rubber plantation with cover crop of *Mucuna bracteata***

estates of dry zone compared to wet zones due to competition for plant available water. In systematically planted large plantations more weed growth is common compared to small holding plantations where high density planting is adopted. In plantations, clean weeding is not desirable as it is not economically viable, may accelerate the chances of soil erosion and hence, troublesome and pernicious weeds only must be taken care of in weed management programmes. Various weed management strategies can be combined appropriately as a viable and economic solution.

## Strategies for management

In plantations, weed growth can be managed by a well scheduled and integrated approach. Preventive measures also should be given prominence in order to check invasion by new species. Prevention is the most effective, but difficult to implement. It encompasses measures to check the accidental introduction and further spread of weed, use of clean agricultural equipment and well decomposed weed free farmyard manure/compost to reduce the weed spread to an extent. Enforcing quarantine laws restrict the entry of new weeds. However, dispersing agents like water, wind and animals are beyond our control. So, if a weed gets introduced once into a new locality, we can minimize the yield loss by reducing the weed population through frequent disturbance and habitat management.

The right choice of a weed management measure is decided by the factors like weed ontogeny, aggressive-ness, propagation mode, reproductive potential etc apart from the growth stage of the crop. An understanding of the type of weed species, their growth habit and associated information on biology can be a good help in containing the problem. For example, *Mikania* sp. which is a climber, common in wet humid tropics can pose a serious problem if not managed timely, before seed production, due to its high seed production and dispersal ability.

## Weed management approaches

The various weed management practices like cultural, manual, mechanical, biological, and chemical methods followed in plantations are discussed below.

**Inter/multi-tire cropping**: The weed menace is more in sole stands of plantation crops than multitier cropping systems or plantations where shade trees are established due to specific requirements of crops. Wider spacing in sole stands of plantation crops favours the fast growth of weeds. So, utilizing these spaces, different crops can be grown along with the plantation crops. Polycropping or multitier cropping in coconut, utilizing nutrients moisture and light at different levels is one, the most popular in Kerala. This will serve as an additional source of income along with weed control. In the case of rubber, if the slope is more than 25%, intercropping is not advocated. Pineapple, ginger, turmeric *etc* are ideal intercrops for plantations with sufficient sunlight availability.

Growing cover crops like *Pueraria phaseoloides, Mucuna bracteata, Calopogonium mucunoides* and *Centrosema pubescens* in the interspaces is a common practice in rubber and it is one of the most sustainable practices recommended for mature plantations (**Figure 2**). Cover cropping is also a practice in coffee and it effectively suppresses weed growth. These cover crops also improve soil health and organic matter status, fix atmospheric nitrogen in the soil, reduce soil moisture loss and prevent erosion. Mulching with organic materials or live mulches can also serve the above purpose apart from weed control. Zero till systems make use of this principle.

In coffee and tea shade trees like silver oak and dadap are grown on, plantations. The shading effects, as well as organic matter addition through litter fall and pruning, forms natural mulch which is very effective in inhibiting weed growth.

Manual weeding is mainly recommended in the nurseries and young plantations as this method is laborious and expensive. Cheeling is the removal of surface weed growth and preparing the ground for pre-emergent herbicide spray, practiced in young tea plantations. Hoeing and forking are followed in the young plantations and it is not advocated in later stages as this may be injurious to feeder roots. Manual slashing and scraping can also be followed and care should be taken not to expose soil so as to prevent chances of soil erosion. So mulching is advocated immediately after weeding.

Tillage efficiently manages weeds in plantations with wide row spacing, but without shade trees. But to protect the feeder roots, deep tillage should be avoided. It is not advocated in sloppy areas, as this operation makes the soil prone to erosion. Usually, twice a year, in June–July and December–January, the inter-space in the coconut garden are ploughed, which take care of weed problem.

In comparison to hand weeding, weed cutters offer 40 to 50% cost reduction in weed control in rubber. This practice has the advantage of not disturbing the soil, leaving the cut vegetation on top of the soil as mulch, and being fast. But in tropical areas with high rainfall, there will be quick regrowth in short span of time. Most cocoa plantations regularly use a machete, a large tool similar to a cleaver, to cut weeds within a 1.0 m radius of the trees.

Domesticated farm animals such as cow, goat, and sheep are allowed to graze in the plantations to forage on weeds. Yet, these are selective in their feeding habit and leave unpalatable species untouched. Cultural methods are more suited to small holder situations. Common traditional practice of burning is not a sustainable option as it will lead to rapid regeneration of some weed species and also pose the risk of forest fire

Herbicidal management is efficient and cheap compared to other methods and is ideal to mature plantations (**Figure 4**). As there is no soil disturbance, herbicide spray is advocated including even in sloppy areas. Depending on the type of weed, different herbicides are recommended. Glyphosate is the common post emergent herbicide used in plantations due to effective broad-spectrum weed control. 2,4-D and glufosinate ammonium are also recommended. The pre- emergent herbicides like oxyfluorfen, atrazine and diuron are also used, especially in nurseries and young plantations.

In coffee, by the end of April or the beginning of May, when the weeds are around 10-15 cm high, the first round of blanket application of broad-spectrum herbicide should be started. Weed growth in isolated regions should be controlled with spot spraying, 15-20 days following the blanket spray. Towards the end of the monsoon, in September/October, a second round of blanket application may be required, spot application of systemic broad-spectrum herbicides can be advocated and number of spraying may be limited to twice per year in large plantations for effectively control weeds and to ensure environmental safety.

Repeated use of herbicides may leave chemical residues. This can also result in the development of resistant weeds and occurrence of shifts in weed flora. For example, in tea, use of 2,4-D to control *Borreria hispida* and *Ageratum conyzoides* resulted in dominance of *Digitaria sanguinalis*. Hence herbicide rotation is important practice in chemical weed control. Only limited numbers of herbicides are permitted in tea, due to concerns on food safety. Therefore, issues like environmental safety aspects, residue accumulation in food items (especially in tea and coffee) and development of herbicide resistance in weeds should be kept in mind while adopting chemical control.

**Figure 4. Chemical weed management in cashew**

A few biological control agents like *Zygogramma bicolorata* and *Ophiomyia lantanae* were introduced, but these were not effective due to many limitations in Kerala. However, *Z. bicolorata* is effective to control weeds in plantation crops in central and north India. Hence a viable and sustainable option for weed management in plantation crops would be an integration of location specific possible weed management methods based on weed flora associated, the crop grown, climate and topography.

## FURTHER READING

Friessleben U, Pohlan J and Franke G. 1991. The response of *Coffea arabica* L. to weed competition. *Café Cacao The* **35**(1): 15–20.

Singh R, Sud R and Pal P. 2014. Integrated weed management in plantation crops. In: Chauhan, B., Mahajan, G. (eds) *Recent Advances in Weed Management*. Springer, New York, NY.

Burgos NR and Ortuoste JD. 2020. Weed management in natural rubber plantations. Pp. 485–504. In: *Weed Control Sustainability, Hazards, and Risks in Cropping Systems worldwide*. Korres NE, Burgos NR and O. Duke SO (Eds.), CRC Press, USA.

# Gaining control on herbicide-resistant weeds: Multiple techniques required

**Amit J. Jhala**
*University of Nebraska–Lincoln, USA*
*Email: amit.jhala@unl.edu*

The evolution and widespread occurrence of herbicide-resistant weeds is a concern for sustainable grain and food production across the globe. Weed scientists are studying on ways to get control over herbicide-resistant weeds and it isn't easy. For example, Palmer amaranth (*Amaranthus palmeri* S. Watson) is occurring in crop fields across the United States and has become resistant to glyphosate and several other herbicides. Palmer amaranth has been ranked as number one problem weed in the United States in a survey conducted by the Weed Science Society of America. Growers of several states, including Nebraska, have Palmer amaranth problem particularly in agronomic crops such as corn, soybean, cotton, sorghum, *etc.* Palmer amaranth has evolved resistance to several group of herbicides in Nebraska, including glyphosate (**Figure 1**). Additionally, some Palmer amaranth populations are resistant to multiple herbicides such as atrazine and HPPD-inhibitors such as mesotrione and tembotrione. Therefore, growers should pay attention to the management of herbicide-resistant Palmer amaranth and follow the best management practices to reduce weed seed dissemination.

Little seed canary grass (*Phalaris minor* Retz.) is a *Rabi* (winter) weed that looks similar to wheat crop. It predominates in the rice-wheat cropping system in Haryana, Punjab, Western Uttar Pradesh and states of the North-Western Indo-Gangetic plains. Being morphologically similar to wheat, it often escapes manual and mechanical control measures. Because of repeated use of similar herbicides, herbicide-resistant populations of *Phalaris minor,* resistant particularly to isoproturon, clodinafop, fenoxaprop, and sulfosulfuron, are widespread. Some biotypes of *Phalaris minor* have evolved resistance to pinoxaden, mesosulfuron + iodosulfuron. Multiple herbicide-resistant *Phalaris minor* is becoming common in certain Indian states. The rapid spread of *Phalaris minor* in India is a risk to the sustainable production of many crops. Therefore, management to minimize the impact of *Phalaris minor* is crucial in India to improvise crop productivity and production.

**Figure 1. Palmer amaranth is the number one weed issue in Nebraska and is becoming a major problem across the country**

Palmer amaranth is widespread and present in almost every Nebraska county and according to a recent state survey, Palmer amaranth is the number one weed problem in Nebraska's crop fields. The author of this article has been researching on the management strategies to find the best combination that will manage herbicide-resistant Palmer amaranth.

Palmer amaranth is an extremely competitive in agronomic crops such as soybean and causes severe yield losses, if not controlled (**Figure 2**). The study we conducted in Nebraska suggest that in the absence of a pre-emergence herbicide during the critical time of Palmer amaranth removal (CTPAR) at 5%, soybean yield loss occurred at V1 (first trifoliate) and V6 (sixth trifoliate) soybean growth stages, in year 1 and year 2, respectively. When Valor (flumioxazin) was applied alone, the CTPAR was delayed until the V3 and V6 soybean growth stages. When Fierce MTZ (flumioxazin + metribuzin + pyroxasulfone) was applied, the CTPAR was delayed until the V2 and R1 (reproductive) soybean growth stages, in year 1 and 2, respectively. Thus, the pre-emergence herbicide with multiple modes of action applied at planting is the key to provide early-season control of Palmer amaranth as well as to delay Palmer amaranth removal and need for a post-emergence herbicide.

Our research team explored different herbicide programs in corn-soybean cropping system in combination with narrow row spacing usage for their effectiveness in controlling or reducing seed production of Palmer amaranth. There are management practices that farmers may adopt to reduce the occurrence of herbicide-

**Figure 2. Palmer amaranth is abundant between soybean rows early in the season, if not controlled. Amit Jhala's research is exploring how herbicide applications and field management practices can reduce the weed's growth and seed production**

resistant weeds including waterhemp and Palmer amaranth. Jhala and the research team have made several management recommendations based on the research projects undertaken.

Growers need to understand the biology of weeds as it is important to know when the weed emerges to gain effective control. The routinely scouting fields is recommended to know the weed emergence pattern in order to ensure proper post-emergence herbicide application timing. Our team also recommends using a diverse approach to weed management that is focused on reducing weed seed production and its seeds number in the soil seedbank. At harvest, if farmers can work toward preventing field-to-field movement of weed seeds, this can help to prevent seedbank build-up.

**Best management practices, needed for effective control of herbicide-resistant weeds, are:**

- Understand the biology of weed species as it is important to know when they emergence for effective control. For example, Palmer amaranth start emerging in eastern Nebraska in May and can emerge until end of August.

**Figure 3. Cereal rye cover crop terminated two weeks after soybean planting can suppress Palmer amaranth emergence**

- Use a diverse weed management approach focused on reducing weed seed production and the number of seeds in the soil seedbank.
- Plant crops into weed-free fields; scout fields routinely.
- Use multiple modes of action pre-emergence herbicide at planting crops; apply labeled herbicide rate at recommended weed growth stage.
- Use cultural management techniques such as narrow row spacing and integrating cover crops when possible that suppress Palmer amaranth through crop competitiveness (**Figure 3**).
- Prevent field-to-field or in-field movement of weed seeds and manage weed seeds at harvest to prevent a buildup of herbicide-resistant weed seedbank.

Herbicide-resistant weeds are tough to manage but using multiple strategies including appropriate herbicide-resistant crop varieties, herbicide treatments and agronomic management techniques, farmers can achieve positive results.

## FURTHER READING


de Sanctis JHS, Barnes ER, Knezevic SZ, Vipan Kumar and Jhala AJ. 2021. Residual herbicides affect critical time of Palmer amaranth removal in soybean. *Agronomy Journal* **113**(2): 1920−1933.

Ward S, Webster TM, Steckel LE. 2013. Palmer amaranth (*Amaranthus palmeri*): A review. *Weed Technology* **27**: 12−27.

# Utilization of weed biomass

**K.K. Barman* and Dibakar Roy**
*ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482004, India*
**Email: barmankk@gmail.com*

## Introduction

Weeds are the plants growing where it is not desired. Although weeds are often considered as harmful for agricultural productivity, human and animal health, biodiversity and environment, many of them also have useful traits that are sometimes disregarded. They may serve as chemotherapeutic agents because of the wide variety of pharmacological activity displayed by their chemical components and essential oils. They are naturally tolerant to a variety of harsh environmental situations, particularly the effects of climate change and other pressures like heavy metals in the natural ecosystem and environment. As a result, they can be employed as management tools in addition to being used as bio-resources. Weeds also produce large quantity of biomass, which can be used as a rich source of nutrients to improve the soil health through green manuring, vermicomposting and composting. There is a resurgence of interest in emphasising their utilisation in innovative and profitable ways in connection with environmental applications so that people might profit from previously underappreciated factors. A sustainable solution to combat adverse impac caused by weeds in the environment, agricultural economy, and natural ecology may be to use them productively.

## Weeds for essential oils

Some species of weed plants produce essential oils. For example, there is 0.4% essential oil content in *L. camara* leaf, 0.56% in the aerial parts of *Eupatorium adenophorum*, 0.3% in aerial parts of *Ageratum conyzoides*, 0.18-0.25% in *Sphagneticola trilobata,* 0.1% in *Cannabis sativa*, 0.5% in *Artemisia annua* and 0.4-0.6% in *Cyperus* rotundus tubers. Those oils can be used in flavor, fragrance, cosmetic and pharmaceutical industries.

## Weeds as herbal medicines and pharmaceuticals

Besides essential oils and aroma chemicals, some weeds also produce secondary metabolites of aromatic and medicinal significance like alkaloid, terpenoid and cardiac glycoside compounds. Several weed plants are rich source of many natural products and have been extensively used for traditional human health care systems viz. Ayurveda, Unani and Siddha. They have shown by generations to be effective against specific disorders. For example, *Phyllanthus niruri*, a very common weed in agricultural field, having wide range of medicinal properties is widely used across the world (**Figure 1A**). In Indian ayurvedic system it is used for jaundice, ulcers, skin diseases, diabetes, chest pain and urinary complications. The *Chenopodium album,* a winter season weed commonly known as *bathua* (in Hindi) due its ability to reduce joint pain initiated due to uric acid accumulation commonly used as blood purifier, sedative role and pharmaceutical studies revealed that the plant possesses anthelmentic, sperm immobilizing and contraceptive properties (**Figure 1B**). *Eclipta prostrata* commonly known as *bhringaraj* which oil commonly used for anti hair fall property (**Figure 1C**). Similarly, *Marsilea quadrifolia* a *kharif* season weed, which grows in submerged soil or moist environment and commonly known as *sushni*, is consumed as vegetable for curing insomnia (**Figure 1D**). In India, about 120 weed species provide the raw materials to the pharmaceutical industries. Hence, there is need to establish suitable marketing chain to enable common farmers to earn additional income by gathering weeds from their farmland.

## Weeds as natural biocide

The *Lantana camara*, an alien invasive weed, exhibits natural biocidal actions. The essential oil extracted from *L. camara* leaves possess adultticidial activity against different mosquito species (Dua *et al.* 2010). Similarly, *L. camara* extracts have shown insecticidal and anti-termite properties. Further, chemicals extracted from *L. camara* leaves using acetone demonstrates its molluscicidal potential (Chauhan and Singh 2010) against freshwater snails (*Lymnaea acuminata*) and other molluscan pests.

## Weeds as metal hyper accumulators

Various organic and inorganic contaminants discharged from industrial, residential and commercial sources degrade the surrounding ecosystems. Weeds by virtue of their genetic ability can absorb or degrade various inorganic heavy metals (cadmium, chromium, lead, nickel, mercury *etc.*), metalloids ( arsenic) and organic substances like pesticides, dye from contaminated soil and water. These plants have intrinsic capacity to accumulate metals into their shoots and roots, have the ability to form phytochelatins and stable compound with ions. This behaviour of accumulation along with formation of chelate and stable compounds can be utilized as phytoremediation agent for reclamation metal contaminated sites. Among various weedy plants, *Typha latifolia* (Cattail), *Arundo donax* (Giant reed), *Phragmites*

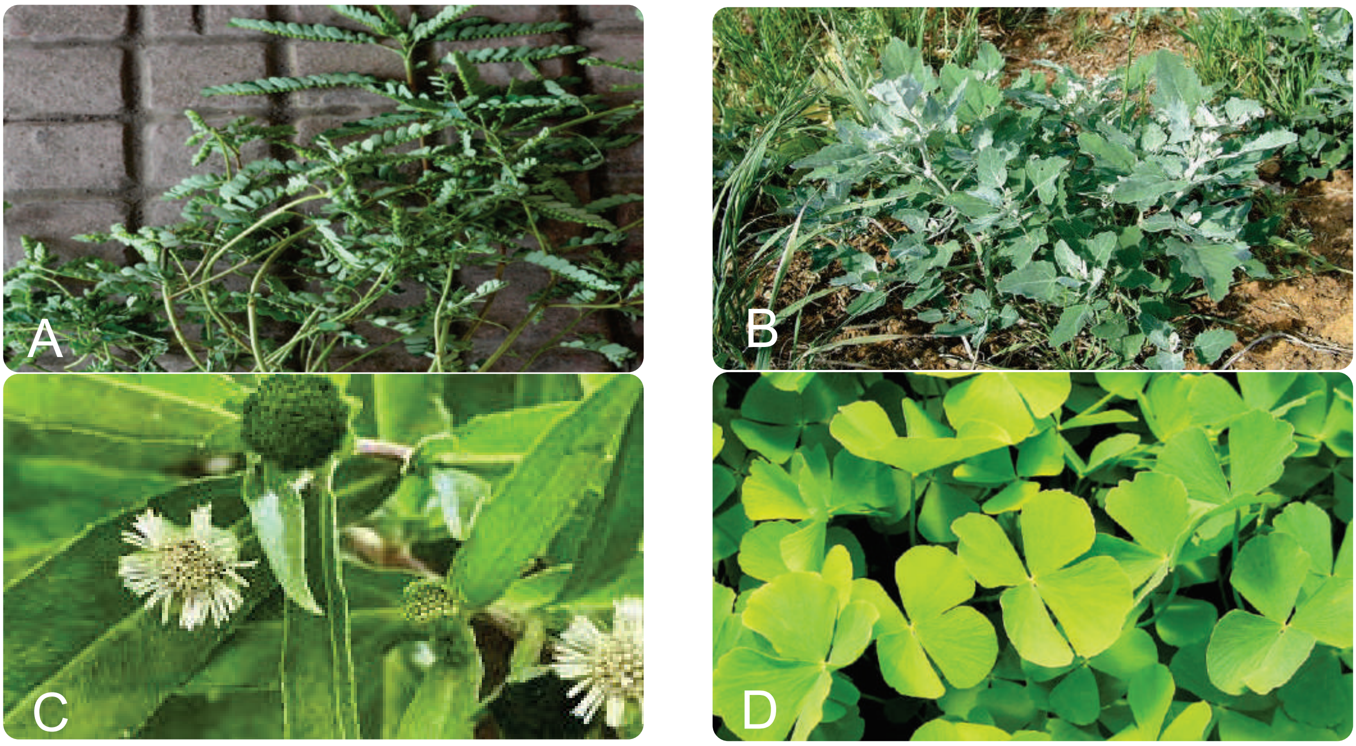



**Figure 1. Weeds with medicinal value (A: *Phyllanthus ninuri*; B: *Chenopodium album*; C: *Eclipta prostrata*; D: *Marsilea quadrifolia*)**

*karka* (Nal), *Chrysopogon zizanioides* (vetivar grass), *Canna indica* (Indian shot), *Pteris vittata* (Chinese brake fern), *Eichhornia crassipes* (Water hyacinth), *Alternanthera philoxeroides* (Aligator weed), *Pistia stratiotes* (Water lettuce), *Salvinia molesta* (Giant salvinia), *Hydrilla verticill*ata (Water weed), *Spirodella polyrhiza* (Giant duck weed) etc. show excellent ability for phytoremediation of heavy metals and metalloids from contaminated soil and water. A weed based phytoremediation model was established by ICAR-Directorate of Weed Research, in farmers field and it provide clear water for irrigation in vegetable crops from contaminated river water (**Figure 2**).

## Weeds as biofuels and bioenergy

Due to increased cost and higher carbon foot print from fossil fuels, many governments are promoting biofuel blending along with fossil fuel to address those points and gradually the moving to cut down dependency on fossil fuel as much as possible. The bioethanol and biodiesel produced from plant biomass are widely used as biofuels in transport vehicles like car and aeroplanes. Currently, bioethanol is mainly produced from surplus food-related crops like sugarcane, sweet potatoes, rice and cassava etc. The biomass contributes a significant share of global primary energy consumption because liquid fuels produced from biomass contain no sulphur, thus avoiding $SO_2$ emissions and also reducing emission of $No_2$.

Weedy plants can be used as alternate substrate for bioethanol production. Various weedy plants like *Eichhornia crassipes*, *Pistia stratiotes*, *Cannabis sativa*, *Pennisetum purpureum*, *Parthenium hysterophorus*, *Chrysopogon zizanioides etc.* can be utilized for biofuel production due to its high cellulose, lignin and reducing sugar content. But for production of biofuel, this weedy biomass has to go through a pre-treatment procedure in which cellulose gets separated from lignin compound. Subsequently, the cellulose and lignin degrade and form monomer sugar compound which after fermentation are converted into ethanol.

## Use of weed biochar in soil amendment, carbon sequestration and biosorption

Biochar is a charcoal-like substance that's produced by burning organic material from agricultural and forestry wastes under oxygen deficient condition or anoxic condition called pyrolysis. Preparation of biochar from weed biomass and its employment as soil amendment, is a sustainable weed management strategy. In addition to storing carbon in soils, it neutralizes soil acidity, reduced mobility of toxic heavy metals, increases cation exchange capacity (CEC) and biological activity by promoting niche for microbial growth ultimately enhances over all soil quality (Jeffery *et al*. 2011). Furthermore, the allelochemicals in weed plants, that could otherwise interfere with crop growth and establishment, are destroyed by the pyrolytic conversion of weed biomass to biochar (Renard *et al*. 2012). Weedy plants like *Lantana camara*, *Saccharum spontaneum*, *Parthenium hysterophorus*, *Eichhornia crassipes etc.* are some ideal candidates for biochar production.

## Utilization as raw material for paper industries

In recent years, due to the rapid growth of population and industry, the forest area of our country is gradually diminishing and also at the same time the supply of plant materials, from the forest to the industry, is decreasing at an alarming rate resulting in a huge shortage of raw


**Figure 2. Floating aquatic weed based phytoremediation model constructed in farmer's field by ICAR-DWR, Jabalpur**

materials for various forests and cellulosic based industries. Therefore, in recent years much attention has been given on utilization of alternate fibrous raw material mostly non woody plants to use in paper and pulp industries. There are many varieties of wild plant available in the forests having potentiality to use as raw material for these industries. For example, *Clynogynae dichotoma* and *Alpinea allughas* are abundantly available weeds growing in the low marshy land of whole NE region, and were found to be potential alternative source of fibre for pulp paper and paper board industry (http://neist.csircentral.net/251/1/2657_2008.pdf). Similarly, *Lantana camara* and *Eichhornia crassipes* could be a good raw material for paper and pulp industry. Both the weeds are rich in cellulose and lignin which make them fit for paper and pulp production industry.

### Other economic uses

A woody weed is used directly as supplementary fuelwood for cooking and heating by village people. For example, *Lantana* wood generates 18.53 MJ energy/kg during burning which make it a good source for firewood. In rural areas of Himalayan region, it is a major source of firewood. Further, stems of *L. Camara* offer very high strength, durability and toughness which allows it to be utilized for making some handicrafts and furniture making purpose. Lantana sticks are extensively used for making baskets for packing and transport of vegetables to distant markets in some parts of Himalayan mountains. In Karnataka, India; *L. camara* stems is being used for making wicker craft along with bamboo stems under resource (bamboo) deficient situation. Similarly, tribal community peoples in the vicinity of India's Mudumalai Tiger Reserve produce similar-looking, high-quality furniture that is almost half the price of cane furniture. Another project called WELFARE (Women Empowerment through Lantana Furniture and Artifacts and Restoration of Environment) has been started on the edge of Corbett National Park in India to investigate business opportunities for this termite-resistant weed by providing training to make furniture from it.

Many weeds such as *Chenopodium album*, *Trianthema portulacastrum*, *Amaranthus viridis*, *etc*. are used as leafy vegetables due to high nutrient contents. Most of the weeds also serve as major source of green fodder for livestock. Several weeds such as *Agropyron repens, Cynodon dactylon, Panicum repens* and *Imperata cylindrica* are excellent soil-binder due to their extensive root system and hence they prevent soil erosion.

### Conclusion

Greater adaptability to diverse ecological habitats, vigorous growth and high proliferation rate helped the weeds to spread and flourish across diverse ecosystems. Weed management is a costly cultural practice with modest success. Hence, attempts are being made to develop new strategies for their management with environmental and economic significance. The chemical constituent and essential oils present in some weeds show range of pharmacological activities. Lignocellulosic weed biomass can be used for phytoextraction and biosorption of pollutants, biochar preparation, carbon sequestration, in soil amendment and energy conserving strategies of biofuel and bioenergy formation. Versatility of applications of weed biomass unfolds numerous ways for weeds use as a component of sustainable integrated weed management. Sustainable intensification of weeds use for various value added products is required, in productive way.

### FURTHER READING

Chauhan S and Singh A. 2010. Molluscicidal potential of Lantana indica and Alstnia scholaris plants against freshwater snail Lymnaea acuminata. *Internet Journal of Toxicology* **7**(2).

Dua VK, Pandey AC and Dash AP. 2010. Adulticidal activity of essential oil of *Lantana camara* leaves against mosquitoes. *Indian Journal of Medical Research* **131**: 434-439.

Jeffery S, Verheijen FG, Van Der Velde M and Bastos AC. 2011. A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, Ecosystem & Environment* 144(1): 175–187

Rajkhowa DJ, Gogoi AK and Yaduraju NT. 2005. *Weed Utilization for Vermicomposting - Success Story*, NRC for Weed Science, Jabalpur, MP.

Renard D, Iriarte J, Birk JJ, Rostain S, Glaser B and McKey D. 2012. Ecological engineers ahead of their time: The functioning of pre-Columbian raised-field agriculture and its potential contributions to sustainability today. *Ecological Engineering* **45:** 30–44

Shah NC. 2008. *Ethnobotany in India*. In: Selin H. (eds) Encyclopaedia of the History of Science, Technology, and Medicine in Non-Western Cultures. Springer, Dordrecht.

Varshney JG and Sushilkumar (Eds.). 2009. *National Consultation on Weeds Use*. October 20 to 21, 2009. Abstracts. Directorate of Weed Science Research, Jabalpur, Madhya Pradesh.

# Tools and techniques for herbicide application and mechanical weed management

**C.R. Chethan[1]*, K. Manjunath[2], D.J. Shrinivasa[3], P.K. Singh[1], R.P. Dubey[1] and J.S. Mishra[1]**
[1]*ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482004, India*
[2]*ICAR-Directorate of Cashew Research, Puttur, Karnataka, India*
[3]*Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India*
**Email: chethan704@gmail.com*

Weeds are one of the major problems in crop production. In India manual weeding using traditional tools like sickle, *Khurpi*, *Kudali*, hand fork, animal operated hoes *etc.* are still common with small and marginal farmers. However, manual weeding is labour intensive, ineffective in moist conditions, costly and involve drudgeries to operate. Therefore, use of herbicides for weed management is increasing in modern agriculture. In chemical weed management, the conventional method of using low pressure sprayers and weeders needs to be improvised to save agricultural inputs and also for better management of weeds. Reports suggested that, even after using traditional weed control methods, farmers are losing closely up to 15-20% of crop yield. Therefore, there is a tremendous scope for improving the weed management techniques and enhancing crop yields by adopting improved weed managing practices.

In conventional practice, the mechanical weeders are used only to remove the inter-row weeds and intra-row weeds are left untouched. Whereas, herbicides are applied throughout the field at constant rate without considering the spatial variability and weed population distribution. Presences of weeds and their population vary throughout the field. Herbicide application in the entire field, irrespective of presence or absence of weeds may lead to wastage of herbicide, increased cost of cultivation, resistance in weeds and unintended contamination of the environment which may have harmful effect on crop and humans, and deteriorates the soil health. Therefore, more precise application of herbicides to the target and management of weeds through sensor guided mechanical weeders are preferable. Interventions on reliable, cost-effective and efficient weed management technologies are being developed throughout the world to overcome the problem. The developments on information and automation technologies have opened a new era for weed management to fit physical and chemical control treatments to the spatial and temporal heterogeneity of weed distributions in agricultural fields. Site-specific weed management (SSWM) considers the spatial and temporal variability of weeds and controls them effectively. A research shows that, using of using species-specific control with a three-tank sprayer resulted in 59-80% untreated area depending on the weed species (Gutjahr *et al.* 2012, Gerhards *et al.* 2022).

## Spatial variability of weed population and their dynamics

The crop fields are usually infested with different kinds of weed species in varying densities. Of the many weed species present in the field, only three to four weed species are of dominant in nature *i.e.* they have high weed density and coverage area. This variation of weed patches and density may also vary with the kind of weed species, time of emergence, growth rate, weather parameters and weed management practices. The high weed density patches are less susceptible to control than the less density patches. Moreover, high density of weeds indicates high seed bank and produce more seeds, which will severely affect the next cropping cycle. In addition, control measures such as tillage or herbicide application are less likely to control all the plants in a high-density patch than in a low-density patch. Site-specific weed management relies upon a good understanding of the distribution of weeds in the field. Aggregation of weeds, their spatial structure, the crop rotation, weed species competition and the planned weed control tactics decide the resolutions of sensors and weeding tools. Studies showed that, application of herbicide only to the patches and also applied at variable rate according to the weed density controlled the weeds effectively and reduced the seed bank. During field operation of the weeders, the high density weed patches can be tackled very easily and effectively by using special kind of weeding tools with the use of SSWM techniques.

## Site-specific weed management

The site-specific weed management (SSWM) is a sensor based machinery embedded precision weed management technique; it observes, records and execute the controlling operations according to the predefined factors such as economics, heterogeneous presence of weeds and/ or weed species within a crop fields. The main purpose of SSWM is to apply the right dose of herbicide at right place and at right time, if it is chemical control and/ or physical removal of weeds through robotic arms. Sensor technologies include multispectral imaging, 3D cameras, computer-based decision algorithms, Artificial Intelligence (AI) and precise spraying and hoeing actuators for weed identification, classification, differentiation and eradication (**Figure 1**). The SSWM mainly has four components (**Figure 2**) through which it execute the different weed controlling strategies.

### Weed detection techniques

The detection of weeds through automation has the capability to increase sample point density and accuracy of the system. Mainly three approaches were used to detect the weeds under automation, they are:

1. Biological morphology: recognition of shape and structure of the plant species.
2. Spectral characteristics: recognition based on the plant reflectance. Pixel based color or hyper spectral classifiers are used for these purposes.
3. Visual texture: recognition based on the gray scale calculation and color of the images.

### Machine vision-based weed detection from images

Machine vision is an optical sensor-based system, which discriminates and differentiate the weeds from crop (**Figure 3**). Main components of the system includes are Image capturing device (by camera or optical sensors), microprocessors (image processing and system control) and weed control actuators.

### Machine vision based spraying system

This system integrated with optical sensors and spraying system detects the weeds in real time, differentiate it from the crops and appliess hericide accordingly (**Figure 4**).

In GPS-controlled patch spraying, an application map has to be developed based on the interpolated maps of weed distribution and economic weed threshold value. The developed application map will be feeded into the spraying system where it sprays the herbicide according to the pre-decided dose. The herbicide application dose will be decided on the basis of weed density and area of coverage.

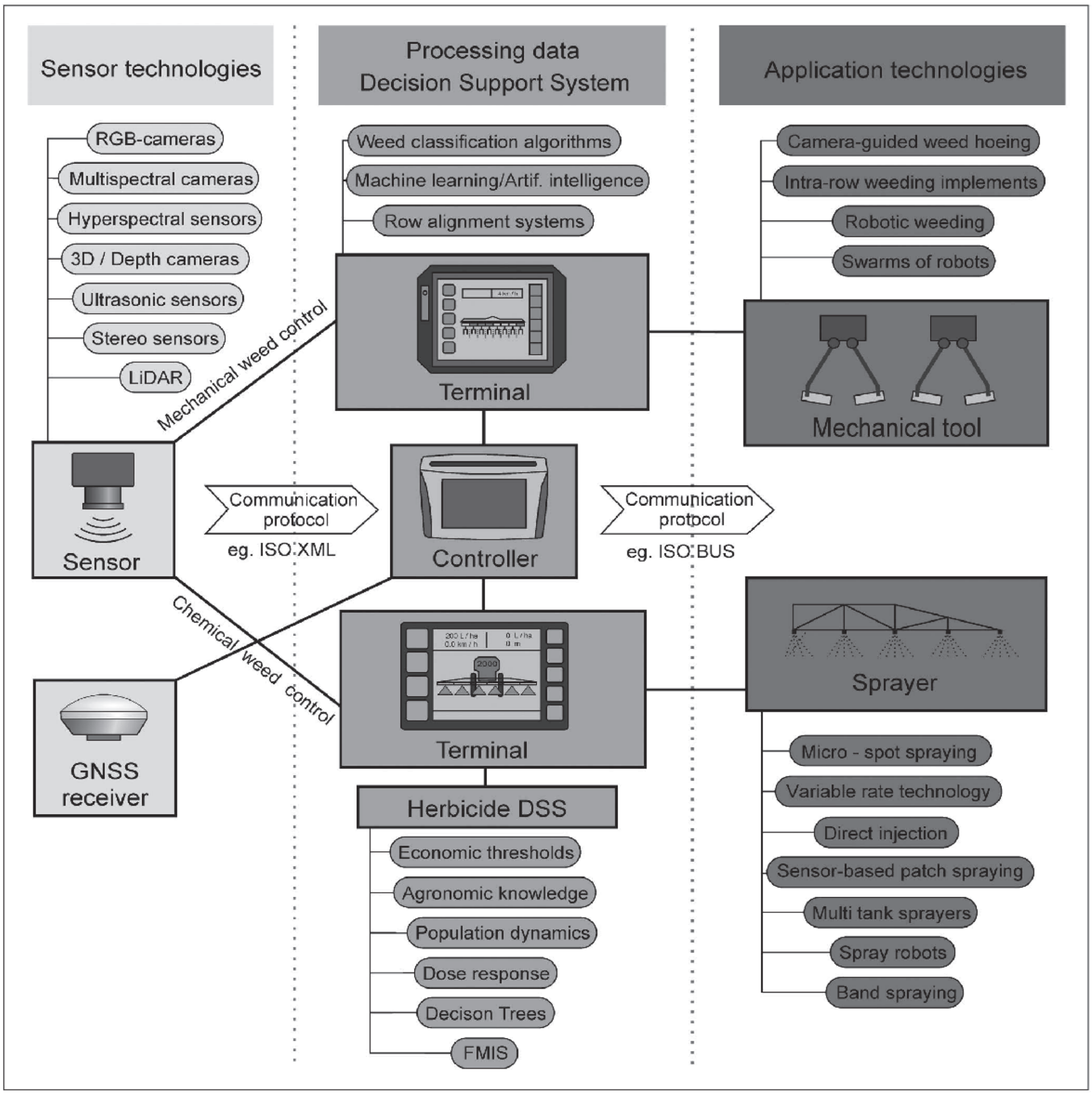



**Figure 1. Flowchart of the sensor identification, weed detection, decision making and actuation of weed controlling tool (Source: Gerhards *et al.* 2022)**

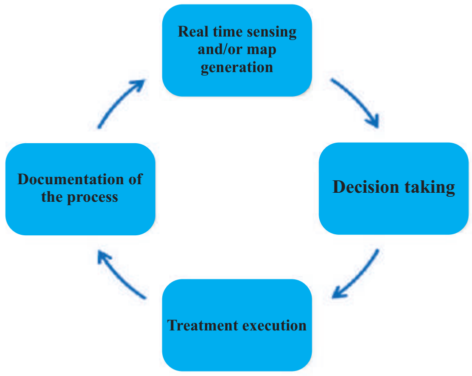



**Figure 2. Components of the site-specific weed management practices**

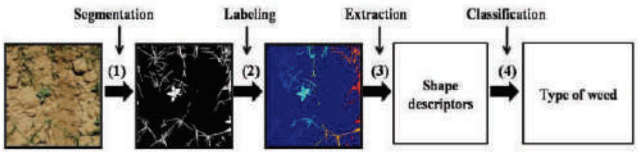



**Figure 3. Weed identification from the images (Source: Herrera *et al.* 2014)**

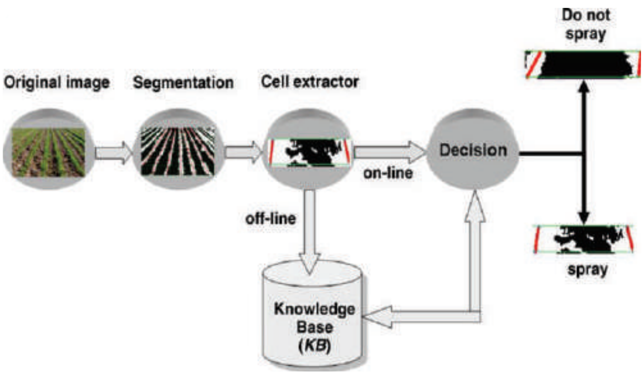



**Figure 4: Machine vision based spraying system (Source: Tellaeche *et al.* 2008)**

## Variable rate herbicide applicator

Variable rate herbicide applicator (VRA) is the application of herbicides based on area, location, and soil conditions, among other characteristics. In this method, significant factors are taken into account, including the variation in infestation and weed density in the application of herbicides in PoE and in the absorption capacity that the soil exerts in the application of herbicides in PE.

The variable rate herbicide applicators can be operated with both real time (optical sensor) and/or with interpolated maps of weed distribution and economic weed threshold (offline) method. Under optical sensor based system, the sensors detects the weed, their density and area of coverage and then decides the dose of herbicide needs to be applied. In map baed approach, variabale dose of herbicide applicaion map will be developed on the basis of weed economic threshold value and then the herbicide will be applied accordingly (**Figure 5**). Adoption of map based VRA techniques saves around 29% of the herbicide solution.

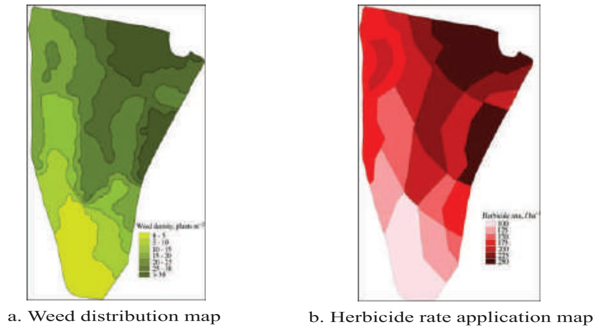



**Figure 5. Variable rate herbicide application map developed on the basis of weed distribution (Source: Carrara *et al.* 2004)**

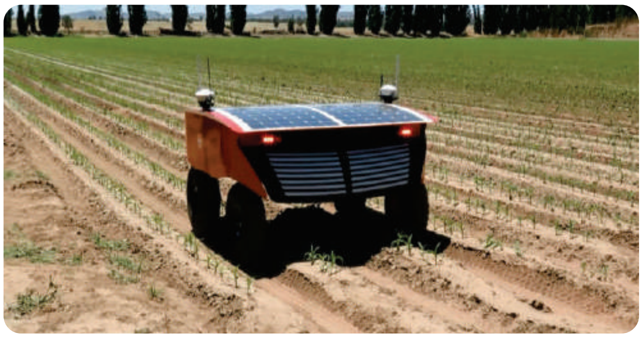


**Figure 6. RIPPA™ on a corn crop (Source: Sukkarieh 2016)**

## Robot for intelligent perception and precision application

The robot for intelligent perception and precision application (RIPPA) is an autonomous system developed by the University of Sydney for detecting weeds and applying herbicides in micro doses. The system has infrared and monochromatic sensors working with neural networks that make it possible to differentiate between crop and weed. Due to its small size and high precision, the system is suitable for smaller areas, such as horticulture. The RIPPA is powered by solar energy through solar panels on the top of the machine (**Figure 6**).

## WEED-IT

WEED-IT is a high-performance localized spraying system comprised of chlorophyll detecting sensors and ultra-fast valves that ensure application just where it is required (**Figure 7**).

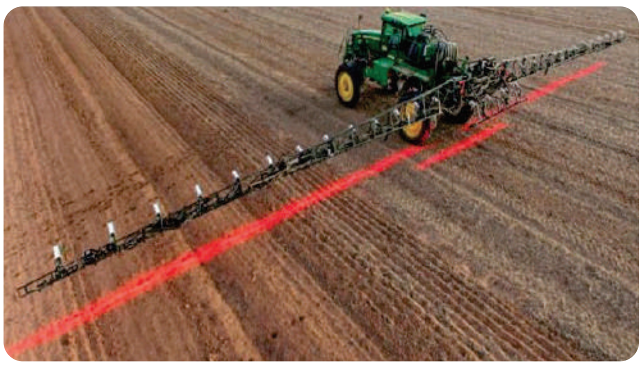


**Figure 7. WEED-IT Application of herbicide with weed detection by infrared sensors (Source: Lima *et al.* 2020)**

The system is based on concept of chlorophyll fluorescence: a light source in the system emits a constant beam of infrared light, which is absorbed by the plant's chlorophyll and re-emitted as near infrared light (NIR). The sensors detect this emission by taking 40,000 readings per second and capturing even the lowest chlorophyll fluorescence emissions by activating nozzle set just on the identified weeds, spraying only what is necessary, based on size of plant.

### WeedSeeker

WeedSeeker also works on the same principles as WEED-IT, where sensor emits a red and near infrared light and a photodiode detects the intensity of the reflected light. Later, the reading is converted into a command to apply or not the herbicide (**Figure 8**).

1: light emitting diodes produce a combination of invisible infrared and visible red light which is projected onto the target approximately 750 mm below the sensor.
2: The light reflected from the target is captured by a detector at the front of the sensor.
3: Sophisticated electronic circuits inside the sensor analyze the reflected light and determine when it matches the light reflected by green plants.
4: When green plant's reflectance is identified, the sensor waits until the plant is under the spray nozzle and then triggers a fast-fire solenoid valve which sprays the plant.

**Figure 8. WeedSeeker applying herbicide only to weeds (Source: Lima *et al.* 2020).**

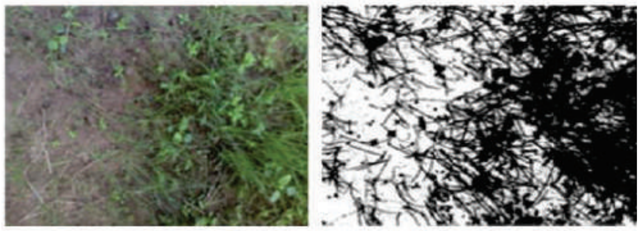
### Roller contact type real-time VRA herbicide applicator

A roller contact type VRA herbicide applicator was developed at IIT Kharagpur, which consits of herbicide storage tank, microcontroller, camera, solenoid valve, herbicide application roller and deflection manifolds. The system captures the images in real-time, anlysis and estimates density of weeds and decides the dose of herbicide application accordingly (**Figure 9**). Around 50% save of herbicide application has been reported by adopting the technology.

### Herbicide application through drones

The drones are unmanned aerial vehicles (UAVs) which are used to develop weed map and to applly the herbicide as part of the precision weed management practice. Through drones, target oreinted as well as variable rate application of herbicides can be performed with increase in field capcacity and efficiecny (**Figure 10**). In addition around 96% of water can be saved in drone based spraying systems.

a. Testing of the developed unit at field condition



b. Weed identificaton and estimation of weed density

**Figure 9. Roller contact type VRA herbicide applicator (Tewari *et al.* 2014)**

**Figure 10. Hebicide application through drone (Source: Anonymous 2020)**

### Row-centering RTK-GPS based cultivator cum band sprayer

A row-centering RTK-GPS based cultivator cum band sprayer was developed to control the weeds effectively in inter-row and intra-row areas. This system consists of a unique combination of inter-row cultivation tooling and intra-row band spraying for six rows with an GPS controlled electro-hydraulic side-shift frame (**Figure 11**). A 50% reduction in herbicide use and operational cost compared to conventional practice was observed in the system.

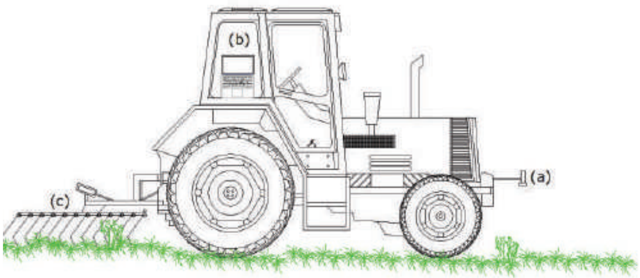
**Figure 11. Row-centering RTK-GPS based cultivator cum band sprayer**

### Machine vision based/ sensor-based weeding machines and robots

An automatic control of weeding operation is possible by using the RTK-GPS, optical and position sensrs like camera, laser, ultra sonic sensor and robotic arms/ weeding tools, etc. Under this system both online (real time) and offline method of weeding can be possible. In online method, a machine vision based system or an object detection based system is used to detect and differntiate the weeds from crops. Later, a decision will be made by a system to perform the weeding operation (**Figure 12** and **13**). In offline method, a GPS based position detection system used to perfrom the weeding operation (**Figure 14**).

### Algorithm based auto-adjusting of harrowing intensity

An algorithm based sysetm which auto-adjust the harrowing intensity was developed for site-specific management of weeds in wheat and barley. The harrowing intensity was auto-adujusted by varying the tine angle and number of passes. The field variability of crop leaf cover, weed density and soil density was acquired with geo-referenced sensors to investigate the harrowing selectivity




(a) The ultrasonic sensor mounted in front of the tractor;
(b) The computational unit responsible for gathering the sensor data, interpreting them, running the decision making algorithm and controlling the actuator
(c) The harrow actuator

**Figure 12. Ultrasonic sensor based online weeding (Sourece: Rueda-Ayala *et al.* 2015)**

**Figure 13. Machine vision based online weeding (Source: Anonymous 2018)**

**Figure 14. Autonomus RTK-GPS based weeding robot (Source: Bakker *et al.* 2010)**


(a) Soil sensor; (b) computing unit; (c) motor; (c1) light intensity; (c2) strong intensity; (c3) strongest intensity; (d) RTK-DGPS.

**Figure 15. Auto-adjusting flexible-tine harrow (Source: Rueda-Ayala *et al.* 2010)**

and crop recovery. Crop leaf cover and weed density were assessed using bispectral cameras through differential images analysis. The draught force of the soil opposite to the direction of travel was measured with electronic load cell sensor connected to a rigid tine mounted in front of the harrow (**Figure 15**). Optimal harrowing intensity levels were derived on the basis of pre-defined parameters based on weed control efficacy and yield gain. Varying the harrowing intensity thoughout the field reduces high weed density and slighlty increases the crop yiled.

### Microwave weeding

The microwave weeding involves the projection of microwave energy on the weeds and on soil through suitable devices to kill the plants and their seeds. The advantage of the microwave energy is that, it is not affected by weather parameters. An ultra high frequency (UHF) electromagnetic energy with wavelengths much greater than those of light (frequency 2450 Mhz and wavelength 12.25 cm) were used in the weeder system to kill a plant and weed seed bank. A portable microwave weeder has been developed and is available commercially (**Figure 16**).

**Figure 16. Microwave weeder (Source: Courtney 2021)**

**Figure 17. Laser beam based autonomus Weeder robot (Source: Lavars 2021)**

## Laser thermal beam based weeders

In this system, laser thermal beams were used to kill the weeds. System involves application of laser radiations on the plants, which affect the thermal balance of a plant and partially destroys the plant tissue through thermodynamic heat transfer mechanisms. Laser beams can selectively impair the growth of plants by destroying the sensitive growth centers (meristems), thus weed can be controlled effectively. However, the system requires a high spatial resolution for more accuracy. The commercially available laser theram beam based weeders can take out 1,00,000 plants per hour (**Figure 17**).

## Conclusions

Site-specific weed management technologies are required and need to be developed indigenously to increase the input use efficiency, environment friendly operations for effectively and ecologically enhancing crop production to meet out the increasing food demand. Through sensor based site-specific weed management, operational cost can be reduced by 30 to 90% and herbicide use by 50 to 80% over conventional practices.

## FURTHER READING


Anonymous. 2018. Robotic Weeding could be coming soon to a farm near you. Engineering.com. https://www.engineering.com/story/robotic-weeding-could-be-coming-soon-to-a-farm-near-you.

Anonymous. 2020. Central province to use drones in rice farming. Accessed from: https://vietnamnews.vn/society/738430/central-province-to-use-drones-in-rice-farming.html

Bakker T, Asselt KV, Bontsema J and Henten EDJV. 2010. Robotic weeding of a maize field based on navigation data of the tractor that performed the seeding. Preprints, Agricontrol 2010, IFAC International Conference, Kyoto, Japan.

Courtney R. 2021. Microwaving the weeds away - Australian engineer invents trailer-mounted weed cooker. Good fruit grower. https://www.goodfruit.com/microwaving-the-weeds-away

Gerhards R, Sanchez DJ, Hamouz P, Peteinatos GG, Christensen S and Quintanilla CF. 2022. Advances in site-specific weed management in agriculture—A review. *Weed Research* **62**: 123–133.

Herrera PJ, Dorado J and Ribeiro A. 2014. A novel approach for weed type classification based on shape descriptors and a fuzzy decision-making method. *Sensors* **14**: 15304–15324.

Lavars N. 2021. Autonomous weeder robot uses lasers to take out 100,000 plants an hour. New Atlas. https://newatlas.com/robotics/autonomous-weeder-robot-uses-lasers/

Lima A da C and Mendes KF. 2020. Variable rate application of herbicides for weed management in pre- and post-emergence. Pp. 1–25. In: *Pests, Weeds and Diseases in Agricultural Crop and Animal Husbandry Production*. Edited by Kontogiannatos, D., Kourti, A. and Mendes, F.S. Intech Open.

Rueda-Ayala V, Peteinatos G, Gerhards R and Andújar D. 2015. A non-chemical system for online weed control. *Sensors* **15**: 7691–7707.

Rueda-Ayala VP, Rasmussen J and Gerhards R. 2010. Mechanical weed control. Pp. 279–294. In: *Precision Crop Protection–The Challenge and Use of Heterogeneity*. Edited by Oerke EC, Gerhards R, Menz G, Sikora RA. Springer: Dordrecht, The Netherlands.

Sukkarieh S. 2016. An intelligent farm robot for the vegetable industry. Accessed from: https://www.horticulture.com.au/globalassets/laserfiche/assets/project-reports/vg12104/vg12014---final-report-complete.pdf

Tewari VK, Kumar AA, Nare B, Prakash S and Tyagi A. 2014. Microcontroller based roller contact type herbicide applicator for weed control under row crops. *Computers and Electronics in Agriculture* **104**: 40–45.

# Impact of toxic weeds on livestock

**Ashutosh Mishra* and Satya Nidhi Shukla**
*Nanaji Deshmukh Veterinary Science University, Jabalpur, Madhya Pradesh 482004, India*
**Email: ashu2397@gmail.com*

India with 11.6% of the world's livestock population, is the world's highest livestock owner. As per the 20th Livestock Census (2019) total Livestock population in the country is 536.76 million showing an increase of 4.8% over livestock Census-2012. The share of total Livestock population in rural areas (95.78%) is quite high as against 4.22% for urban areas. However, the average productivity of the animals is very low due to unavailability of balanced ration and proper veterinary facilities. Adequate fodder and feed are essential for optimum productivity of livestock. There is a deficit of 36% in the availability green fodder, 11% in dry fodder, and 44% for concentrates in the country (Singh *et al*. 2022). In rural areas, the much of the green fodder requirement of the animals with small and marginal farmers is still met with natural grazing. The population of livestock is increasing rapidly, but the grazing lands are gradually decreasing. Most of the available grazing lands are either degraded or invaded upon, limiting its availability for grazing. Severe infestation of invasive and toxic weeds in many grazing lands also limits the availability of natural grasses.

Weeds, in general, compete with desirable plant species for nutrients, moisture, solar radiation and space, and adversely affect the growth and productivity of the desired plant species. Although many weeds including natural grasses such as *Cynodon dactylon, Echinochloa* spp., *Brachiaria* spp., *etc.* are liked by the animals during grazing, but encroachment of grazing lands by certain weeds with toxicity potential like *Parthenium hysterophorus*, *Lantana camara, Ageratum conizoides,* etc. in grazing lands reduces livestock performance, land productivity and animal health. The weed infestation level in grazing lands largely depends upon the soil type, topography, rainfall and agro-ecological regions. However, still some weeds like *Cynodon dactylon*, *Cyperus rotundus*, *Parthenium hysterophorus*, *etc.* are most common in every ecology. Many toxic weeds such as *Parthenium, Lantana, etc.* grow in grasslands and pastures, road sides, railway tracts, and in other non-cultivated areas which livestock use to walk and graze. Because of their invasiveness due to excessive seed production, regular germination, vigorous growth and allelopathic effects, these weeds do not allow the other natural vegetation to grow, and thus, reduces the productivity of grasslands and pastures. Although these poisonous weeds are not liked by the animals during grazing, but many a times they do come in contact during walking through or grazing, and eat these weeds accidently. These weeds when mixed with fodder, animals may not be able to avoid the ingestion of such weeds.

Even common fodder crops like forage sorghum, forage maize, pearl millet, cowpea, berseem, lucerne, oats, and many cultivated grasses such as napier grass, guinea grass, dinanath grass, setaria grass, anjan grass, para grass, (some of these species are grassy weeds as well) *etc.* are infested with many toxic weeds such as *Parthenium* and others. Even these grassy fodder crops/grasses including grassy weeds also contains toxic compounds such as 'prussic acid (cyanogenic glycosides)' and 'nitrate' in various amounts that get accumulated in hot and dry conditions. Inside the animal's rumen the cyanogenic glycosides is hydrolysed to release hydrogen cyanide. Fatalities can occur when ruminants graze sorghum crop or fed sorghum hays containing excess level of prussic aid and or nitrate toxins. The sensitivity level of animal species to toxic plants may however vary. It is also quite evident that certain animal species may adapt to a potentially toxic plant if exposed for a longer period (Puschner *et al*. 2006).

The importance of toxic weeds vary depending on the availability of other plants (non-poisonous). If sufficient rainfall (moisture) is there for a longer period of time, the more palatable grasses may be available for grazing and the critical amount of toxic plants are not grazed. However, in drought conditions when most of the annual grasses may not grow sufficiently, the toxic weeds grow more vigorously and may be grazed by the animals due to non-availability of desirable plants leading to detrimental effects on animals. Lack of awareness of livestock farmers about the toxic plants, precautionary measures and knowledge of how to cope up with, are the major factors in animal poisoning.

## Impact of toxic weeds on animal productivity

The toxic weeds are of major concern to the livestock farmers and veterinarians because of their harmful effects to livestock in terms of chronic illness and debilitation, photosensitization, abortion and birth defects, death, reduction in productivity, *etc.* (Diaz 2011). However, the adverse effect of some of the weeds are not instantly understandable. Exposure of animals to toxic weeds may results to entering of toxic weed constituents in the animal body during grazing. This may leads to deterioration in animal health and quality of animal products. Toxic weeds vigorously growing in grazing lands are the main source of exposure of animals, but feed-lot and intensively reared livestock are also unprotected when toxic components of weeds pollute hay, grain and other items of feed (Edgar 1992). Some deleterious substances such as 'pyrrolizidine alkaloids' present in weeds like *Echium plantagineum* (paterson's curse) are considered to have a delayed effect on animal health and production (Molyneux *et al*. 1988). Some spiny weed species such as *Xanthium strumerium* (rough cocklebur), *Cenchrus pauciflorus* (spiny burrgrass), *Solanum xanthocarpum* (yellow-fruit nightshade) can deteriorate animal health and productivity by causing irritation in animals, prevent uniform grazing and reduce forage intake by causing physical damage to feet and mouth parts, eyes, etc.

## Lantana

Lantana (*Lantana camara*) is an invasive alien weed belongs to the family Verbenaceae. It is one of the most troublesome noxious weeds worldwide causing major threats to biodiversity and ecosystem. The weed was introduced in India by a British in 1809 as an ornamental plant. Most of the grazing lands in Himanchal Pradesh, Central India and Souther-western Ghats are occupied by this invasive weed. It competes with native plants for space and resources, and reduces the amount of forage available to livestock. Scarcity of green fodder is the main cause of Lantana toxicity. When hungry animals are sent to pastures/grazing lands, they consume lots of young lantana leaves (**Figure 1**). Because of its harmful effects in terms of mortality and reduction in productivity, it has emerged as a major threat to the livestock. The red flower species are more toxic than white and pink flowers. The toxic effects however vary depending upon the amount of toxic component consumed, species, age, size and body weight of the livestock. The majority of Lantana poisoning occurs when unfamiliar livestock are introduced to Lantana-growing areas. Young animals are more vulnerable. Lantana poisoning is more common in cattle, sheep, goats, guinea pigs, and rabbits.

The major toxic compound present in Lantana are triterpene acids, lantadene A (rehmannic acid), lantadene B, lantadene C, lantadene D, and their reduced forms. Lantadenes are mainly present in Lantana leaves. Cattle, buffalo and sheep are more susceptible as compared to goats to lantadene toxicity. A toxic dose for a 500 kg cow varies from about 5 to 20 kg of fresh leaf (one per cent or more of an animal's body weight), depending on the toxin content of the Lantana eaten.

The types and quantities of Lantana consumed as well as the amount of sunlight that the animals were exposed to will determine the symptoms of Lantana poisoning. After one feed and, in severe cases, within 24 hours, symptoms may appear. Poisoned animals may show following symptoms.

- Excessive skin sensitivity to sunlight (Photosensitisation) leading to necrosis.
- Depression, loss of appetite and decrease in ruminal motility
- Constipation and frequent urination
- Liver damage
- Yellow discolouration (Jaundice) of the whites of the eyes and gums, and skin of the nose and mouth
- Reddening and inflammation of unpigmented (white) skin, muzzle may become inflamed, moist, ulcerated and very painful (pink nose) and slough (fall off)
- Swelling of ears and eyelids if unpigmented
- Reddening and discharge from the eyes (Conjunctivitis)
- Ulceration of the tip and under surface of the tongue (if unpigmented)
- Blow fly and bacterial invasion of raw, exposed flesh, in chronic cases; affected skin may slough leaving raw ulcerated surfaces.
- In acute/ more severe cases (death within 2 to 4 days).

If untreated, the affected animals die in 1-3 weeks. Animals killed by Lantana poisoning show the following post-mortem symptoms:

- Yellow discolouration of tissues (jaundice)
- Hard, dry, mucus-covered faecal masses in large intestine
- Dry, undigested plant material in the rumen
- Swollen and discoloured (yellow to orange) liver
- Swollen gall bladder
- Swollen and pale kidneys that turn green when exposed to air and cutting
- Ulcerated cheeks, muzzle, nostrils, tongue and gums (in severe cases in cattle).

## Treatment

- Giving intravenous fluids to the animal and encouraging it to eat
- Antibiotics and sunscreens are used to treat skin damage; other medications that can provide relief are only available with a veterinarian's prescription.
- Drenching with a slurry (2.5 kg activated charcoal in 20 litres of electrolyte replacement solution for cattle; 500 g in 4 litres for sheep and goats).
- Activated charcoal is the best antidote to reduce poisoning. Bentonite, is another cost-effective treatment.

## Parthenium

Parthenium (*Parthenium hysterophorus*) also known as congress grass or carrot grass in India, has quickly become a serious weed in the majority of nations. It is a serious invasive weed of pasture and other grazing lands, reducing their productivity to a large extent (**Figure 2**). In addition to its invasion in non-cropped areas, it has now spread in many crop fields including fodder crops. This noxious weed reduces crop yields and quality, increases production costs, and significantly threatens biodiversity and human, livestock and environmental health.

**Figure 1. A. Lantana shrub, B. Grazing land covered with Lantana, C. Goats grazing Lantana leaves (Photos by: Dr. Himanshu Mahawar)**

**Figure 2. A. Grazing land infested heavily with parthenium. B. Cattle movement in Parthenium infested grazing land Photo Credit: Agricultural Research Council - Plant Health and Protection;** (https://www.agrilinks.org)

Exposure to *Parthenium* causes systemic toxicity in livestock. Feeding the weed to animals at different levels causes both acute and chronic forms of toxicity. The harmful health effects of the weed are ascribed to the 'sesquiterpene lactones' and 'parthenin' content in the plant which are toxic to livestock. Animals living in Parthenium-infested areas in India face serious health risks. Parthenium causes lesions, mouth ulcers, rhinitis, asthma and atopic dermatitis diseases in animals. Reduced fertility, and even there may be death of the animal in extreme cases, if livestock consume an excessive amount of *Parthenium*. While goats willingly graze *Parthenium* weed, cattle and buffalo dislike it. *Parthenium* intake during grazing affects both milk and meat quality. The milk of cattle, buffalo and sheep may be tainted. The price of tainted milk is lower than that of untainted milk tainted due to bitter taste.

Animals that consume Parthenium may develop:

- Dermatitis and noticeable skin lesions in a variety of animals, including horses and cattle.
- Ulceration of muzzle and alimentary tract, dental pads, tongue and palate, necrosis and severe congestion of liver and gastrointestinal tract, and congestion and oedema of lungs (https://www.cabi.org/).
- In dogs, along with acute illness, it also makes dogs anorexic, itchy, alopecia, diarrhoeic, and irritation in the eyes.
- Bitter milk disease in livestock if grazing animals fed grass contaminated with *P. hysterophorus*.
- Weakened immune system due to reduction in WBC count.

## Treatment

It is suggested to give symptomatic treatment to affected livestock. Medications should be done with a veterinarian's prescription.

- Dermatitis lesions are treated by applying topical agents to the affected skin. Topical oxytetracycline (OTC) is the most reliable treatment for quick recovery.
- For treatment of diarrhoea, use of antibiotics or anthelminthics, anti-inflammatories, rehydration fluids, mineral supplementation, and ration management.
- Antibiotics and eye drops are typically prescribed for canine eye irritation.
- Giving the animal intravenous fluids and enticing it to eat.
- Antibiotics and sunscreens are used to treat skin damage.
- Drenching with a slurry with activated charcoal.

**Table 1. Toxic weeds for livestock**

| Weed species | Poisonous parts | Symptoms |
|---|---|---|
| *Ranunculus* spp. | Leaves and stems | Oral and gastrointestinal irritation. Inflammation and blisters where plant juice touched the animal. |
| *Xanthium strumarium* | Young seedlings and seed. The seed bur causes mechanical injury. | Weakness, depression, nausea, vomiting, rapid weak pulse, twisting of neck muscles. |
| *Datura stramonium* | Seeds contain the greatest concentration of the toxic alkaloids atropine, hyoscyamine and hyoscine. | Increased heart rate, tremble, become delirious, appear to be hallucinating, have convulsions, become comatose, and may die. |
| *Sorghum halepense* | Leaves and stems of young shoots contain cyanide. Under stress conditions, cyanide becomes readily available in the leaves. | Deep and rapid breathing, anxious and stressed, trembling, incoordination, attempts to urinate and defecate and collapsing leading to death. |
| *Asclepias* spp. | Stems, leaves and roots contain glycosides. The sap contains a resin, known as galitoxin, which contributes to its toxicity. | Muscle tremors and spasms, bloat, increased heart rate, difficult breathing, and occasionally death. Toxic signs are more apparent in animals that cannot vomit, such as horses. |
| *Solanum* spp. | Foliage and egg-shaped berries | Abdominal pain, stupidity, dilation of pupils, loss of appetite, diarrhoea, loss of muscular coordination, unconscious and death. |
| Brassica spp. | All parts, especially seeds contain isoallyl thiocyanates, irritant oils, and under some conditions, nitrates. | Oral and gastrointestinal irritation is most common leading to head shaking, salivating, colic, abdominal pain, vomiting and possibly diarrhoea. Generally, for problems to occur, large quantities have to be consumed over a period of time. |
| *Euphorbia* spp. | All parts | Nausea, vomiting and diarrhea. The toxins are diterpene esters contained in the milky sap of the plant. Contact with sap causes inflammation of skin. |
| *Eupatorium rugosum* | Leaves and stems | The toxic component is tremetol. Symptoms include depression, stiff gait, muscle tremors, trembling, partial throat paralysis, jaundice, passage of hard feces and prostration. Death may be sudden with no prior signs of toxicity. Because tremetol is excreted in the milk, nursing animals will be affected by the toxin. |
| *Croton capitatus* | All parts | Cattle are poisoned by the croton oil contained in the plants. It is toxic only if large quantities are consumed. Vomiting, diarrhoea and nervousness are primary symptoms. |

Source: Fred Fishel, Plants poisonous to livestock. https://extension.missouri.edu/publications, Common weeds poisonous to grazing livestock. http://omafra.gov.on.ca/

## Other weeds

In addition to above, there are many other weeds (**Table 1**) which are poisonous to livestock. These weeds may be found in cultivated fields, farm fence, roadsides, hedge rows, *etc*.

## FURTHER READING


Diaz GJ. 2011. Toxic plants of veterinary and agricultural interest in Colombia. *International Journal of Poisonous Plant Research* **1**: 1–19.

Edgar JA. 1992. Impacts of weeds on animal productivity. pp. 140–144. In: *Proceedings of the First International Weed Control Congress*, Melbourne.

Molyneux RJ, Johnston MS and Stuart LD. 1988. Delayed manifestation of Senecio-induced pyrrolizidine alkaloidosis in cattle: Case report. *Veterinary and Human Toxicology* **30**: 201–205.

Puschner B, Peters A and Woods L. 2006. Toxic weeds and their impact on animals. Pp. 1-6. In: *Proceedings, 2006 Western Alfalfa and Forage Conference, Sponsored by the Cooperative Extension Services of AZ, CA, CO, ID, MT, NV, NM, OR, UT, WA, WY.* Published by: UC Cooperative Extension, Agronomy Research and Extension Center, Plant Sciences Department, University of California, Davis.

Singh DN, Bohra JS, Tyagi V, Singh T, Banjara TR and Gupta G. 2022. A review of India's fodder production status and opportunities. *Grass and Forage Science* **77**(1): DOI:10.1111/gfs.12561

# Biological control of Parthenium, water hyacinth and water fern: A few successes stories

**Sushilkumar***
*ICAR-Directorate of Weed Research, Jabalpur-482 004, Madhya Pradesh, India*
*Email: sknrcws@gmail.com*

Biological control of weeds involves the use of living organisms to manage a weed population to keep at or below desirable level without significantly affecting useful and wanted plants. The history of biological control of weeds dates back to the seventeenth century and since then a great deal of success has been achieved in biological methods of weed control. In fact, the first unintentional outstanding success of biological control of prickly pear in India during 1795 by cochineal insect led the word to use natural enemies against exotic weeds. It is evidently proved that biological control methods do best on large infestation of a single weed species, which usually occurr in rangelands or in water bodies. In spite of abundant success in classical biological weed control in wasteland and fallow land or large water bodies, it has not developed to the point that it has any appreciable impact on to suppress weeds in cropping situations. Biological control includes the classical (inoculative), bioherbicides (inundative) approaches and herbivore management. In India, maximum degree of success with classical biological control agents was achieved in biological control of aquatic weeds (55.5%); homopterous pests in crop situations (46.7%) followed by terrestrial weeds (23.8%).

## SUCCESSES STORIES OF BIOLOGICAL CONTROL OF PARTHENIUM, WATER HYACINTH AND WATER FERN IN INDIA

### Biological control of Parthenium

*Parthenium hysterophorus* (Family: Asteraceae) is an alien and invasive notorious weed known for causing health hazards to man and animals besides loss to crop productivity and biodiversity. It abundantly occurs throughout India except at very high elevation and desert areas. It has the capacity to grow at any time on the availability of adequate moisture (**Figure 1**). It proliferates quickly by rapid and abundant production of seeds, which are very light and small hence easily get dispersed across vast areas quickly. The weed has spread to all the states of India covering about 35 million hectares land after its noticeable occurrence in Pune (Maharashtra) in 1956.

**Figure 1. Parthenium menace on road side, near water channel and in the forest**

**The technology:** In non-cropped area, Parthenium can be managed effectively by using a host specific exotic bioagent *Zygogramma bicolorata* of family Chrysomelidae, a native of Mexico, which is also the adobe of Parthenium. The bioagent in 500 to 1000 numbers should be released in the Parthenium infested area in 50 to 100 numbers in different patches covering entire infested area during rainy season (June to August) when plenty of fresh Parthenium plants are available. After establishment, the bioagent will themselves migrate from non-cropped area to cropped area to destroy *Parthenium* amidst the crop.

Once established, bioagents work on sustainable basis. On approaching of winter season, a survived population undergoes in diapauses in soil and emerges intermittently in future when conditions become suitable for them. Maximum population emerges during the succeeding rainy season but a part may emerge throughout the year. Augmentative release may be made by collection of adult beetles from area of abundance to the area of poor establishment to increase the existing population of the bioagents. Biological control not only helps to control existing population of Parthenium but also helps to reduce the seed bank of Parthenium in long term in the infested site encouraging the establishment of other vegetation and restoration of biodiversity which was lost due to invasion of Parthenium (**Figure 2**).

In North, South and central parts of India, this bioagent has shown spectacular success in large area to bring down the Parthenium population below infestation level and helped the local vegetation to grow in the niche vacated by the Parthenium.

### How beetles kill the Parthenium?

Both adults and grubs are capable of feeding on Parthenium leaves. Grubs after hatching, starts to feed on soft growing leaves which on maturity prefer mature leaves. Adults also feeds on leaves. On well establishment after its release in Parthenium infested area, it may cause large scale defoliation of Parthenium (**Figure 3** and **4**). Continuous defoliation of Parthenium brings reduction in seed bank and restoration of other vegetation. In general *Z. bicolorata* remained most active during July to September except a few exceptions where beetle had caused appreciable damage on Parthenium, during February to April at some places in patches near the good moisture regime.

### Economic benefits of biological control by *Z. bicoorata*

In a study conducted at Jabalpur, it was found that the beetle controlled 200-hectare land infested with Parthenium within three years of its release and by fourth, fifth and sixth year of its release, beetle caused 100% control in the area of about 900, 4000 and 18000 hectares, respectively besides mild to severe damage at the places of its spread. In a conservative estimate made in 2022, it was found that *Z. bicolorata* has spread and established well in about 25 million hectares out of 35 million infested area of India, which amounts to be about 71% area. This bioagent controls Parthenium at varied level from nil to 100%. Taking only 10% complete control (100%) amounts the saving of about ₹ 6 billion every year in terms of herbicides required to control it. If we also calculate 10 to 80% varied level of control by the bioagent, the benefit will be more than about ₹ 20 billion very year by this single bioagent.


**Figure 2. Sequence of restoration of biodiversity due to continous efficacy of bioagent in a site**

**Figure 3. Sequence of killing of Parthenium plants by adults and larvae of *Z. bicolorata***


**Figure 4. Sequential stages of bio-control of Parthenium by *Z. bicoorata* in a severely infested area**

Restoration of biodiversity and creation of healthy environment are the additional benefits.

**Precaution:** After release, bioagents start breeding soon and enhance their population in due course. The initial releases must be made on small and succulent growth of Parthenium in undisturbed areas. Once plants are eaten up in the released area, the insects migrate to adjacent areas. Initial release should be avoided in cultivated land because ploughing of land may disturb the pupation process hence poor survival and subsequent establishment. Low lying areas prone to water logging should also be avoided because pupation takes place in soil and if bioagents are released in such area, there will be no proper population build-up due to death of pupae during inundation of the area.

In addition to Mexican beetle, growing competitive crops (fodder, sorghum, sunflower and maize) or self-perpetuating competitive plant species like *Senna sericea*, *S. tora* and *Tagetus erecta* in non-crop ped areas is also effective to manage Parthenium. In non-cropped area, *S. tora* at the rate of 40-60 kg/ha should be broadcasted in the pre-marked Parthenium infested sites during March-April. The plants will grow during rainy season and will replace Parthenium. In the protected premises and farms, on the road side and bunds in field where Parthenium grows, marigold should be grown. Marigold will dominate over Parthenium in addition to suppressing nematode populations. By this approach, extra earning can be done by selling flowers besides beautification of premises (Video Hindi: https://www. youtube.com /watch?v=i4S45K-aqTY&t=8s and video English https://www.youtube.com/watch?v= UIZrZOAhkiQ&t=153s.

### Biological control of water hyacinth

Water hyacinth, *Eichhornia crassipes* Mart (Solmns.) is a free-floating, annual or perennial exotic aquatic plant of Brazilian origin. In India, the plant was first introduced into West Bengal, most probably in early 1890s as an ornamental plant but by now it has spread in all types of fresh water bodies throughout the country covering about 0.80 million hectares of water surface. It has been categorized as one of the worst 10 weeds of the world. It is one of the most successful colonizers in the plant kingdom with beautiful lavender blue flowers which produce seed prolifically, an important factor contributing to its distribution besides fast vegetative reproduction. The seeds have been reported to remain viable in water bodies up to 20 years. Water hyacinth is a major menace severely affecting navigation, fishing, recreational use of aquatic bodies and hydroelectric generation. It causes human health hazards by harboring harmful insects and vectors of diseases. Due to its negative impacts the water hyacinth is popularly known as 'Blue devil'. A huge amount of money is spent world over every year for controlling this pernicious weed – thus qualifying for the sobriquet "*Million dollar weed*". By increasing the evapotranspiration losses of water by three times of the natural surface evaporation, the weed is responsible for drying up of innumerable water tanks and ponds which are the mainstay of agriculture in rainfed areas besides causing malaria, encephalitis, filariasis *etc*.

In India, some of the well-known fishery lakes like Ansupsa lake in Orissa, Gujar lake in Uttar Pradesh, Kollern lake in Andhra Pradesh and the world famous Dal, Nagin and Walur lakes in Kashmir, Ootacmund and Kodaikanal in Tamil Nadu, many lakes and water bodies like water canals, ponds and dams in Rajasthan, Gujarat, Maharashtra, Haryana, Punjab *etc.* have been largely infested with water hyacinth. This weed has received prime attention by the planners and Government. Manual or mechanical methods of its control are not cost effective. In general, about ₹ 60,000 to 1.0 lakh are required to remove water hyacinth from a severely infested water body. Use of herbicides is effective and economical but may have potential risks on non-target organisms, water quality and due to multifaceted use of water such as for human drinking and washing. Moreover, there is lack of label claim herbicides to control aquatic weeds in India in general and water hyacinth in particular.

**Biocontrol technology:** Exotic bio-control agents, two coleopteran weevil namely *Neochetina bruchi* and *N. eichhorniae,* commonly called *Neochetina* spp. are effective bioagent for biological control of water hyacinth. The Adults of *N. eichhorniae* and *N. bruchi* are superficially very similar but *N. bruchi* is slightly larger and can be distinguished easily by the broad, crescent–shaped or chevron like tan band across the elytra (**Figure 5**). The presence of bioagent can be distinguished easily by observing feeding scarce on the leaves of water hyacinth (**Figure 5**). *Neochetina. eichhorniae* and *N. bruchi* deposit their eggs below the epidermis of the petioles and laminae near the base. Full-grown grub come out and pupate on live roots of water hyacinth by cutting small lateral rootlets for making a small spherical cocoon around themselves. Under ideal conditions the grub and papal periods are completed within two months. The adults of *N. eichhorniae* and *N. bruchi* live for 125 - 145 and 128-138 days and lay about 880 and 688 eggs, respectively. The mean egg production was 4.5 eggs per day. The typical adult damage on the leaf in the form of symmetrical scrapings/scars could be easily distinguished (**Figure 5**). Incidentally both the weevils have different feeding preferences. *N. bruchi* preferred the area beneath the basal ligules of the outer leaves wrapped around the central petiole. Both the species co-exists together. It is also well known that *N. bruchi* is relatively more active in warmer months and *N. eichhorniae* in colder months. *N. eichhorniae* has a lower rate of growth. The bioagent in 1000 to 5000 number may be released in the water hyacinth infested aquatic bodies in different patches in 50 to 100 numbers in each patch covering entire pond area. Though weevils can be released at any time of the year, but the optimal time for initial releases, especially in tanks and lakes is after the commencement of rains. Once, the bioagent is established in the released area, the augmentative release may be made by collection of adult beetles from area of abundance to area of poor establishment. After multiplication, the bioagents will themselves migrate from attacked area to non-attacked area of the pond. The Insects control water hyacinth in cycles. In general, weevils take about 20-48 months to achieve first cycle of control depending on number of initial releases (**Figure 6**). Second and subsequent cycles of control may occur in 11 to 24 months depending on the population build-up of the bioagent Successful establishment and control of water hyacinth by the weevil have been reported from different parts of India like Karnataka, Uttar Pradesh, Madhya Parades, Andhra Pradesh, Haryana, Maharashtra

**Figure 5.** ***Neochetina bruchi*** **and scarce caused by it on water hyacinth leaves**

*etc*. In Jabalpur (MP), water hyacinth in 5 water bodies was controlled using *Neochetina* spp. (https://icar.org.in/files/dwsr-Story6.pdf : https://www.youtube.com/watch?v=feyRhAGRcvs&t=50s).

**The economic benefits:** The benefit of biological control can be judged comparing the cost of herbicides used or the expenditure to be incurred for manual removal of water hyacinth. In general, manual removal from one hectare area may cost about ₹ 60,000 to 1.0 lakh per hectare for one time removal depending on the severity of infestation while biological control may cost only a few thousands for initial release of bioagents and subsequently by augmentative release. The bioagent may also be collected free of cost from the bioagent infested ponds engaging labors. Thus, the only cost of labors may be taken as an expenditure. The biological control is self-perpetuating and will require minimum efforts for fast re-establishment in the same water body if weeds regenerates from the seeds, which remain buried in the mud. The benefit is more

**Figure 6. A same pond before (1) release of bioagent, severe infestation of bioagent has dried the weed (2) and clear pond (3) after gradual decay and sinking of attacked water hyacinth**

than the direct estimated cost in terms of saving loss of water and reducing disease incidence caused by the mosquitoes.

**Precaution:** The bioagents works well in the bounded aquatic bodies like ponds, lakes and tanks where water remains throughout the year. The release of bioagent should be avoided in the water bodies, which are likely to dry during summer season. In such situations, bioagetns will not be able to multiply due to anchoring of roots in the soil as its pupation takes places amidst the floating roots of water hyacinth. The bioagent will not work effectively on water hyacinth in running water like in rivers and irrigation canals because bioagent population will disperse fast in such situation and will not be multiplied as desired to exert effective population pressure for biological control of water hyacinth. The bioagent infested water hyacinth mats are carried away by flood water during rainy season in such situations which, however, helps for self-spread of bioagents to far areas.

### Biological control of water fern

The *Salvinia molesta*, commonly known as "water fern" is an aggressive and a fast-growing alien invasive aquatic weed of the South-Eastern Brazil origin. This free-floating perennial aquatic plant is also popularly called as 'Kariba weed' after its widespread incursion in lake Kariba, a very big reservoir along the Zambia–Zimbabwe border. *Salvinia molesta* has spread extensively throughout the world, becoming an invasive alien species in many countries including India. In view of its seriousness, it has also been added in the list of the world's 100 most problematic invasive weeds. The weed affects irrigation, hydroelectric generation, water availability and navigation choking rivers, canals, lagoons besides drastic reduction in fish production. In Kerala (India), it was first seen in 1950s in Veli Lake of Thiruvananthapuram but soon became invasive causing navigational problems, interfering with irrigation and fishing, rendering the water unfit for human consumption, and facilitating mosquito breeding, *etc. Salvinia* infestation in more than 30,000 hectares of paddy in the 'rice bowl' Kuttanad area of Kerala during 70s made rice cultivation costly because of the labour-intensive clearing work before planting.

In central India, first time during a survey, severe infestation of *S. molesta* was noticed in Satpura reservoir at Sarni in district Betul of Madhya Pradesh in more than 70% out of total 1100 hectare area of reservoir. The severe infestation of *S. molesta* in Central part of India adjoining to Northern part of India prompted the author to undertake a study to delineate its further spread in other parts of India out of its earlier well documented habitat and to explore the possibilities of its biological control in this region of India by the bioagent *Cyrtobagous salviniae*, which has provided an effective and sustainable solution in Kerala and other areas of introduction. However, its effect was not yet studied in Central and Northern part of India, which faces large temperature fluctuations. The severe occurrence of *S. molesta* during surveys were recorded in 09, 12, 04 and 01 water bodies in Madhya Pradesh, Maharashtra, Chhattisgarh and Haryana, respectively. This spread in different parts of India having wide climatic range clearly reflects its increasing invasion in India.

**The technology:** The bioagent *Cyrtobagous salviniae* (Coleoptera: Erirhinidae), has provided an effective and sustainable solution to control this dreaded weed. The bioagent was first searched by in the native range of Brazil. The weevil was first released as a biological control agent onto *S. molesta* in Australia in 1980 and has afterward been released in 22 countries included India and in 17 countries, its general impact has been significant. This Brazilian native was imported into India via Australia in 1982 and after its host-specificity tests, it was released first in Bengaluru and subsequently into Kerala. After its introduction, bioagent did extreme suppression of *Salvinia* throughout Kerala and now weed is not a problem in Kerala and is under an equilibrium status with bioagent.

A pond of about 20 hectares was selected in the village Padua of Katni district in Madhya Pradesh for demonstration of biological control using bioagent *Cyrtobagous salviniae* brought from Kerala. This pond was severely affected by *Salvinia molesa* since 2015 and all the efforts by villagers, to remove the weed from the ponds, were proved futile due to its aggressive multiplication. About 2000 adult weevils collected from the Kerala were released in the mid of the pond in December, 2019 after population build-up, augmentation releases were made. There was no visible impact of bioagent by the June, 2020, however 50, 80 and 100% of water surface appeared during September, 2020, November, 2020 and June 2021, after 9, 11 and 18 months of release of weevil, respectively (https://icar.org.in/content/biological-control-alien-invasive-weed-salvinia-molesta-central-india-0 and https://www.google.com/url?sa=t&source=web&rct=j&url=https://en.gaonconnection.com/weed-insects-madhya-pradesh-invasive-plant-salvinia-molesta-cyrtobagous-salviniae-water-bodies-ponds-hyacinth/&ved=2ahUKEwjykeHs9oH1AhVbyYsBHURFBQIQFnoECAkQAQ&usg=AOvVaw3lnAXcmI97iz11_W8edCm3). It was first successful demonstration of biological control of *S. moleta* by *C. salviniae* in central India (**Figure 7**) out of its known habitat of Kerala and Karnataka. Seeing this biological control success, bioagents have been released in different 15 water bodies comprising of about 3400 hectares areas.

**The economic benefits:** The cost to remove *Salvinia* from a water body may requires ₹ 60,000 to 1.0 lakh per hectare for one time removal depending on the severity of the weed. It was estimated that ₹ 170 million were required to remove the *Salvinia molesta* from the 1100 hectares large reservoir Sarni in Betul district of Madhya Pradesh, India.

**Precaution:** The release of bioagent should be avoided in the water bodies, which are likely to dry during summer season or in running water such as rivers and canals. In such situations, bioagents will not be able to multiply. The bioagents works well in the perennial water bodies.

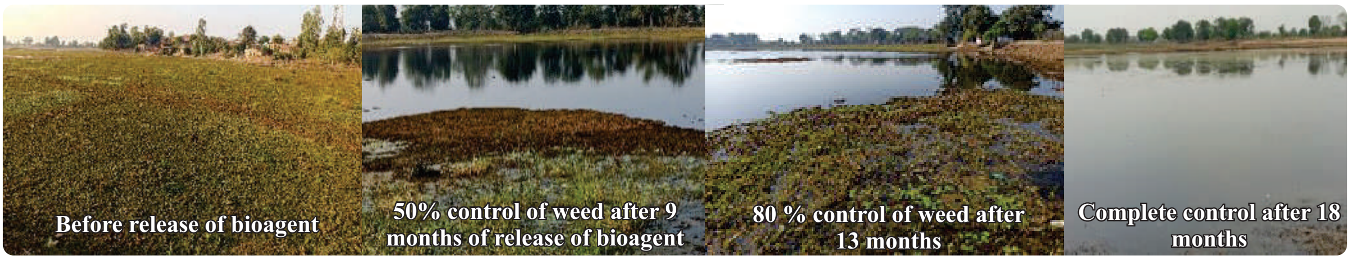



**Figure 7. Successful biological control of *Salvinia molesta* in Madhya Pradesh**

## Frequently asked questions on biological control

**Advantage of biological control:** It is inexpensive; It poses little threat to non-target organism; Once established, self-perpetuating and can spread on their own; Little additional efforts are required once a biological control organism is established while other control measures require inputs periodically: Poses no threat to environment and biodiversity: Easy to integrate with other control measures.

**Limitation of biological control:** It is not broad spectrum; It requires host specificity; It needs specific climate and conditions; It loses its efficacy after passing of the time.

**Types of bio-control agents:** Insects; Fish; Fungus; Nematodes; Snails, Slugs *etc*. Insects followed by pathogens have received maximum attention in biological control of weeds.

**How do these bioagents harm their target weeds?** By destroying flower buds, growing points and seeds; Destroying stem and roots zone; Making galls on stems; Defoliating the plant completely

**Are herbicides compatible with bio-control?** Yes. Generally, first release of bio-agents should be in an area away from livestock, and not mowed or sprayed and at least two years should be allowed for insect population build up. Herbicides can be integrated as for most of the cases while herbicides may not kill the bio-control agents, the damage done to the host plants prevents the insects from completing their development, and hence timing of spraying should be on the basis of development of the insect.

**How many numbers of bioagents are enough for weed infestation?** More releases means more quick establishment of the bioagent hence more early control. So, do as many releases as affordable during first couple of months of introduction and make additional releases in isolated area in future. This method reduces the time for an insect to build up and help insects to disperse fast. The least affordable approach is to introduce one or two releases into infested area and do nothing more. This method will get a colony started but will be slow in terms of time and area

**What happens to the bioagents after the weeds are destroyed?** Weeds will never be eradicated. Some plants will always escape from the attack, which will allow the bioagent population to sustain itself during years of low weed density.

## FURTHER READING

DWR. 2012. Environment friendly biological control of Parthenium. Extension Bulletin. Directorate of Weed Science Research (DWR), Jabalpur, Madhya Pradesh, India.

DWR. 2012. Integrated Parthenium management. Extension Bulletin. Directorate of Weed Science Research (DWR), Jabalpur, Madhya Pradesh, India. (https://dwr.icar.gov.in/Downloads.aspx).

Harley KLS and Mitchell DS. 1981. The biology of Australian weeds. 6. *Salvinia molesta* D.S. Mitchell. *Journal of the Australian Institute of Agricultural Science* **47**: 67–76.

Jayanth KP. 1987. Biological control of the water fern *Salvinia molesta* infesting a lily pond in Bangalore (India) by *Cyrtobagous salviniae*. *Entomophaga* **32**: 163–165.

Joy PJ, Satheesan NV, Lyla KR and Joseph D. 1993. Biological control of aquatic weeds in Kuttanad. Pp. 153–155. In: *Proceedings of the National Symposium on Rice in Wetland Ecosystem*, Kottayam, India,

Julien M, 2012. *Salvinia molesta* DS Mitchell – Salvinia. Pp 518-525. In: Biological control of Weeds in Australia, (Eds. Julien M, McFadyen R, Cullen J), CSIRO, Australia.

Martin GD, Coetzee JA, Weyl PSR, Parkinson MC and Hill MP. 2018. Biological control of *Salvinia molesta* in South Africa revisited. *Biological Control*. **125**: 74-80.

Michael JP, Pratt PD, Villegas B, Popescu V, Borkent C and Reddy AM. 2021. Biological control of water hyacinth, *Pontederia crassipes* ©. Mart.) Solms (Pontederiaceae), in California: release and re-distribution of biological control agents 1987–2006. *The Pan-Pacific Entomologist* **97**(2), 55–66.

Sushilkumar, Kumar L and Gharde Y. 2022. Enhanced biological control of Parthenium by release of female dominated sex ratio population of *Zygogramma bicolorata* Pallister. *Indian Journal of Weed Science* **54**(1): 58–65

Sushilkumar. 2012. Current spread, impact and management of Parthenium weed in India. *International Parthenium News* **5**: 1-6

Sushilkumar. 2011. Aquatic weeds problems and management in India. *Indian Journal of Weed Science*, **43**(3&4) : 118-138.

Sushilkumar. 2006. Economic benefits in biological control of Parthenium by Mexican beetle, *Zygogramma bicolorata* pallister (Coleoptera: Chrysomelidae) in India. *Annals of Entomology* **24**(1&2): 75–78.

Sushilkumar. 2005. *Biological control of Parthenium through Zygogramma bicolorata*. National Research Centre for Weed Science, Jabalpur, India: 88p.

# Some thoughts on the occasional failure of herbicides to manage weeds

**Amit J. Jhala***
*University of Nebraska-Lincoln, USA*
**Email: Amit.Jhala@unl.edu*

Herbicides are chemicals being used globally for weed management since several years in several crops and cropping systems. Herbicides usage is an important and effective tool in the toolbox for weed management for the improvement in crop productivity and profitability by limiting negative impact of weed competition with crops. If applied as per label instructions, herbicides provide effective control of weeds listed in the label; however, there are certain conditions or weather limitations where weed management with herbicides fail. Here are some causes for failure which need to be corrected while using herbicides to prevent herbicides failure to manage weeds and enhance herbicides efficacy.

### Untimely herbicide application or incorporation

Timely herbicide application is critical for optimum weed control. Residual pre-emergence herbicides must be applied before crop and/or weed emergence. Additionally, moisture is needed to activate pre-emergence residual herbicides. Therefore, if irrigation or rain events do not occur within 12 days of residual herbicide application, a light tillage is necessary to incorporate the herbicide into the soil to improve activation. If weeds have germinated and emerged before the pre-emergence residual herbicide incorporation and activation, residual herbicide program will fail.

### Too much rainfall and/or irrigation

The variability of weather is a major cause of unreliable herbicide performance resulting in either inadequate control of weeds or crop damage (**Figure 1**). For example, excess rainfall after residual herbicide application increases the likelihood of herbicide leaching and off-target movement. Additionally, the increased microbial activity of moist soil degrades herbicides more rapidly compared to dry soil.

### An herbicide barrier was disrupted or moved

This can happen when crop residue containing the herbicide is moved, such as by trash whippers, row cleaners, fertilizer units, planters, or the wind. Crop residue can reduce weed pressure.

### Application equipment did not do a uniform application

This can be due to inaccurate sprayer calibration, wind, sprayer speed, using the wrong nozzle,

**Figure 1. Control failure of horseweed (*Erigeron canadensis* L.) in this field was due to rain fall occurrence within 30 minutes of applying a post-emergence herbicide**

inappropriate pressure for the nozzle used, or not enough overlap in the spray pattern. We recommend 100% overlap so the pattern from one nozzle ends under the next nozzle tip. Other causes include boom bounce and a boom that's either too high or too low or uneven pressure along the spray boom. Spray uniformity can be affected by using a spray volume (liters per acre) that's incorrect for the herbicide being applied.

### Herbicide rate did not match soil type, weed pressure and/or tillage practices

Soil type is an important consideration when selecting pre-emergence residual herbicide application rates. Most residual herbicide rates vary based on soil type and organic matter content. For example, if the soil is sandy loam with less than 1% organic matter content, a lower herbicide rate is required than if it is a silty-clay loam soil with more than 3% organic matter content. For example, pyroxasulfone, a residual soybean herbicide, should be applied at 1.5 to 2.1 ounces/acre (0.11 to 0.15 kg/ha), if the soil is sandy loam (< 1% organic matter) and if the soil is a silty clay loam (>2% organic matter), the rate can be increased to 2 to 3.5 ounces/acre (0.15 to 2.5 kg/ha).

If weed pressure (density) is high, consider using a labeled herbicide application rate on the high end if soil type permits. It is also important to include more than 15 gallons per acre (140 liters/ha) spray volume to improve coverage in dense weed areas. Under no-till production practices, weed control is primarily through herbicides. No-till growers should consider applying preplant burndown herbicides, if a field has a history of early emerging weeds such as giant ragweed (*Ambrosia trifida* L.). An herbicide can fail if soil type, weed pressure, and tillage practices are not considered before planning and applying herbicide.

### Weeds are present or about ready to emerge before residual herbicide is applied and activated

Soil residual herbicides must be applied before the crop and weeds emerge. If they are applied after weeds emerge, your herbicide program will fail. Timing of herbicide application is critical with respect to weed emergence. If wet weather or a busy schedule do not permit application of residual pre-emergence herbicides before crop emergence, there are several residual herbicides registered in maize and soybean that be applied after crop emergence. They should be tank-mixed with foliar active, post-emergence herbicides to control existing weeds.

### User did not read herbicide label

An herbicide label is a legal document. It is a violation of law to not follow the herbicide label. Reading the herbicide label is important for successful weed management and to protect applicator, others, and the environment. The label contains legally binding information — approved by the government— on how much herbicide to use for optimal weed control, how to handle the product, and when, where and how it should be applied. The label also lists all the weeds controlled or suppressed by the herbicide. Often growers may not carefully read the label and then apply a herbicide that isn't labeled to control the predominant weed in the field. This is how herbicide fails to provide optimum weed control.

**Figure 2. Glyphosate applied at labeled rate two times in this soybean field did not control waterhemp [*Amaranthus tuberculatus* (Moq.) J D Sauer] in Nebraska, USA because it has evolved resistance to glyphosate**

### Evolution of herbicide-resistant weeds

Several weeds have evolved resistance to number of herbicides. If herbicide applicator do not know that weeds have evolved resistant to certain herbicide(s), then applying that herbicide(s) would not provide effective control (**Figure 2**).

The failures of herbicides may be avoided by applying herbicides as per label instructions, technological recommendations and precautions suggested, and thus the effective weed management by herbicide usage can be realized.

## FURTHER READING

GOI. 2022. *Instruction for Safe Use of Pesticide*. Government of India (GOI), Ministry of Agriculture & Farmers Welfare, Department of Agriculture & Farmers Welfare, Directorate of Plant Protection, Quarantine & Storage. http://ppqs.gov.in/divisions/integrated-pest-management/instruction-safe-use-pesticide

Tu M, Hurd C and Randall JM. 2001. Chapter 5 – Guidelines for herbicide use. In: *Weed Control Methods Handbook*, The Nature Conservancy, http://tncweeds.ucdavis.edu, version: April 2001

# Herbicide application using drones: Advantages and constraints

**P. Murali Arthanari* and R. Arockia Infant Paul**
*Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore 641003, Tamil Nadu, India*
*Email: agronmurali@tnau.ac.in*

Drone is a flying device which can fly a pre-set course with the help of GPS and an autopilot coordinates. Drone stands for Dynamic Remotely Operated Navigation Equipment. Drones are remotely piloted aircraft systems (RPAS), having a programmable controller with or without the satellite navigation system, a propulsion system, automated flight planning features and capable of carrying payload such as cameras, spraying and spreading systems *etc.* In 1987, the first commercial use of unmanned aerial vehicles (UAV) was developed by Yamaha Motor Co. Ltd., in Japan for pesticide spray. Later on, R50 and RMAX were developed during 1990 and 1997 respectively by integrating efficient control systems for better stability in flight and spraying. The commercial success of Yamaha drones in Japan covers nearly 40% of the rice areas for pesticide spraying. Later many developed and developing countries adopted drones for their field operations includes non-agricultural purposes.

Drone is a multispecialty device, which is used for many agricultural applications such as soil analysis, irrigation, bird control, pesticide spray, farming system and ground water quality monitoring. In addition, the drone's mounted sensors are used for crop health monitoring, weed mapping and pest detection. The initial use of drones was emphasized with visual inspection of crop and tracking machinery assets. The agriculture drones are mostly utilized by the farmers for pesticide application. Using drones will reduce considerable time for spraying and there is no need to walk directly into the field by carrying any containers by the farmers. This technology is a phenomenal innovation with potential to transform the routine manual activities which are carried out in agriculture. In addition, it replaces the labour and hazardous conventional methods for spraying. This technology aims to overcome the ill effects of pesticides on human beings and it also used to spray pesticide over large areas in a short interval of time compared to conventional spraying. At a global level, agricultural industries are increasingly using drone technology to modernize farming. UAV have improved the plant protection mechanization through its low altitude and low volume spraying. It replaced the manual spraying and increasing the sustainability, stability, mechanization and modernization of agriculture.

Now a days, Precision agriculture concept is gaining importance to minimize of productivity cost of the field crops. This is relying on technologies that combine sensors, information systems, and informed management to optimize crop productivity and to reduce the environmental impact. Precision agriculture concept can be effectively applied to integrated weed management. In the last decade, precision agriculture has very quickly advanced because of technological innovations in the areas of sensors, computer hardware, nanotechnology, unmanned vehicles systems and robots that may allow for specific identification of weeds that are present in the field. Unmanned aerial vehicles (UAV) are one of the most successful technologies applied in precision agriculture. Unmanned Vehicles systems are mobile Aerial (UAV) or Terrestrial (UTV) platforms that provide numerous advantages for the execution and monitoring of farming activities. UAVs can be highly valuable since they allow for Site-Specific Weed Management (SSWM). The application of UAVs to weed control can, therefore, contribute to improve the sustainability of future agricultural production systems.

## Drone technology adoption in India

Agriculture sector is a backbone of India's economy and it contributes around 20% of the county GDP. To overcome the constraints faced by farmers the Government of India (GOI) focuses more attention towards the latest technology drones. On 26th January 2022, the Ministry of Civil Aviation, GOI, released a notification of certification scheme for agricultural drones. Later to reduce the labour burden and drudgery, the GOI offered a subsidized scheme to the farmers, which release a sum of 10 lakhs for purchase of drones from the Farm Machinery Training and Testing Institutes, ICAR Institutes, Krishi Vigyan Kendra's & State Agriculture Universities. In addition, the government released many schemes to encourage farmers to use drones. Recently, Finance Minister of India in her budget speech, 2022 announced the launch of 'Kisan Drones'. The Drone Federation of India even worked out that the use of drones will help facilitate the vision of 'One village – one drone' in the next three years in India. In lieu of this announcement, the Central Insecticides Board and Registration Committee granted an interim approval for spraying 477 registered chemical pesticides, including herbicides and also plant growth regulators. Later, Agriculture Minister of India announced that a subsidy of 75% will be provided to the Farmers Producers

Organization for purchase of a drone and its demonstrations to the farming community. As a result, the major pesticide manufacturers are planning to use drones extensively over farm lands of India during cropping period. This convergence with farming community will lead to the fine tunning of technological innovations, like the spray nozzle size, chemical composition to reduce drift *etc.*

## Possibilities of drones use to spray herbicides for weed management

The future farming may depend more on mechanization due to labour scarcity. Hence, drones can be a very effective tool to apply the herbicides in a timely manner. Moreover, it is highly useful to the applicator due to the less operator exposure. There is huge scope for using an unmanned spraying system to cover thousands of acres in a day. In India, the average land holding by the farmers are small. However, the farmers are currently using hired drones for spraying insecticide, fungicide and other agrochemicals. But spraying herbicide by a drone is quite difficult in fragmented landholdings. Unlike other agrochemicals, herbicides are not sprayed blindly in the field and it requires some precautionary measures before spraying. Flying height of the drone is more important to get uniformity in spray deposition over the weed canopy. Improper and less deposition of herbicides in the field leads to poor weed control. The flight height for herbicide application is varied from the range of 1-3 m depending on crop. Drone flying and herbicide application should be avoided during heavy windy days which reduces the percentage of spray deposition. The ideal time for herbicide spray with drones is either early morning or late evening with less than 10-12 km/ hr wind speed. Herbicides should be diluted with clean water before filling into the drone tank and optimum spray fluid should be maintained to get better area coverage and weed control. The better deposition may increase the efficacy of contact herbicides resulting in improved weed control. When foliar hericides are applied using drones, the droplet size and droplet density are the important characteristics to improve the efficiency. Insecticides and fungicides require smaller droplets than herbicide applications. Hence, the droplet size and droplet density of herbicide molecules are critical to improve the herbicide efficacy. Whereas, for pre-emergence herbicides coarse to very coarse droplet size are sufficient, meanwhile foliar applied post-emergence herbicides require medium to coarse sized droplets for better control. Before drone spray ensures the optimum to high soil moisture for application of pre-emergence herbicide will achieve greater weed management. The low spray volume is sufficient to spray the post-emergence herbicides by drones, but it is not ideal for all crops. Low spray volume, low droplet density and poor penetrability are associated with drones will affect the weed control efficiency.

Drones are high-handedly used to precisely apply the herbicides on unreachable places such as undulated sloppy lands, steep mountainous and terrains where the conventional spraying is not possible. Drones are equipped with altitude sensors, which helps to maintain desirable flying height above the crop canopy throughout the field to ensure good area coverage and better weed control uniformly all over the field. Drones are highly useful to spray the herbicides on fluffy soil paddy fields, where the manual method is more drudgery. Likewise, drones play a key role in controlling the perennial thorny weeds by applying the herbicides over a weed. An autonomous drone spraying system is integrated with remotely sensed data, which offers the precise herbicide application, which helps to prevent the development of herbicide resistant weeds. The drones are having better spray coverage compared to conventional spraying systems, it can save the usage of herbicides and recorded 75% of weed control. Unlike conventional spraying systems, drones aerial services are available to manage the weeds in lakes and ponds. The advanced features (leading edge aerial technologies) equipped drones are used to complete the herbicide application more effectively to manage the nuisance and invasive aquatic weeds such as water hyacinth and giant salvinia.

## Drone herbicidal weed management experiments at Tamil Nadu Agricultural University (TNAU)

A field experiment was conducted in summer 2021 at Tamil Nadu Agricultural University to study the effect of herbicides applied through drones in maize. The recommended dose of herbicides for atrazine, tembotrione and 2,4-D herbicides were applied with different spray volume (40, 60, 80 and 100 L/ha) using a hybrid drone. The application of recommended dose of herbicides *viz.,* atrazine, tembotrione, 2,4-D with spray fluid of 80 liter/ha in maize recorded higher penetrability and uniformity in spray deposition. The weeds were segregated from crops through RGB analysis with maximum likelihood classifier to prepare the weed mapping for the possibility of site-specific weed management in maize. Similarly the field experiment was conducted to study the efficacy of herbicides applied through drones in direct seeded rice. The drone parameters were taken such as flying height (1m), effective swath (3m) and drone speed (4 m/s) (**Figure 1**). The greater uniformity in spray droplet was recorded in drone spray with spray fluid of 40 litre/ha than knapsack spray (500 L/ha) in Direct Seeded Rice (DSR). The better weed control efficiency was recorded in application of pretilachlor with safener in knapsack sprayer and it was closely followed by drone application.

Likewise, application of recommended dose of early post emergence herbicides, *viz.,* bispyribac sodium, fenoxaprop-ethyl and carfentrazone ethyl were applied with different spray volume (30, 45 and 60 lit/ha) using battery operated drone fitted with flan fan nozzle (**Figure 2**). Among the different spray volumes, application of herbicides using 60 lit/ha recorded the highest weed control efficiency and better area coverage than 30 and 45 lit/ha spray volume.

**Figure 1. Spraying of pre-emergence herbicides by drones, Tamil Nadu Agricultural University, Coimbatore**

**Figure 2. Spraying of early post-emergence herbicides by drones at Tamil Nadu Agricultural University, Bhavanisagar**

## Constraints in drone technology

Drone spraying systems are having many positive things for future farming. However, it has some operational constraints in practical conditions.

### i) Connectivity issues

The majority of farm holdings by the farmers are situated in remote rural areas, where the connectivity of the network is poor. Improper signal contact of GPS coordinates in rural areas resulted in the flight operation being complex and difficult.

### ii) Weather dependent

The efficiency of herbicides and spray deposition are highly influenced by local weather conditions. Weather parameters such as temperature, wind velocity, wind direction, rainfall and relative humidity are having a greater impact on drone flight and spray fluid deposition. Among the different parameters, wind velocity plays a key role in drone flying. The drones are lighter than aircraft systems, so the wind velocity should not exceed 2.5-3.5 m/s. Heavy windy and high temperatures accelerate the evaporation of spray fluid, reducing the herbicide availability in the targeted weed canopy.

### iii) Crop constraints

Drones are suitable for the majority of the crop, but the penetration of spray fluid is very less in perennial shrubs and trees. In this condition, the drones should be equipped with additional features to increase the penetration of herbicides to reach the soil.

### iv) Buffer zone

Drift is one of the major constraints in drone application. Herbicides are not selective to all the crops. The drone application is very easy in large landholdings, but in India majority of the lands are highly fragmented and small. Hence, need to maintain the buffer zone or geofence area within the field while spraying herbicides. So it can reduce the off-target movement of herbicide spray drift into neighboring sensitive crops.

### v) Lack of drone pilot

The pilot needs a lot of skills to handle the drones properly. In India, only Directorate General of Civil Aviation (DGCA) approved pilots are eligible to fly the agricultural drones. The pilot should know the training modules of National Institute of Plant Health Management (NIPHM) for handling insecticides and herbicides. In the rural areas, lack of trained pilots for drone flying.

## Conclusion

Use of drones in herbicidal weed management with precise weed mapping campaigns is highly beneficial. Further, it also creates a scope to the younger generation employment opportunity to contribute to the national agricultural production increase in a better way. In future, the limitations of drones usage in herbicides are overcome with the latest inventions and scientific ideas, this technology has potential for herbicide application to achieve better weed management with minimum cost in near future.

## FURTHER READING

Hafeez A, Husain MA, Singh SP, Chauhan A, Khan MT, Kumar N, Chauhan A and Soni SK. 2022. Implementation of drone technology for farm monitoring and pesticide spraying: A review. *Information Processing in Agriculture*. https://doi.org/10.1016/j.inpa.2022.02.002.

# Editors

**Dr. J.S. Mishra** joined ICAR as ARS scientist on 5th August 1991. He served ICAR-DWR, Jabalpur (1992-2008), ICAR-IIMR, Hyderabad (2008-2014) and ICAR Research Complex for Eastern Region, Patna (2014-2020) in various capacities before joining as the Director ICAR-DWR, Jabalpur on 27th November, 2020. He has made outstanding contributions in the field of weed management research. His pioneering contributions are in the area of biology of parasitic weed *Cuscuta campestris* and its management, conservation tillage and weed management in rice/soybean/sorghum-based cropping systems, weed seedbank dynamics, popularization of resource conservation technologies in rice-fallows, and development & popularization of CA-based crop management practices in rice-based cropping systems in Eastern region. He has been honored with ISA PS Deshmukh Young Agronomist Award (1999), DWR Best Scientist Award (2007), Fellow of Indian Society of Weed Science-ISWS (2007), Indian Society of Agronomy-ISA (2010) and Society for Upliftment of Rural Economy (2015), ISWS Gold Medal (2014), ISA Gold Medal (2016), Fellow of National Academy of Agricultural Science (NAAS) 2022 for his significant contributions.

**Dr. Sushilkumar** obtained his M.Sc (Entomology) from Meerut University in 1981 and Ph.D. from Forest Research Institute, Dehradun in 1986. He started his service career as Research Assistant from Forest Research Institute, Dehradun (1983-1991) and joined Agricultural Research Service (ARS) in December 1991. During his ARS services, he served in Potato Research Institute, Shimla for about two years before joining the then National Research Center for Weed Science (NRCWS). At Forest Research Institute, he made significant contribution in understanding the behavior of termites and their management besides many other insect pests of forestry and agroforestry importance. In his brief period at Potato Research Institute in Shimla, he contributed mainly to assess the losses caused by rodents and slugs in potato fields. He has worked extensively on biological based integrated management of terrestrial and aquatic weeds besides their utilization. His most pioneering contributions are for the management of Parthenium and water hyacinth besides making public aware about them. He has been recipient of many awards like AZRA Young Scientist Award (1998), DWR Best Scientist Award (2004 and 2014), Fellow of Indian Society of Entomology (2008), ISWS Recognition Award (2008), ISWS Best Book Award (2008), Fellow of AZRA (2011), ICAR Extension Award (2011), Crystal National Agri Award (2014) etc. He served ISWS as Secretary (2008-2011 and 2017-2018) and as Chief Editor of Indian Journal of Weed Science (2013-2016).

**Dr. Adusumilli Narayan Rao** (A.N. Rao) is a Consultant Scientist (Weed Science) in Hyderabad, India. Dr. A. N. Rao has led various research projects on weed management in various crops and is an expert in developing and disseminating integrated crop-weed management technologies for optimal crop productivity and sustainable agri-food systems. His Ph.D. thesis was on "Eco-physiological responses of crops and weeds against herbicides and their residues". He did postdoctoral studies at ICRISAT (1978 to 1980) and IRRI (1985 to 1988). Dr. Rao worked as an Agronomist (Weed Scientist) at the International Rice Research Institute (IRRI), in the Philippines and Egypt. He has over 40 years' experience in Weed Science gained working at organizations like ANGRAU, APCOST, IRRI/India, IRRI/Egypt, ICRISAT/Hyderabad at various capacities. He has authored more than 150 research publications including book chapters and 6 edited books. He is Life Member and Fellow of Indian Society of Weed Science (ISWS) and is recipient of ISWS Gold Medal award in recognition of his contributions to Weed Science. He also won RAITU NESTAM best Scientist award. He is currently Chief Editor of the Indian Journal of Weed Science. Asian-Pacific Weed Science Society (APWSS) Logo was designed by Dr. Rao, which won him the Ciba-Geigy Best Logo award in 1985. He is APWSS General Secretary since 2015 to to-date.


NABARD
Indian farmers are going hi-tech
Digital Money
Modern Farming
Digital Marketing
www.nabard.org
/nabardonline
/nabardonline
/nabardonline
Taking Rural India >> Forward