SOUVENIR

25th Asian-Pacific Weed Science Society Conference

Hyderabad, India

NABARD

Organized by

Indian Society of Weed Science

In collaboration with

Indian Council of Agricultural Research
Directorate of Weed Research
PJT State Agricultural University

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Cover page: Major weed species in the Asian-Pacific region (in sequence): *Phalaris*, *Avena*, *Echinochloa*, *Cyperus*, *Ageratum*, *Parthenium* (cropland weeds); *Mikania, Lantana, Alternanthera*, *Chromolaena*, *Mimosa*, *Saccharum* (non-cropland weeds); *Eichhornia*, *Salvinia*, *Ipomoea* (aquatic weeds); and *Striga*, *Orobanche*, *Cuscuta* (parasitic weeds). (Designed by: Mr. V.K.S. Meshram and Mr. Sandeep Dhagat, DWR, Jabalpur, India)

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PREFACE

Weeds are a major biotic constraint in agricultural production systems worldwide. Besides reducing crop yield and quality, these unwanted plants adversely affect biodiversity, animal health and environmental security. In fact the problem of weeds is as old as the agriculture itself as almost all crop plants have been domesticated from their wild relatives only. Despite the development of weed management technologies, the weed related problems have been virtually increasing. This is due to adoption of so-called modern cultivation methods which also promote the growth of weeds. The threats posed by climate change, globalization, herbicide resistance development in weeds and commercialization of herbicide-tolerant crops are bound to accentuate the problem.

Realizing the growing weed infestations in the cropped and non-cropped lands, agricultural scientists of the world have been undertaking research and sharing their findings at various platforms. One such initiative was taken way back in 1967 when weed scientists of 22 countries of the Asian-Pacific region met at the Hawaiian Island of Kauai to establish linkages and discuss what should be done in weed science in this part of the world. This meeting led to the birth of the Asian-Pacific Weed Science Society (APWSS), and since then, the Society has grown and developed into a major regional and international weed science society.

Over the years, the discipline of weed science has also developed in many countries of the region and professional societies dealing with the subject have been established for mutual exchange and sharing of knowledge. Besides organizing various activities including conferences and symposia at the national level, these professional societies have also been providing a platform for sharing of international experiences on emerging issues in weed science. The APWSS has been providing a major platform for these regional weed science societies for organizing the APWSS Conferences every two years. These Conferences have been organized in different countries of the Asian-Pacific region like Philippines (1969, 1983, 2003), Malaysia (1971, 1997), New Zealand (1973), Japan (1975, 1995), Indonesia (1977, 1991, 2013), Australia (1979, 1993, 2011), India (1981), Thailand (1985, 1999), Taiwan (1987), Korea (1989), China (2001, Vietnam (2005), Sri Lanka (2007) and Pakistan (2010) by the respective weed science Societies. It is matter of great honour for the weed scientists of India to organize the 25th Asian-Pacific Weed Science Society Conference after a gap of 34 years since the 8th APWSS Conference was organized at Bengaluru in 1981.

On the special occasion of the Silver Jubilee of the APWSS Conferences being organized at Hyderabad, India during 13-16 October, 2015, an initiative was taken by the Indian Society of Weed Science to bring out a Souvenir containing messages of goodwill, articles on weeds and advertisements from herbicide industry. It is hoped that this book will be useful to the scientists, teachers, students, policy makers and other stakeholders dealing with weed management.

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

13 October, 2015

Dr. N.T. Yaduraju
President, 25th APWSS Conference

Dr. A.R. Sharma
Organizing Secretary, 25th APWSS Conference

Content

HYDERABAD

K. CHANDRASHEKHAR RAO
CHIEF MINISTER

22.09.2015

MESSAGE

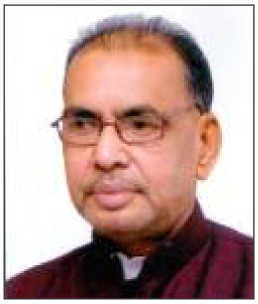
I am happy to note that the Indian Society of Weed Science, Jabalpur in collaboration with Professor Jayashankar Telangana State Agricultural University (PJTSAU) is organizing the 25th Asian-Pacific Weed Science Society Conference at Hyderabad.

I am also happy to note that a souvenir is being brought out on this occasion.

I wish the event a grand success and wish PJTSAU all the best in their future endeavours.

K. Rao

(K. CHANDRASHEKHAR RAO)



राधा मोहन सिंह
RADHA MOHAN SINGH

सत्यमेव जयते

कृषि मंत्री
भारत सरकार
Minister of Agriculture
Government of India

8 September, 2015

MESSAGE

The agriculture and allied sectors continue to be the largest source of livelihood security for millions of households across the world, especially in the developing countries. This necessitates innovations for improving efficiency, equity and environment with simultaneous enhancements in farm productivity and profitability. The scientific and technological inputs have been major drivers of growth and development in agriculture and allied sectors that have enabled us to achieve self-reliant food security with a reasonable degree of resilience even in times of natural calamities. In the present times, agricultural development is faced with several challenges relating to state of natural resource, climate change, fragmentation and diversion of agricultural land to non-agricultural uses, factor productivity, global trade and IPR regime. Some developments are taking place at much faster pace than ever before. In order to address these challenges impacting agriculture and to renna:n competent, it is essential that our scientific institutions are able to foresee the challenges and formulate prioritized research programmer so that our agriculture is not constrained for want of technological interventions.

Weeds are one of the major biotic constraints in agricultural production and cause up to one-third of the total losses in yield, besides impairing produce quality and various kinds of health and environmental hazards. Despite development and adoption of weed management technologies, the weed infestations are still a big threat for farming. In this endeavour, efforts of the Indian Society of Weed Science, and Directorate of Weed Research (DWR) in jointly organizing the Silver Jubilee Asian-Pacific Weed Science Conference at PJTSAU, Hyderabad from 13-16 October, 2015 on the theme "Weed Science for Sustainable Agriculture, Environment and Biodiversity" are timely and praiseworthy.

I hope that deliberations during the Conference will culminate in developing strategies and an action-oriented framework to promote weed science in a more scientific and precise manner for the benefit of farming community.

Radha Mohan Singh
(RADHA MOHAN SINGH)

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Minister of State for Agriculture
Government of India

डॉ. संजीव कुमार बालियान
DR. SANJEEV KUMAR BALYAN

MESSAGE

It is heartening to know that the Indian Society of Weed Science in collaboration with Indian Council of Agricultural Research, Directorate of Weed Research and PJT State Agricultural University, Hyderabad is organizing the 25th Asian-Pacific Weed Science Society Conference from 13-16 October, 2015 on the theme "Weed Science for Sustainable Agriculture, Environment and Biodiversity".

In the Conference, scientists from different disciplines from across the world would come together to share their views, ideas and promote research in different areas of weed science. I am hopeful that the interactions between delegates and experts will lead to more viable research development for the benefit of human mankind.

I extend my greetings to the organizers and participants, and wish the 25th Asian-Pacific Weed Science Society Conference a grand success.

(Dr. Sanjeev Kumar Balyan)

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Hyderabad

22 September, 2015

MESSAGE

It give me immense pleasure to know that Indian Society of Weed Science, Jabalpur in collaboration with Professor Jayashankar Telangana State Agricultural University is organizing the 25th Asian-Pacific Weed Science Society Conference at University Auditorium, PJTSAU, Hyderabad from l3-16 October, 2015.

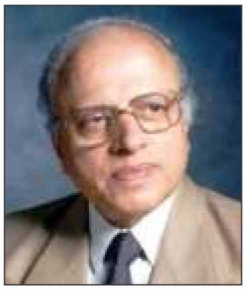
Further, I look forward to this Conference with great optimism that a forum like this would provide cost-eflective, realistic solutions to weed management related problems faced by the farmers in the newly fonned state of Telangana. I commend the Professor Jayashankar Telangana State Agricultural University for hosting this prestigious international conference, as it will certainly enhance the visibility of the newly formed state and University among the scientific fraternity of the world.

I convey my best wishes to all the participants and organizers of this Conference with a warm hope that this event turns out to be a productive one.

(POCHARAM SRINIVAS REDDY)

M.S. Swaminathan Research Foundation

Centre for Research on Sustainable Agriculture and Rural Development



11 September, 2015

Prof. M.S. Swaminathan
Founder Chairman & Chief Mentor
UNESCO Chair in Ecotechnology

MESSAGE

Experiences since the onset of the green revolution in the 1960s have shown that if farm ecology and economics go wrong, nothing else will go right in agriculture. The triple alliance of weeds, pests and pathogens causes considerable damage to crops. It is important that we try to manage these threats to yield and stability of production. Weed management has a great role to play in increasing productivity and sustainability and one cannot imagine a successful crop without proper weed management. To address critical issues related to weed management, the discipline of weed science has expanded over the decades into an amalgam of scientists who employ a myriad of tools focused on understanding and managing weeds. Use of herbicides in today's agriculture has contributed in realizing increased yields of many field crops; however, at the same time, it also raised some concerns resulting from excessive and non-judicious use of agrochemicals which may have adverse effects on human health, environment and biodiversity. So, it is equally crucial to study and assess the risk involved with the use of herbicides. Further, possible impacts on weed management under changing climate scenario must be a prioritized researchable avenue for weed scientists.

It is indeed a matter of great pleasure that Indian Society of Weed Science is organizing the 25th Asian-Pacific Weed Science Society Conference from 13-16 October, 2015 at Hyderabad in collaboration with Indian Council of Agricultural Research, Directorate of Weed Research and PJT State Agricultural University. The Conference theme "Weed Science for Sustainable Agriculture, Environment and Biodiversity" is appropriate since our country is trying to increase productivity in perpetuity without associated ecological harm, thereby achieving an ever-green revolution. It is an opportune time that the galaxy of weed scientists from around the world is going to meet and deliberate on emerging challenges in weed management. I hope outcome of this mega event would benefit not only the farming community but also other stakeholders in developing effective collaborations and linkages amongst institutions.

I am confident that the Conference will provide a road map for enabling our country to fulfil the legal obligations of ensuring food for all and forever. I wish the Conference great success.

(M.S. Swaminathan)

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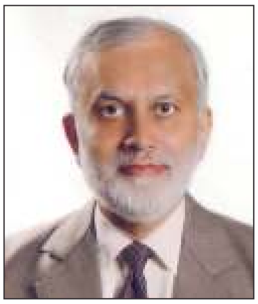

डा. एस. अय्यप्पन
सचिव एवं महानिदेशक
Dr. S. AYYAPPAN
SECRETARY & DIRECTOR GENERAL

भारत सरकार
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MESSAGE

I am happy to know that the Indian Society of Weed Science in collaboration with Indian Council of Agricultural Research and Directorate of Weed Research is organizing the 25th Asian-Pacific Weed Science Society Conference from 13-16 October, 2015 at PJT State Agricultural University, Hyderabad on the theme 'Weed Science for Sustainable Agriculture, Environment and Biodiversity'.

Weeds have been reckoned as a major threat globally and act as dampener for crop production despite the farmers putting enormous effort in their removal to get better yield. Modern agriculture is typified by and large with fixed cropping pattern, accompanied by a considerable percentage of uncultivated land - which is the ideal environment for weeds to prosper in the first stage of succession. Appreciable efforts have been made by the weed scientists in India, still deliberations are required in order to address the emerging issues like climate change. Invasive weeds, herbicide resistance and threats posed by weedy rice and parasitic weeds. Concerns associated with emerging technologies like herbicide resistant crops have to be addressed scientifically.

I hope deliberations during the Conference would help in streamlining the roadmap for addressing the future challenges in weed management.

I extend my greetings and best wishes for the grand success of this Silver Jubilee Asian-Pacific Weed Science Society Conference.

Dated the 14th August, 2015
New Delhi

(S. Ayyappan)

कृषि वैज्ञानिक चयन मंडल
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डॉ. गुरबचन सिंह
अध्यक्ष
Dr. GURBACHAN SINGH
CHAIRMAN

MESSAGE

The agriculture and allied sectors continue to be the largest source of livelihood security for millions of households across the world, especially in the developing countries. Farmers have to produce more from less and less resources. This necessitates innovations for improving efficiency, equity and environment with simultaneous enhancements in farm productivity and profitability. The scientific and technological inputs have been major drivers of growth and development in agriculture and allied sectors that have enabled us to achieve self-reliant food security with a reasonable degree of resilience even in times of natural calamities. In the present times, agricultural development is faced with several challenges relating to state of natural resources, climate change, fragmentation and diversion of agricultural land to non-agricultural uses, factor productivity, global trade and IPR regime. Some of these developments are taking place at much faster pace than ever before. In order to address these challenges impacting agriculture and to remain globally competent, it is essential that our scientific institutions are able to foresee the challenges and formulate prioritized research programmes so that our agriculture is not constrained for want of technological interventions.

Weeds are one of the major biotic constraints in agricultural production and cause up to one-third of the total losses in yield, besides impairing produce quality and various kinds of health and environmental hazards. Despite development and adoption of weed management technologies, the weed infestations are still a big threat for farming. In this endeavour, efforts of the Indian Society of Weed Science and Directorate of Weed Research (DWR) in jointly organizing the Silver Jubilee Asian-Pacific Weed Science Society Conference at PJTSAU, Hyderabad from 13-16 October, 2015 on the theme "Weed Science for Sustainable Agriculture, Environment and Biodiversity" are timely and praiseworthy.

I hope that deliberations during the Conference will culminate in developing strategies and an action-oriented framework to promote weed science in a more scientific and precise manner for the benefit of farming community.

(GURBACHAN SINGH)

Steve W. Adkins
Immediate Past President, APWSS

THE UNIVERSITY OF QUEENSLAND
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MESSAGE

Weeds are a serious threat to agricultural productivity, environmental biodiversity and animal and human health. Despite all efforts, weed invasions are still a major concern to scientists, agriculturists, environmentalists, policy makers and administrators. I am pleased to see that the Indian Society of Weed Science is organizing the 25th Asian-Pacific Weed Science Society Conference during 13-16 October, 2015 at Hyderabad, India and organising it under the theme 'Weed Science for Sustainable Agriculture, Environment and Biodiversity'. I understand that the organizers have been successful in acquiring some of the most eminent weed scientists from around the world to speak on subjects of topical interest, recent advances in weed science and considering future prospects. More than 600 weed scientists are expected to participate in this significant event. I extend a warm welcome to all participants and wish the Hyderabad APWSS Conference every success.

Steve Adkins

(Steve W. Adkins)

The School of Agriculture and Food Sciences undertakes teaching and research activities on the St Lucia and Gatton campuses of the University of Queensland

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Chairman, NBA

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Website : moef.nic.in

9 September, 2015

MESSAGE

I am happy to know that Indian Society of Weed Science in collaboration with Indian Council of Agricultural Research (ICAR), Directorate of Weed Research, and Professor Jayashankar Telangana State Agricultural University is organising the 25th Asian-Pacific Weed Science Society Conference on "Weed Science for Sustainable Agriculture, Environment and Biodiversity" from 13-16 October, 2015 in Hyderabad.

India, with more than 3.5 billion years of evolutionary history and famous as one among the eight Vavilovian centres of the world, is well known for its biodiversity. Considered to be the primary center of origin of rice, with 15 agro-climatic zones and 811 cultivable plants, the rich diversity of traditional farming systems practiced in India contributes to food security, besides securing livelihoods for 70% of the population.

Of late, proliferation of unwanted plants that compete for nutrients and resources alongside cultivated ones, poses a challenge to the economy, the environment, and human health. Some alien invasive weeds like *Parthenium hysterophorus*, *Lantana camara, Mikania micrantha* and *Prosopis juliflora* pose a serious threat to human and animal health besides causing loss of biodiversity in terrestrial ecosystems. Invasion of *L. camara, P. juliflora, Senna spectablilis, P. hysterophorus*, *Mikania micrantha, Mimosa* species and *Chromolaena odorata* in grassland ecosystems, threatens the survival of herbivores an indigenous plant including keystone species in several protected areas. Aquatic weeks like water hyacinth (*Eichhornia crassipes*), *Salvinia molesta* and water cabbage (*Pistia stratiotes*) pose a big menace to fresh water and to paddy cultivation.

Despite the development and adoption of weed management technologies, weed infestations are increasing in most countries including India. Weed problems are dynamic in nature, requiring continuous monitoring and refinement of management strategies in order to sustain agricultural productivity, environmental health and biodiversity. In this context, this Conference is crucial and I hope it will help to address the emerging challenges in weed management in significant ways. I compliment the organizing committee for their timely and commendable effort, and wish the Conference every success.

9/9/15
(Hem Pande)

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MkW- vkyksd dqekj flDdk
mi egkfuns'kd (izk la iz)

DR. ALOK K. SIKKA
Deputy Director General (NRM)

MESSAGE

Weed management is a multi-disciplinary and dynamic area of research. The subject is very much advanced in developed countries where weed management is undertaken with minimal labour by harnessing the advances made in cutting edge disciplines such as agronomy, biotechnology, farm machinery, information and space technology. Keeping in view, the current advances and changing dynamics of weeds in crops and cropping systems in the country, it is necessary to revise and prioritize the research and development programmes to ensure increased role of research-based technologies for eco-friendly weed management and sustainable crop production. Agriculture and rural development will be sustainable only when they are ecologically-sound, economically-viable, and socially-justified based on scientific approaches. Further, weed problems are likely to aggravate due to increased emphasis on high-input agriculture as well as invasion of exotic weeds. With greater public awareness on environmental pollution, the focus is shifting towards the development of eco-friendly weed management technologies. Further, new and emerging issues like climate change, herbicide resistant weeds, and environmental hazards have necessitated a thorough review of weed management strategies.

I am glad to know that the Indian Society of Weed Science in collaboration with Indian Council of Agricultural Research (ICAR) and Directorate of Weed Research (DWR) is organizing 25th Asian-Pacific Weed Science Society Conference from 13-16 Ocotober, 2015 at PJT State Agricultural University, Hyderabad. The theme of the Conference 'Weed Science for Sustainable Agriculture, Environment and Biodiversity" and various sub-themes are very relevant and timely to address the challenges in agriculture particularly in Asian-Pacific region. Indeed, I am excited to know that about 600 experts from all over the world are coming to participate in this conference. I hope discussions and interactions among experts and delegates from all over the world would turn into specific recommendations for devising viable weed management strategies for sustainable agriculture and environment protection.

My best wishes to the organizers and delegates for grand success of this important event.

8 September, 2015

(Dr. Alok K. Sikka)

C. Partha Sarathi, I.A.S.
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Dt. 24-09-2015

MESSAGE

I am extremely happy to learn that Indian Society of Weed Science, Jabalpur and Prof. Jayashankar Telangana State Agricultural University (PJTSAU) are jointly organizing the 25th Asian-Pacific Weed Science Society Conference, Hyderabad from 13-16 October, 2015 with the main objectives of holding wide-ranging discussions, presentation of research findings and to conduct brain-storming sessions to develop ecologically sustainable weed management strategies for enhancing the agricultural productivity and reducing weed related losses.

I am also happy to know that around 600 delegates from reputed agricultural universities and institutes all over world will participate in this Conference to present their research achievements and share their thoughts in the field of weed science.

Biotic stresses like weeds are known to cause more than 30 percent crop losses and their cost-effective management approaches should be developed to suit the location specific needs of the farmers and evolve continuously with the changing climate. There could not have been an opportune time than this, to host and organize this Conference and I fully support the objectives set for this meet.

I wish all the best for the successful organization of the convention.

C.PARTHA SARATHI

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Dr. V. PRAVEEN RAO
M.Sc. (Ag.) Ph.D
Registrar & Special Officer

MESSAGE

Weeds are the most severe and widespread biological constraint to crop production and cause invisible damage ti1l the crop is harvested. They reduce crop yield and degrade quality of the produce besides raising cost of production. Unlike other pests, weeds are ubiquitous and affect almost all crops. The composition and competition by weeds is dynamic, and is dependent on soil, climate, crop and management factors. The biology and ecology of weeds is not the same for all regions and hence, weed management strategies will have to different for each agro-ecological condition. Greater awareness about the losses caused by weeds and the need for improved weed management technologies are, therefore vital. Proper training and reorientation of the personnel of the state agricultural departments is essential for successful management of weeds.

The Asia-Pacific region covers a wide geographic area with diverse climates, cultures and economies with more than half of the world's population in this region. Sustained agricultural production is a challenging task. Alleviation of major impediments such as weeds and efficient use of natural resources by the crops will definitely lead to enhanced productivity. Considering the growing infestation of weeds in cropped and non-cropped lands, it becomes necessary to develop innovative strategies for managing harmful weeds. A multi-disciplinary approach is required to understand weed biology and develop methods to control the already existing and newly-emerging threats.

I am glad to know that a platform like the Asian-Pacific Weed Science Society exists to address issues related to weeds at the global level. The 25th Asian-Pacific Weed Science Society Conference on "Weed Science for Sustainable Agriculture, Environment and Biodiversity" during 13-16 October, 2015 would bring together experts, researchers and students of different disciplines from across the world to deliberate on the topic. I hope that the scientific interactions will lead to more viable research developments for the benefit of farming community and biodiversity.

PJTSAU is proud to host this prestigious event and it gives me great pleasure to welcome the galaxy of researchers to the historical city of Hyderabad.

I extend warm greetings for the success of this Conference.

Date: 05.09.2015

(V. PRAVEEN RAO)

Trends in managing weeds of rice in Asian-Pacific region

A.N. Rao[1] and S.P. Wani[2]

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Rice is the main staple in the Asia and the Pacific (AP) region. It is often said that in AP region "Rice is Life" and rice availability is equated with food security. It is estimated that demand for food and non-food commodities is likely to increase by at least 60% globally between 2010 and 2050, with many developing countries having to double their food production, which is possible only by the increased production of major staple crop, rice. Future rice production will be limited on a global scale by the availability of land, water, and energy for which weeds compete with rice. Weeds associated with rice vary with the country, method of rice establishment, the rice cultivar grown, management practices used and the environment. Publications enlisting predominant weeds associated with rice in each of the country of AP region are available. The extent of yield losses caused by weeds depends on the weed species associated with rice, their predominance and associated environmental factors. Estimates at global level indicate that weeds account for 48.2% of potential losses and 27.3% of actual losses caused by all pests together. Hence weed management will play a critical role in realizing needed increase in rice production in AP region. Integrated weed management practices are needed for achieving increase in productivity and production of rice while addressing the environmental and other problems created by current and past weed management practices.

Manual weeding, alone or in combination with other methods, is still the most predominant method of weed removal in many countries in the AP region. However, it is not only tedious, time-consuming and inefficient but is increasingly becoming uneconomical as well. Wage rates for farm workers in South East Asia have steadily increased; the average wage rate today is 5-10 times greater than what was prevalent in the 1970s. For example: in India the wages were less than US $0.5 in 1970s, which currently range from US $ 4-5 per person per day. In other words, one time hand weeding of one hectare rice which used to cost us $10, costs now a minimum of US $80. Poverty alleviation programs introduced in some countries to promote inclusive growth in economy have also contributed to the scarcity of labor for farm work. Use of draught animals for intercultural operations is also coming down even though in upland dry-seeded rice of India, inter cultivation using blade harrow is common method of managing weeds in combination with hand weeding. Cono weeders are also used in row wet-seeded and transplanted rice in India and other developing countries by a few farmers. Power tillers are being introduced under programs such as Bhoo Samrudhi in Karnataka state of India.

As farm wages have increased due to economic growth and government policies in some countries in AP region, herbicides have increasingly been substituted for hand weeding. Between 100-200% increases in the current labor price are expected within 5-10 years. Farmers are left with little choice but to reduce labor and production costs, particularly for the most labor-intensive tasks, such as manual weeding. Studies by scientists in Bangladesh revealed that pre-emergence herbicides in rice are 38.46% cheaper than one hand weeding and the herbicide application gave 116% higher net income than hand weeding due to increased yield and lower cost of weeding. Thus, the use of herbicide has increased over years in AP regions developing countries including China and India. In China, the area treated with herbicides has increased from less than one million hectares (mha) in the early 1970s to more than 60 mha in 2000. Rice accounted for 17% of total herbicides (6705 metric tonnes) used in India in 2010. In Malaysia, weed management is herbicide-based and about US $ 4.10 million is spent annually on herbicides for rice alone, and this amounts to approximately 7% of the total expenditure on herbicides as per reports in 2004, which might have increased further by now. In Philippines, 96-98% of rice farmers use herbicides with the majority of farmers supplementing herbicide application with hand weeding. In Pakistan, about 20% area in rice is treated with herbicides. In Korea, the rice area treated with herbicides was 27% in 1971, 65% in 1977 and currently entire area is treated with herbicides. The trend of increasing use of herbicides in rice production has been observed in Vietnam. There are about 37 compounds or proprietary mixtures formulated in 79 commercial products available for use in Vietnam. Vietnam used 5,000 tonnes of herbicides (19% of total pesticides) costing US $18 million, with rice herbicides contributing 89% in 2002. In Nepal, 91% of rice farmers were reported practicing manual weeding and only about 2% reported to have used butachlor.

Herbicides have been and will continue to be the major tool for managing weeds of rice in AP region. However, continuous use of herbicides have resulted in the incidences of resistant weeds, which is more in developed countries like Australia, where herbicides have been in use for long. Among crops, wheat and rice have more herbicide resistant weeds than maize. In developing countries of AP region also, the shift in method of rice establishment to direct-seeding, increased herbicide use and continuous use of similar herbicides is resulting in weeds resistance in rice. For preventing the development of herbicide resistance in weeds, the best management practices (BMPs) were suggested by Weed Science Society of America (WSSA) and these may also be popularized among the rice farming community of AP region. WSSA (Thanks to WSSA) says that effective herbicide-resistance management programs must consider all available options for effective weed control and use the following BMPs:

- Understand the biology of the weeds present
- Use a diversified approach toward weed management focused on preventing weed seed production and reducing the number of weed seeds in the soil seed-bank
- Plant into weed-free fields and then keep fields as weed free as possible
- Plant weed-free crop seed
- Scout fields routinely
- Use multiple herbicide mechanisms of action that are effective against the most troublesome weeds or those most prone to herbicide resistance
- Apply the labeled herbicide rate at recommended growth stage of weeds
- Emphasize cultural practices that suppress weeds by using competitive cultivars of crops
- Use mechanical and biological management practices where appropriate
- Prevent field-to-field and within-field movement of weed seeds or vegetative propagules
- Manage weed seeds at harvest and post-harvest to prevent a buildup of the weed seed-bank
- Prevent an influx of weeds into the field by managing field borders

In addition to recommending specific BMPs, the WSSA also endorses the following:

- Reduce the weed seed-bank through diversified programs that minimize weed seed production
- Implement an herbicide mechanism of action labeling system for all herbicide products, and conduct an awareness campaign
- Communicate that discovery of new effective herbicide mechanisms of action is rare and that the existing herbicide resource is exhaustible
- Demonstrate the benefits and costs of proactive, diversified weed management systems for the mitigation of herbicide-resistant weeds
- Foster the development of incentives by government agencies and industry that conserve critical herbicide mechanisms of action as a means to encourage adoption of best practices
- Promote the application of full-labeled rates at the appropriate weed and crop growth stage. When tank mixtures are employed to control the range of weeds present in a field, each product should be used at the specified labeled rate appropriate for the weeds present
- Identify and promote individual BMP that fit specific farming segments with the greatest potential impact
- Engage the public and private sectors in the promotion of BMPs, including those concerning appropriate herbicide use
- Direct federal, state and industry funding to research addressing the substantial knowledge gaps in best management practices for herbicide resistance and to support cooperative extension services as vital agents in education for resistance management

The BMPs that are of relevance for each of the country in the AP region may be effectively used for managing weeds of rice and rice-based cropping systems.

Weedy rice is becoming a threat in rice and especially in direct-seeded rice fields of AP region and it needs special attention by researchers to prevent its spread and effectively manage, in each of the country of AP region. Clearfield rice – an imidazolinone (IMI) resistant rice derived from conventional breeding technique, has been in cultivation in Malaysia mainly for managing weedy rice. It is under testing stage in Vietnam. The possible evolution of resistance to ALS-inhibitor herbicides in weedy rice and the risk of weedy rice acquiring resistance to herbicides following introgression of resistant gene from the HT rice are the major concerns that need to be addressed adequately. Educating rice farmers is essential prior to the release and popularization of genetically/conventionally modified rice varieties tolerant to herbicides.

Climate change is of concern to rice farming community, as loss in yield so far in rice was estimated to be around 17% due to changing climate. The impact of climate change on weeds, rice-weed competition and weed management in rice of AP region is yet to be understood clearly. Future research efforts must be made to evolve and popularize climate resilient strategies by integrating herbicides and non-chemical methods for effective, economical and eco-efficient weed management in rice and rice-based cropping systems.

Herbicide residues vis-a-vis food safety

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Organic chemistry has been, and for the foreseeable future will remain, vitally important for crop protection. Control of weeds, fungal pathogens and insect pests is crucial to enhanced food provision. As world population continues to grow, it is timely to assess the current situation, anticipate future challenges and consider how new chemistry may help to meet those challenges. In future, agriculture will increasingly be expected to provide not only food and feed, but also crops for conversion into renewable fuels and chemical feed stocks. This will further increase the demand for higher crop yields per unit area, requiring herbicide chemicals used in crop production to be even more sophisticated. In order to contribute to programmes of integrated crop management, there is a requirement for herbicides to display high specificity, demonstrate benign environmental and toxicological profiles, and be biodegradable. It will also be necessary to improve production process of those chemicals, because waste generated during the production of such chemicals mitigates the overall benefit. Herbicide chemistry has shown remarkable shift over the years from conventional herbicides-phenoxy alkanoic acids, carbamates, phenylureas, triazines to fops and dims and lately to sulfonylureas, sulfonamides, imidazolinones etc. with low dose technology suitable in integrated weed management without leaving herbicide residues.

Herbicide residues

Herbicide applied to soil or foliage tends to persist in the soil environment and enter into plant through root or foliage absorption and may be translocated to other parts of the plant. The use of herbicides in agriculture has increased both quantity and quality of food crops. Nevertheless, herbicides are toxic substances and, as a consequence of their large quantities used, their residues may be present in soil environment and foods. Residues of herbicides will persist in the soil and plant for variable time, depending upon their physico-chemical properties and on the environmental conditions. Knowledge of their physico-chemical properties is important to develop analytical procedures for the determination of herbicide residues. Several techniques have been used for the analysis of herbicides in soil, water and foods.

***Residues in soil**:* Herbicides degrade over time. Persistence of herbicide in soil depends on soil factors (soil moisture, pH, CEC, microbial population), climatic factors (temperature, light, rainfall) and physico-chemical characteristics of the herbicide (solubility, volatilization). Herbicides dissipate via several pathways including: photo degradation, chemical degradation, microbial degradation, leaching, and volatilization. Some herbicides resist these factors and persist for extended period. Photodegradation occurs when ultraviolet (UV) light breaks chemical bonds of the active ingredient of a herbicide. Secondary molecules resulting from the cleavage of the parent molecule are generally less effective in providing weed control. Degradation of some herbicides (sulfonylureas and imidazolinones) is reduced or stopped as soil pH rises above 7. Most soils have a pH lower than 7, and herbicides which are affected by pH are not often used in alkaline soils. Excessive persistence in soil may have carry-over effects on the subsequent crops and leaching may lead to ground water pollution.

Residues in ground water: There have been reports of ground water contamination with some of the herbicides. When used years after years, some of the herbicides tend to leach down in soil beyond permissible level and pollute the underground water reservoirs. This has been more prevalent with newer herbicide like sulfonylureas with higher water solubility.

***Residues in crops**:* Residues are estimated in the harvested produce and to determine pre-harvest waiting period in an edible food commodity following application at a recommended dose. Pre-harvest waiting periods (are index of safety of herbicides in a crop) determine the safe period of harvesting subsequent application of pesticide especially in vegetables and fruits meeting MRL standards.

Analytical methodology

Knowledge of physico-chemical properties of a herbicide is important to develop analytical procedures for the determination of residues in soil, ground water and plant parts. Several techniques have been used for the analysis of residues of herbicides. Foremost step in analysis is sample preparation.

Sample preparation: Sample preparation includes all techniques that involve extraction of herbicide from soil, water or foods which depends on the polarities of these compounds as well as on the property of the sample matrix. Homogenization of the sample with organic solvents having high or medium polarity will depend on the polarity of the extractable herbicide. Supercritical fluid chromatography (SFC), matrix solid-phase dispersion (MSPD), solid-phase micro-extraction (SPME), microwave assisted extraction (MAE) and accelerated solvent extraction (ASE) are some recent extraction techniques. Cleanup procedure is required for most agricultural sample extracts prior determination of herbicides. Extracts are usually cleaned up by liquid-liquid partition (LLE) chromatography on columns packed with different adsorbents. The solid-phase extraction (SPE) cartridges are attractive techniques for cleanup of extracts. Gel permeation chromatography (GPC) also reduces substantially solvent consumption and analytical time. QuEChERS (Quick, Easy, Cheap, Effective, Rugged and Safe) method developed using primary and secondary amine exchange material (PSA) has been devised as a highly streamlined sample preparation method with excellent results for a wide range of pesticides in many types of samples. This method provides satisfactory results for determination of multi residues of more than 200 pesticides in vegetables and fruits. Another sample preparation procedure for residue analysis is derivatization of pesticides. This procedure is sometimes necessary for analyte stability or detectability by specific detector.

Chemical techniques: Gas chromatography (GC) is a technique widely used in the analysis of herbicide residues. Packed and subsequently developed capillary columns have been widely used to determine pesticide residues in recent years. The increase in sensitivity and resolution achieved with these columns has produced the replacement of packed column by capillary. Various selective detectors are generally used in the trace analysis of herbicides such as the electron-capture detector (ECD), nitrogen-phosphorus detector (NPD) or also called thermoionic ionization detector (TID) is commonly used in the analysis of nitrogen-containing herbicides. Mass-spectrometry can be easily coupled with capillary GC for the identification for herbicides and their toxic degradation or metabolites in the samples. Capillary GC with tandem mass spectrometric (MS-MS) detection is a technique lately used for determination of non-polar pesticide residues in food and environmental samples with good selectivity and high sensitivity.

High-performance liquid chromatography (HPLC) is a technique used in the analysis of herbicide residues for the determination of thermally unstable herbicides that cannot be analyzed directly by GC due to their breakdown in the GC injection port. Most HPLC methods used for the determination of herbicides perform analysis by reversed–phase chromatography with C_{18} or C_8 columns using relatively polar solvents. Ultraviolet (UV) detection with fixed or variable wavelength has been the most commonly used detection method in the HPLC determination of herbicide residues. Recent developments in HPLC-MS have the advantage, of not requiring a derivatization step while providing a high degree of structural information that allows their identification. GC and HPLC are the primary methods used in residue analysis in food. Nevertheless, other techniques such as thin-layer chromatography (TLC), capillary electrophoresis (CE), and the enzyme linked immunosorbent assay (ELISA) are also employed.

Multi-residue analysis: The wide range of polarities and physico-chemical properties of herbicides do not allow the determination of most of them in a single analytical method. Thermally labile and non-volatile herbicides are determined by HPLC method. The use of mass spectrometry (MS), a universal selective detector, permits the detection and confirmation of a wide range of herbicides in complex extracts of foods. GC/LC-MS and GC/LC-MS-MS detection techniques have gained popularity for determining and identification of herbicide residues in agricultural food commodities. Due to the ever-lower detection levels required by the regulatory bodies and the complex nature of the matrices, efficient sample preparation and low-level detection and identification are important aspects in the development of analytical chemistry.

Food safety

Government is responsible for ensuring that the public must be protected from potential health risks posed by eating foods that have been treated with pesticides. Government is responsible both for the registration of new herbicides before they can be marketed and the re-registration of older herbicides to ensure that they meet current scientific standards. To prevent consumers' health, maximum residue limits (MRLs) have been established at international and national levels.

Determination of MRLs for herbicide residues in food crops: For setting MRL of a herbicide in a crop, the country is required to scientifically generate herbicide residue data as per standard guidelines.

Supervised field trials: Terminal residues of a particular herbicide on a treated crop are estimated from supervised trials designed to determine the nature and level of residues resulting from the registered or approved use of herbicides when used as per the good agricultural practice (GAP). Residue data should be for mature crops at normal harvest. However, where a significant part of the consumable crop is present at the time of application of the pesticide, some residue dissipation studies are required to complement the residue data obtained at normal harvest such as pre harvest interval (PHI) or waiting period. It is not a regulatory standard. The interval is based on the number of days it takes for the chemical or residue to breakdown in the plant. No traces of chemical may be found in seed or food commodity destined for human consumption.

Residue data must be based on three locations (different agro-climatic zones), two seasons and on the recommended and double the recommended doses. Data also must be

collected on parameters namely - location of the trial (country, state); crop and its variety; trial design; plot size; active ingredient; formulation; application parameters (spray concentration, application rate, spray volume); sprayer; number of applications; interval between applications; crop growth stage; harvest day and pre-harvest interval, field sample size, replications; analytical method, procedural recoveries; time for which sample stored in freezer; and residue levels in samples from control (untreated) plot.

Validated analytical methods: The methods used in the supervised trials and processing studies must be validated for the substrates and herbicides. Herbicide will include active ingredient and relevant metabolites that need to be measured in the trials (based on enforcement and dietary intake). Analytical recoveries are acceptable in the range 80-110%. The limit of quantification (LOQ) of the analytical method is taken as the lowest residue level where analytical recoveries were tested and shown to be acceptable. Extractability of the residue should be tested by analysis of samples from the metabolism studies, where concentrations of the parent compound and its metabolites are already known from radiolabel (usually ^{14}C) measurement.

Metabolism: Information are required on animal metabolism, plant metabolism, and environmental fate in soil and in water-sediment systems. Metabolism studies are conducted to determine the qualitative metabolic fate of the active ingredient and elucidate its metabolic pathway. Many pesticides undergo change during and after application to plants, soil, water and livestock. The composition of the terminal residue must, therefore, be determined before the residue analytical methodology can be developed and residues quantified.

The estimated intake of pesticide is calculated on the basis of the terminal residues in a crop, the nation's mean food intake and average body weight of a person. This value is called theoretical maximum daily intake (TMDI) of that pesticide in the crop.

Fixation of MRLs: MRL of a herbicide on a crop is derived from TMDI value and acceptable daily intake (ADI) evaluated from toxicological (generated from metabolic studies on laboratory animals) studies using Codex guidelines.

Codex MRLs. The Codex Alimentarius Commission was established in 1963 by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) with the objective of developing international food standards, guidelines and codes of practice to protect the health of the consumers and ensure fair practices in the food trade. The Commission has a specialist committee on pesticide residues for the establishment of MRLs. As Codex MRLs cover a very wide spectrum of use patterns and "good agricultural practices" and need to reflect residue levels closest to harvest, they may occasionally be higher than the levels of residues found at national or regional level, or established by other bodies (such as the European Union, EU) which do not cover such a variety of spectra. However, Codex MRLs are established only where there is supporting evidence concerning the safety to humans of the resulting residues as determined by the JMPR, after a thorough toxicological evaluation. The Codex MRLs are recognized by most UN member countries and are widely used, especially by countries that do not have their own system for evaluating and setting MRLs.

MRLs vary from country to country depending on the pesticides available, the crops being treated and the way the pesticides are used. Governments around the world are cooperating in an effort to establish synchronized MRLs and to minimize the differences in tolerance. This effort occurs on a bilateral basis between two nations as well as through multilateral international organizations such as the UN (Codex Alimentarius Commission). Each year at Codex, representatives of member countries meet to establish tolerance that can be used as international MRL standards.

Recently, in November 2010, the Organization for Economic Cooperation and Development (OECD) MRL Working Group finalized its MRL calculator, user guide, which officially has been approved by The Working Group on Pesticides (WGP) and became available for download from the OECD web site.

Indian MRLs: Till recently, The Ministry of Health and Family Welfare with the help of the Directorate of Plant Protection, Quarantine and Storage; and Ministry of Agriculture, was responsible for fixing MRLs of herbicides in various crops in accordance of the Prevention of Food Adulteration Act (PFA), 1955 as amended in 2004. However, with the implementation of Food Safety and Standards Act (FSSA), 2006, the PFA rules are being phased into the Food Safety and Standards Regulations, 2010. The new Act authorizes the Food Safety and Standards Authority of India (FSSAI) to "specify the limits for use of food additives, crop contaminants, pesticide residues, residues of veterinary drugs, heavy metals, processing aids, myco-toxins, antibiotics and pharmacological active substances and extent of irradiation of food." The existing MRLs on pesticides and agrochemicals specified in the PFA have been incorporated in the Food Safety and Standards Regulations, 2010. MRLs are listed by chemical product for specific food items/commodities.

Some recent developments related to MRLs in India

Pesticide standards in drinking water: There were reports in the media in February, 2003 with respect to residues of extremely harmful pesticides found in popular brands of bottled water marketed in and around Delhi and Mumbai. FAO decided to include water in the definition of food for setting permissible limits vide a notification issued on July 18, 2003 effective from January, 2004, the pesticide residues in carbonated water, fruits and vegetable juices, fruit syrup, fruits squash, fruit beverage or fruit drink, soft drink concentrates (after dilution as per direction), and ready to serve beverages of any kind were set as 0.0001 mg/L (1 ppb) for individual pesticide residues and 0.0005 mg/L (5 ppb) for total pesticide residues with the condition that the analysis should be conducted by using internationally established test methods meeting the residues limits specified herein.

MRLs - a pre-requisite for pesticide registration: Henceforth, the Pesticide Registration Committee will consider only those pesticides for registration for which MRL has been fixed on the specified crops. No registration will be granted to any pesticide for which tolerance limits are not prescribed under the PFA Act.

Deletion of crops from label and leaflet of pesticides for which MRL is not fixed: Manufacturers of various pesticides are advised from time to time to generate and submit the data for MRL fixation in respect of those pesticides which are sold in market for use on crops without fixation of MRLs. The Central Government, in consultation with the Registration Committee, has decided for deletion of the names of the crops from labels and leaflets of such pesticides. Recently, as per notification of Ministry of Agriculture dated 24 September, 2014, the label claims of some of the pesticides on certain crops have been deleted from approved

Herbicide resistance in *Phalaris minor* in India and its management

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Rice-wheat is the dominant cropping system in the North-Western Indo-Gangetic Plains of India. Little seed canary grass (*Phalaris minor* Retz.) is the single most important grass weed of irrigated wheat, especially in this cropping system. Large scale adoption of high yielding dwarf varieties of wheat, which are less competitive with *P. minor*, under increased fertilisation and irrigation practices favoured its dominance. Further, intensive rice-wheat cropping system and consequently changes in wheat production practices after the green revolution eliminated some of the broadleaf weeds and aggravated the infestation of *P. minor*. It germinates in different flushes- along with the crop, after first irrigation, or before if there is rainfall and after second irrigation also- during the growing period of crop. The wheat grain yield losses due to competition with this weed varies from 25-80%; however, the extent of yield losses depends on the intensity and duration of weed competition along with soil and climatic factors.

The herbicides such as methabenzthiazuron, nitrofen, metoxuron and isoproturon were recommended for its control. The farmers opted isoproturon mainly because of its cost effectiveness, wider application window, flexibility in method of application and broad-spectrum weed kill along with its selectivity under wheat and mustard intercropping. After continuous use of isoproturon for around 15 years, *P minor* evolved resistance to this herbicide in Punjab, Haryana and Uttar Pradesh in the early 1990s. Alternate herbicides viz., clodinafop, sulfosulfuron and fenoxaprop were recommended for its control and were widely adopted by the farmers. Complains of poor efficacy of these alternate herbicides started appearing at farmers' field, after decades of their use.

A farmers' field survey conducted during 2011 in Punjab indicated the evolution of cross resistance in *P. minor* to clodinafop and sulfosulfuron (Table 1). The results of the survey indicated that farmers used to apply recommended rates of these herbicides till 2008-09 and got effective control of *P. minor* (>85%). In 2009-10, clodinafop started showing signs of reduced efficacy and >30% farmers used 1.5 times of recommended dose and still got poor control (<65%). Even, few farmers (<10%) used 2 times of recommended dose with little success. In 2010-11, the farmers (<50%) used 2 times and <30% used even 3 times or higher dose of clodinafop alone/tank mix of clodinafop with sulfosulfuron or used both herbicides in sequence and control was still poor (0 - <60%). Sulfosulfuron efficacy also showed declining trend (<60%) in this year. The spray technology adopted by the farmers was better than what they were using in the previous years, hence could not be related to the reduced herbicide efficacy. Recently, cross-resistance to pinoxaden have been reported from Punjab and to mesosulfuron + iodosulfuron, sulfosulfuron and pinoxaden from Haryana.

Table 1. Herbicides use pattern, herbicide efficacy and development of cross resistance in *P. minor* over the years at farmers' field in Moga district of Punjab, India

Herbicides	Dose (g/ha)	2008-09		2009-10		2010-11	
		Farmers (%)	WCE (%)	Farmers (%)	WCE (%)	Farmers (%)	WCE (%)
Clodinafop	60	62	85.5	33	60.2	0	
Clodinafop	90	0	-	9	60.0	9	40.0
Clodinafop	120	0	-	0	-	14	45.0
Clodinafop *fb* clodinafop	120 + 90	0	-	0	-	9	20.0
Clodinafop + sulfosulfuron + metribuzin	120 + 25 + 50	0	-	5	45.0	0	
Clodinafop *fb* clodinafop + metribuzin	120 *fb* 60 + 75	0	-	0	-	5	30.0
Clodinafop *fb* sulfosulfuron	60 *fb* 25	0	-	0	-	21	30.0
Sulfosulfuron	25	38	75.0	33	62.2	14	25.0
Sulfosulfuron *fb* clodinafop	25 *fb* 60	0	-	0		0	
Clodinafop + sulfosulfuron	60 + 25	0	-	21	65.0	14	40.5
Clodinafop *fb* sulfosulfuron + clodinafop	90 *fb* 25 + 120	0	-	0	-	9	35.0
Sulfosulfuron *fb* clodinafop *fb* clodinafop	25 *fb* 60 *fb* 120	0	-	0	-	9	30.0

Looking into the present scenario, it seems that the problem of herbicide resistance in this weed may again pose a serious threat to the sustainability of wheat productivity in the near future. The herbicides alone could not provide long term control of wide range of weed flora present in a field. The aim should be to manage the weed population below a level that reduces farmers' economic returns. The adoption of integrated approach of weed management that relies on multiple management interventions related to maximizing crop growth and minimizing weed growth will help in preventing/delaying the evolution of resistance. Non-chemical weed management practices may help in reducing weed populations and are of increasing importance due to consumers' concerns about pesticide residues and potential environmental contamination from pesticides. The integration of multiple cultural practices along with chemical use for weed control provides greater benefits than the effects of using just one or two weed control practices in isolation.

Preventing the entry of new weeds and spread of existing weeds: It is possible to prevent many new weeds from being introduced onto the farm, and to prevent existing weeds from producing large quantities of seeds. Preventing invasive and alien weeds in fields is usually easier and less costly than controlling them after severe infestation, as it is difficult to control weeds once they are established. Some weed preventive measures include the use of clean crop seeds, the use of clean agricultural implements, and managing weeds on bunds and roads can greatly reduce the introduction of weed seeds and difficult weed species. It is even possible to selectively hand-eradicate isolated outbreaks of new weeds to avoid future infestations. Hand-

roguing of weeds before seed-shed could be an important practice. This helps in prevention of build-up of weed seed bank in the fields. Preventive measures, unfortunately, are always forgotten.

Laser levelling the field: Laser land levelling provides uniform soil moisture in the entire field and allows uniform crop establishment and growth leading to better suppression of weeds. The herbicides efficacy tends to be better in precisely levelled fields in comparison to traditionally levelled fields.

Adoption of stale seedbed: A stale or false seedbed involves applying pre-sowing irrigation. This stimulates the emergence of *P. minor* seedlings which are then killed by cultivation when wheat is sown by conventional tillage or by application of paraquat under zero-till sowing. Stale seedbed is very helpful in reducing pressure of *P. minor* in zero-till sown wheat. When this practice is used, the crop emerges under weed-free conditions and it will have a competitive advantage over late-emerging weed seedlings.

Early sowing of wheat in narrow rows: The crop should be planted at a time when the temperatures are favourable for crop growth. The early sowing help in significantly reducing the first flush of *P. minor*, which is the most damaging for the crop. Sowing in narrow rows improves ability of the crop to compete with weeds. The crop sown in narrow rows rapidly closes canopy and shades out later-emerging weeds and prevents germination of light sensitive weeds. Similarly, quick growing varieties, due to early canopy closure, enhance the competitive ability of wheat over weeds.

Sowing wheat with zero-till drill, happy seeder or bed planter: Zero tillage offers good opportunity to manage *P. minor* but continuously practising zero tillage may increase the problem from other weeds. The sowing of wheat with Happy Seeder machine in standing stubbles of rice significantly reduces the problem of *P. minor*. The Happy Seeder machine can sow the wheat in field with heavy rice residues of 8-10 t/ha. The residues retained on the surface prevent germination of many light sensitive weeds such as *P. minor* by blocking light penetration. However, some manual weeding/herbicide application is still necessary. If this machine is not available, then first chop the standing stubbles of rice with 'chopper' and then sow the wheat with normal Zero-till drill. Alternatively, collect the rice residues with 'bailer' and sow with normal Zero-till drill. The burning of rice residues stimulates *P. minor* germination. Hence, the priority should be to retain the residues on the surface.

Alternatively, sowing wheat on raised beds with 'Bed Planter' provides good management of *P. minor*. In raised bed method, the top portion of the bed dries faster which reduces weed germination. The fertilizers in this method are banded close to the seed thus enhancing crop roots accessibility to nutrients and competitiveness over weeds. Additional light penetrates into the crop canopy from both sides of rows on bed which strengthens the straw and soil becomes dry around the base of the plants. The weeds emerged in the furrows and along sides of the bed can be controlled by inter-cultivation with tractor along with drilling of second dose of urea, which is not possible in case of wheat sown on conventional flat beds. The emerged weeds can also be controlled mechanically by detaching the shaper of the bed planter.

Hence, the problem of *P. minor* can be reduced with the adoption of zero-till, Happy Seeder and raised-bed sowing methods.

Forming soil mulch before sowing: Most of the small seeded weeds germinate in the surface layer of the soil. This aspect of germination ecology of weeds can be exploited for their control, when wheat is sown on conventional flat beds. After seed bed preparation, allow the top layer of the soil to dry and form 'dust mulch', and then sow the wheat. The dust mulch is pushed away by the seed drill and large-seeded wheat seed is planted into the zone of soil moisture. This practice prevents the germination of early flush of weeds and provide initial weed free environment for the crop. When combined with early sowing, soil mulch helps in eliminating the first flush of weeds.

Light irrigations: Weeds can adapt to both excess and deficient soil moisture whereas crop plant do not posses this characteristic. Generally, the first irrigation tends to be heavy and consequently crop turn pale yellow, due to reduced conditions in the soil for a longer period, particularly in a rice-wheat system. Under such situations, the competitive ability of the wheat gets reduced and it is overpowered by weeds. The herbicide application also gets delayed which reduces herbicide efficacy. On the other hand, the presence of more moisture, especially in heavy textured soils, sometimes results in toxicity of some herbicides such as sulfosulfuron, mesosulfuron + iodosulfuron, sulfosulfuron + metsulfuron, fenoxaprop + metribuzin on wheat plants. Hence, always apply light irrigations for proper growth and development of wheat plants and better control of *P. minor* and other weeds.

Crop rotations: Crop rotation is a key control method to reduce weed problems, and it has been mistakenly eliminated with the introduction of more agrochemicals. The growing of the same crop in the same field year after year results in a build-up of weed species that are adapted to the growing conditions of the crop. When diverse crops are used in a rotation, weed germination and growth cycles are disrupted by variations in cultural practices associated with each crop (tillage, planting and harvest dates, crop competition and weed control methods). Replacing rice with alternate crops like cotton, maize and sugarcane in the summer season, and wheat with egyptian clover, potato, Indian mustard, oilseed rape, sunflower, winter maize in winter season for 2-3 years significantly reduces the problem of *P. minor* (Table 2).

Table 2. Status of *P. minor* seed bank in different crop rotations in Kapurthala and Patiala districts of Punjab, India in 2002

Crop rotations	No. of *P. minor* seeds/kg top soil			
	0-7.5 cm soil depth		7.5-15.0 cm soil depth	
	Kapurthala	Patiala	Kapurthala	Patiala
Rice-wheat	40	30	18	10
Rice-potato-sunflower/wheat	7	0	3	0
Rice-toria (Indian rape)-sunflower	0	-	0	-
Rice-berseem (*Egyptian clover*)	0	0	0	0
Rice-gobhi sarson (oilseed rape)	5	-	0	-

Alternative herbicides and herbicide mixtures: Alternative herbicides play a key role in managing herbicide resistance in weeds. Different pre- and post-emergence herbicides are available for control of *P. minor* in wheat. For example, for control of isoproturon-resistant *P. minor*, pinoxaden, mesosulfuron + iodosulfuron, flufenacet, metribuzin, pendimethalin, trifluralin and sulfosulfuron can be used. For control of clodinafop-resistant populations, sulfosulfuron, mesosulfuron + iodosulfuron, flufenacet, metribuzin, pendimethalin and trifluralin can be used. For controlling sulfosulfuron resistant populations, clodinafop, fenoxaprop, pinoxaden, flufenacet, metribuzin, pendimethalin, trifluralin can be used. However, major concern is multiple rersistance in *P. minor* against isoproturon, clodinafop and sulfosulfuron. Under such conditions we have limited options and effective herbicides are flufenacet, metribuzin, pendimethalin, trifluralin, pyroxasulfone and pre-mixes of metribuzin with pendimethalin, clodinafop and fenoxaprop. There is need to evolve new herbicides with modes of action different from the herbicides currently available for control of *P. minor*.

Depletion of weed seed bank: Even after practicing different weed control measures, some weeds plants can escape and produce a large number of persistent seeds, which may or may not reduce crop yields but will increase weed management costs in subsequent seasons. These weed plants need to be removed/uprooted before they set seed so as to reduce the weed problem in the succeeding cropping seasons, and this tactic is affordable for most farmers in the state.

Adoption of integrated weed management: Any single method of weed control described above, used in isolation, cannot provide season-long effective weed control because of variations in the growth habit and life cycle of weeds. For example, cultural/non-chemical methods alone cannot control weeds, but help in reducing weed population. Anyway, the weed management should start with non-chemical methods that reduce problems caused by weeds. Weeds of secondary importance may emerge as a primary weed problem because of the continuous use of a single herbicide or herbicides with a similar mode of action. This problem can be avoided by adopting an integrated approach that includes combination of various approaches, given above, to restrict weed populations to manageable levels in wheat.

Non-chemical weed management in field crops

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Presence of weeds in crop field cause considerable reduction in productivity of crops. Unlike insect, pests and pathogens, where the effect on crop is visible, the damage done by weeds is often not noticed. In addition to direct effect on crop yield, weeds result in considerable reduction in the efficiency of inputs used. In reality, weeds cause serious yield losses if they are not controlled fully and at the right time. Losses due to weeds are higher in crops grown in rainy season than in winter season. The degree of yield reduction depends on a number of factors such as weed flora, intensity, tillage and cultural practices, input use, soil and weather conditions. Cultural weed control has been practiced by farmers for centuries. In many instances the weed control practices followed by the farmers are either incomplete or are not applied at proper time resulting in a loss of about 10-15% of the potential yield. Cultural weed control practices can be effective when utilized individually, but more effective when practiced in combination and year after year.

In general, the weeds have to be checked through prevention, eradication and control. The non chemical weed management in crops requires an integrated approach that utilizes preventive, cultural, mechanical, biological, ecological methods in a mutually supported manner into the crop production system. It is difficult to eradicate all the weeds, therefore, it is better to manage them to a certain stage of the crop, where they could cause minimum damage to the crop. Different methods of weed management have been used with different degree of success in different agro-ecological zones and productions system, which are as follows.

Weed prevention: The prevention of a weed problem is usually easier and less costly than control or eradication. Use of 'clean' (weed seed-free) crop seeds for planting; use of organic manures only after thorough decomposition having no viable weed seeds; clean harvesters and tillage implements before moving to non-weed infested area; avoiding transportation or use of soil from weed infested area; inspecting nursery stock or transplanting seed and vegetative propagules of weeds; removing weeds that are near irrigation ditches, fence rows, right-of-way and other non-crop land; preventing reproduction of weeds; use of weed seed screens to filter irrigation water; restricting livestock movement in to non-weed infested area prevents weed multiplication.

Physical weed management: Though physical methods (manual and mechanical) are very effective, they have certain limitations such as unavailability of labour during peak period, high labour cost, and unfavorable environment for weeding operation. Mechanical weed management includes tillage, mulching, flooding, draining, beating, cutting, pulling, dragging and hand weeding. These practices can be done by unskilled labour and generally are economical, non-polluting without residual problems.

Tillage: Timely and effective tillage is a good means of weed control. Weeds emerge with pre-monsoon showers before the crop is planted. Various forms of pre-planting tillage serve both for

seed bed preparation and control of emerged weeds. Use of several shallow tillage prior to planting increase weed seed germination and depletes the number of weed seeds that germinate later and require control during the season. Tillage helps in controlling weeds by killing emerging seedlings, burying weed seeds, delaying germination of perennial weed seeds, leaving a rough surface to hinder weed seed germination. Scientific studies of summer tillage indicate that an interval of 15-20 days after fresh weed emergence was optimum and eventually after a few years of properly spaced tillage programme, the underground parts of the weed will be weakened to acceptable levels. Dry weather and dry soil are pre-requisites for the success of summer tillage as a weed management practice.

Mulching: Suppression of weeds by mulch is attributed to various chemical and physical factors. In case of some weed species where light is necessary to stimulate seed germination, mulches hinder weed germination by reducing light transmission and subsequently for photosynthesis. The chemical effect of mulches on weed control includes allelopathy, toxic microbial products and pH changes in soil.

Solarisation: Solarisation is a method of heating the surface soil by using plastic sheets placed on moist soil to trap the solar radiation. In hotter regions after removing plastic mulches, fields will be free of soil borne pests - diseases, nematodes and weeds.

Stale seed bed: A stale seed bed is a one where initial 1-2 flushes of the weeds are destroyed before planting of a crop. The technique allows the crop to germinate in almost a weed – free environment.

Cultural weed management: Any practice which benefits the crop by enhancing its competitive ability against weeds has to be considered. Seedling vigour, growth rate, early rooting, and plant height give competitive advantage to the crop. Cultural practices such as land preparation, timely weeding, proper seed rate, and spacing and fertilizer management boost the competitive ability of crops and also substitute for chemical weed control. Plant density, row spacing, intercropping and crop rotation influence weed incidences. Deep tillage, periodical cultivation of land before sowing, repeated harrowing and hoeing, line planting, raising quick growing crops, crops having large canopy are known to reduce weed intensity. Trap crops which induce germination of parasitic weed without being parasitized also reduce weed intensity.

Crop rotation and cover crops: Diverse crop rotations are to be integrated for improved weed management systems. Rotating crops with different life cycles can disrupt the development of weed–crop associations. Diverse crop rotations can aid in reducing the weed seed bank. Certain weed species are often associated with particular crops and the population of such weeds usually increases when that crop is grown on the same field continuously for several seasons. Cover crops can aid in weed management through diverse mechanisms such as resource competition, reducing weed establishment and growth through physical and chemical means. Inclusion of cover crops in the rotation at a time when land might otherwise lay without crop will suppress weed development, yet maintain soil fertility and prevent erosion. Further, the decomposing cover crop residues may release allelochemicals that inhibit the germination and development of weed seeds.

Intercropping: Intercropping suppresses weeds better than sole cropping. Intercropping with short duration pulses like, cowpea, greengram and soybean effectively smoother weeds without causing reduction in the yield of main crop.

Competitive crops and cultivars: Crop competition is an important and cost effective weed management option for enhancing weed suppression. Crops differ in relative growth rate, spreading habit, height, canopy structure and inherent competitive character and accordingly differ in their weed suppressing ability. Early crop competitiveness is essential and depends on optimal crop establishment and early vigor. A quick growing and early canopy-producing crop would be expected to be better competitor against weeds than crops lacking these characters. Generally, cereal crops are more competitive than grain legumes, and oilseed crops. Cultivars within crop species differ in competitiveness with weeds. Older, taller crop cultivars are often more competitive than the modern semi-dwarf types. Further, early and uniform crop establishment is essential for crops to successfully compete with weeds. The concept of critical period of control, reflects crop tolerance to both early-season and late-season weed interference. A key principle is that controlling weeds early in the crop season is most favorable for preserving crop yield.

Plant geometry and plant density: Increasing crop density and reducing row spacing increases the competitive ability of crops with weeds. Narrow row spacing will bring variation in microclimate viz., light intensity, evaporation and temperature at soil surface. The establishment of a crop with a more uniform and dense plant distribution may result in better use of light, water and nutrients and lead to greater crop competitive ability. Crops grown in narrower rows start competing with weeds at an earlier stage than those in wide rows because of more rapid canopy closure and probably better root distribution. Increased shading at soil surface will smother weed growth.

Nutrient management: Use of fertilizers in cropping systems alters soil nutrient levels that can affect crop–weed competitive interactions. There is good potential to manipulate fertilizer timing, dose and placement to reduce weed interference in crops.

Water management: Proper water management can reduce weeds in both wet and dry seasons. More weeds emerge earlier at high soil moisture than at low moisture level. Method of irrigation also influences the weed density. In drip irrigation, the weed density is greatly reduced due to the wetting of soil near the plant base only. In rice, flooding suppresses weeds by imposing anaerobic conditions in the soil, which is lethal to many weed seeds, seedlings and perennial storage organs.

Cropping system approach: Different cultural practices involved in a cropping system strongly influence the composition of weed flora. Weed management practices should be followed for the entire system as a unit instead of considering weed problem of individual crops. This is necessary because weed shift occurs due to crops grown in the system and the carry over effects of weed control methods on succeeding crop.

Mycoherbicides: Plant pathogens have been used effectively to control weeds in augmentative type biological control program. The native pathogens are artificially applied at very high inoculum levels so that the weeds succumb. Several mycoherbicides have been commercialized for weed control in crops.

Site-specific weed management: The technological developments like remote sensing, geographic information systems, and the global positioning system have increased the potential for site-specific weed management.

Herbicide resistance: Lessons learnt and future directions

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The development of herbicide resistance is an escalating threat to agriculture globally. Despite enormous research and extension efforts from weed scientists, herbicide resistance cases are continuing to grow and expand rapidly (see http://www.weedscience.org). Herbicide resistance and its management have considerable economic implications in production agriculture worldwide. Herbicide resistance is expected to remain one of the major pest management concerns in high-input, intensive-farming systems because selection pressure generated at the population level from the repeated use of a same herbicide or mechanism of action will inevitably lead to the evolution of herbicide-resistant weed biotypes.

Resistance has become an important consideration in the herbicide discovery and regulatory process, both in the developed and developing nations. With the advent of herbicide-tolerance trait technologies, for instance, glyphosate-resistant (Roundup Ready®) cotton, soybean, and corn commercialized in North and South America in 1996/1997, the weed management practices in these crops have been oversimplified. Glyphosate-resistant crops were rapidly adopted by growers in U.S. and South America. In the U.S., 94% of soybean, 91% of cotton, and 89% of corn area, with a total of almost 45 million hectares (mha), was planted with glyphosate-resistant cultivars in 2014. Globally, 82% of soybean, 68% of cotton, and 30% of corn area was planted with glyphosate-resistant cultivars in 2014. Concomitantly, the U.S. has the greatest number of hectares in conservation tillage (~46 mha). In these no-till glyphosate-resistant cropping systems, farmers abandoned the use of pre-emergence soil-residual herbicides, with sole reliance on multiple post-emergence glyphosate applications. There was a phenomenal drop in the number of herbicide mechanisms of action used in these crops from an average of seven in 1995 to only one in 2005. Even with the predicted low probability of occurrence of resistance to glyphosate (1×10^{-10}), the first glyphosate-resistant weed, horseweed (*Conyza canadensis*), was discovered in U.S. in 2000. The next most devastating glyphosate-resistant weeds in U.S. were Palmer amaranth (*Amaranthus palmeri*) (first reported in 2005), common waterhemp (*Amaranthus rudis*) (first reported in 2005), common ragweed (*Ambrosia artemisiifolia*), and giant ragweed (*Ambrosia trifida*) (first reported in 2004). Since then, glyphosate-resistant horseweed, Palmer amaranth, and common waterhemp have been confirmed in more than 20 states in U.S., an impending disaster for the no-till glyphosate-resistant soybean and cotton production. Because of the inability to control the glyphosate-resistant *Amaranthus* species with currently available weed control tools in conservation tillage systems, hundreds of thousands of conservation tillage hectares are at risk of being converted to high-intensity tillage systems. This has resulted in a paradigm shift in U.S. soybean and cotton production system. By 2015, 32 weeds have been reported to develop resistance to glyphosate globally.

Concomitantly, there is an increase in the evolution of weed resistance to other herbicide mechanisms of action in agricultural production systems. By 2015, there are more than 400 reported herbicide-resistant weed biotypes, with resistance to almost all of the herbicide mechanisms of action; more than a two-fold increase in the cases compared to 1995. More alarmingly, there has been an increase in the number of weed species with evolved resistance to multiple herbicide mechanisms of action, with cytochrome P_{450}-based enhanced metabolism, multiple target-site mutations, over expression of the target site (for instance, *EPSPS* gene amplification), and reduced absorption/translocation as some of the key mechanisms conferring multiple resistance. These newly evolved, multiple herbicide-resistant weed biotypes are a serious concern for the farmers and have significantly reduced on-farm weed control options. Development and adoption of effective, integrated weed management programs based on the concept of "diversity" is the key to delay or prevent herbicide resistance, sustain conservation tillage practices, and reap the benefits of new weed control technologies.

Successfully managing herbicide resistance would require collaboration and information from multiple disciplines, including applied weed science, evolutionary biology, population and molecular genetics, biochemistry, physiology, and ecology. Additionally, economics, sociology and other social sciences would play an important role for the adoption of integrated resistance management programs and changed farming practices at a community level. There is need for an active, strong linkage between innovation (discovery or development of a new technology), adoption (actual use of the new technology by the farmers), and diffusion (percentage of farmers utilizing the new technology or percentage of farm land dedicated to the new technology) of new weed control technologies and changed farming practices.

Switching to new herbicide-tolerance stacked-trait crop technologies may not be the ultimate, long-term weed management solution, unless "holistic approaches" for innovation, adoption, and diffusion of these new technologies are adopted. Currently, Monsanto, Dow, Bayer, Syngenta and BASF are developing new stacked-trait crops in combination with glyphosate resistance. They are glyphosate, glufosinate (soybean, corn, cotton); glyphosate, ALS inhibitors (soybean, corn); glyphosate, glufosinate, 2,4-D (soybean, cotton); glyphosate, glufosinate, dicamba (soybean, corn, cotton); glyphosate, glufosinate, HPPD inhibitors (soybean and cotton); glyphosate, glufosinate, 2,4-D, ACCase inhibitors (corn); and glufosinate, dicamba (wheat). These stacked-trait crops will provide new options with existing herbicides, but it is to be noted that several weeds have already evolved resistance to these herbicides. Another technology in the early stages of development that has potential to combat herbicide-resistant weeds is use of RNA interference (RNAi) technology (BioDirect™ by Monsanto). The use of RNAi involves the topical application of double-stranded RNA (dsRNA) to interfere with the expression of herbicide resistance genes in weeds. The field experiments have demonstrated that BioDirect™, when combined with herbicide, can reverse resistance. The technology has also been demonstrated with weeds resistant to ALS-, HPPD- and PPO-inhibiting herbicides. RNAi is a revolutionary technology for resistant weed management, but is still years away from commercialization. While no new herbicides are on the horizon, in the near future, the herbicide resistance management strategies must utilize an array of tools to disrupt herbicide-resistant weeds from evolving and spreading, with the ultimate goal of not allowing any weeds to survive and set seed.

There is a need for development of an "Herbicide-Resistance Task Force" by coordination of existing committees and members of the Asian-Pacific Weed Science Society (APWSS), with

focus primarily on applied research and extension activities to implement best management strategies (BMPs) at a local and regional level. The aim of this task force would be to provide a platform for dialogue amongst weed science researchers, extension specialists, pest managers, genetics and molecular biologist, ecologist, economists, and sociologist, with a common goal of managing pest resistance in different agro ecosystems and geographical locations. Through discussions on a range of pest resistance issues at local/regional level, members will gain unique interdisciplinary perspectives and information regarding implementation of BMPs across different regions and systems. Additionally, this task force would serve as a liaison between the APWSS and other international weed science societies such as IWSS, WSSA, HRAC, chemical industry, government regulatory bodies, and organizations like FAO, ICAR, USDA, and U.S. EPA.

Management of parasitic weeds in India

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Parasitic weeds are those plants which require growth stimulants for germination, and or host plant to support growth and development and to complete their life cycle. Parasitic weeds depend on host plant for nutrients, water, photosynthates and minerals etc. Parasitic weeds are gaining importance in recent times in view of their wide spread occurrence, host-specificity and difficulties in managing them. Parasitic weeds have certain specific characteristics like prolific seed production potential, competitiveness and aggressiveness with the host plants, prolonged seed viability, troublesome and very difficult to control by normal weed control measures.

Parasitic weeds are two types based on dependence on host plants – complete parasite which depends on host plants entirely for its survival (Ex. *Orobanche* and *Cuscuta*) and semi-parasite which depends on host plants for physical support, nutrients, water, minerals for its survival (Ex. *Striga* and Mistletoe). The former does not have green leaves and hence depends on host plants for photosynthates, while the latter have green leaves and synthesize photosynthates on its own for its survival. Parasites are of two types based on occurrence on – a) root parasite like *Striga* being partial parasite occurring on sorghum, maize, sugarcane, and *Orobanche* being complete parasite occurring on tobacco, tomato, brinjal, potato, mustard, etc; and b) stem parasite like *Cuscuta* being complete parasite occurring on lucerne, fennel, niger, bengal gram, plantation crops, hedge plants, etc. and *Dendrophthoe* or *Viscum* being partial parasite occurring on timber crops, fruit trees, plantation crops, etc. The brief status of these parasitic weeds in crops, losses caused by them and management strategies to contain the menace of the parasitic weeds are as follows.

Orobanche

Orobanche sp. (broomrape, Orobanchaceae) is a complete root parasite with about 130 species occurring only on varied broad leaf crops world over. It is concentrated in Mediterranean countries, Europe, Africa, Australia, Asia and North America. Broomrape parasitizes wide range of hosts comprising food leguminous crops, oilseed crops, solanaceous crops and medicinal plants belonging to families – Solanaceae, Chenopodiaceae and Asteraceae. The four virulent species are *O. cernua* on tobacco, sunflower, tomato, brinjal; *O. ramosa* on carrot, cabbage, cotton, sunflower, tomato, Brassica crops; *O. aegyptiaca* on tomato, cotton, cucurbits, brinjal, potato, tobacco; and *O. crenata* on carrot, tomato, peas and broad beans *(Vicia faba).* In India, *O. cernua* and *O. aegyptiaca* are occurring on crops – tobacco, cumin, mustard, plantago, lentil, potato, brinjal and tomato and cause losses from 30-35% in tobacco to more than 80% in solanaceous vegetables. As the broomrape entirely depends on host plants, at times it will be devastating where mono-cropping of solanaceous vegetables are grown in succession. The broomrape is distributed in Karnataka, Andhra Pradesh, Tamil Nadu, Gujarat, Maharashtra, Rajasthan, and Haryana states causing greater concern among farmers.

Broomrape is an annual, host specific parasitic herb propagated by seeds and gets germinated if the host root exudates reaches the seed for one week and if the seeds lie within 10 mm distance from host fibrous roots. The parasite seedlings then infect the nearby host roots forming haustoria on them. It emerges through the soil as pale shoots, devoid of chlorophyll around 45 to 55 days after planting of host crops and starts flowering a week after emergence. Fleshy shoot grows up to 20 to 30 cm and dries up in 30 to 40 days. Each shoot can produce as high as 6 lakh seeds and as high as 30 to 40 shoots/plant in case of tobacco or tomato crops due to wide root ramification/spread. The broomrape seeds disseminate by wind, birds, farm animals, implements, water, seeds etc. They can remain dormant in soil for more than 15 to 20 years.

Control: The broomrape can be managed by following suitable preventive, cultural, physical, biotechnological, biological and chemical methods. Suggested control measures that can be adopted in India are avoiding the use of seeds from infested areas, use of clean and certified seeds; deep tillage incorporates seeds well below root zone and prevents the contact of the stimulants of host crops with the parasite seeds; soil solarisation with the use of 0.05 mm thick white polyethylene sheets for 30 to 40 days during hot summer, though expensive can lower the menace by 60 to 80%; flooding of the field during germination of parasite (i.e., around 20-25 days after planting); physical removal of emerged shoots of parasite and burning them; repeated directed application of 1 to 2 drops of mineral oils – diesel, kerosene or plant oils – coconut, neem, caster, cottonseed, gingili or linseed on emerging shoots before flowering would desiccate them and prevent seed formation; passing spear or iron blade below the host plant would cut young shoots of parasites followed by manual removal of shoots within the rows, collecting and burning them; use of trap crops – pepper *(Capsicum annum* L.), Amaranthus, cowpea, greengram, blackgram, pigeonpea, Dhaincha for 3 to 4 seasons before taking up main host crops in sick fields; use of suitable intercrops in areas having lower infestation of parasite; soil application of analogue of Strigol – GR-24 or GR-7 at 0.3 kg/ha in acid soil to 1.5 kg/ha in alkaline soil about 6 weeks before sowing of host crops induce suicidal germination of the parasite; use of pre-emergence herbicides relevant to the host crops will delay and lower the emergence of broomrape; use of ammonical or urea based fertilizers at 2 mg/liter of water lowers the emergence and length of the radicals of the parasite; directed spraying of glyphosate at 0.1 to 0.2% on the lower side of the host plants around 50-55 days after planting, use of neem cake at 150 to 200 kg/ha in rows at planting, soil drenching with 5% copper sulfate around host crops between 45 to 55 days will lower the emergence of broomrape. Other options are use of Agromyzid shoot borer – *Phytomyza orobanchaia* lowers seed production by 30 to 80%; use of *Fusarium* specific to broomrape species can lower the menace of broomrape by 60 to 80%; while biotechnological approach of developing glyphosate resistant lines of host crops would also lower the menace of the parasite.

Broomrape also infests weeds like *Parthenium hysterophorus, Solanum kasianum* and *Physalis minima* and thus perpetuate by forming numerous seeds. Therefore, integrated efforts namely preventive, physical, cultural and chemical approaches should be adopted to destroy these weeds before they set seeds.

Striga

Striga (witchweed, Orobanchaceae), is an annual, partial root parasite propagated through tiny dust like seeds with 41 species having wide distribution. Of these, 11 species occur on important tropical cereals (maize, sorghum, pearl millet, finger millet, upland rice and sugarcane) and many grasses. Of these, only four species are considered noxious inflicting greater losses to the farmers. They are i) *Striga asiatica* (also known as *S. lutea*), wide spread in Africa, Asia occurring on sorghum, bajra, maize, sugarcane, rice, millets and grasses; ii) *S. hermonthica,* wide spread in Africa, North and South Yemen, Madagascar and Saudi Arabia occurring on sorghum, maize and other grasses; and iii) *S. gesnerioides*, wide spread in Africa, South Yemen, South Arabia, Oman, India and USA, exclusively occurring on dicotyledonous crops - cowpea, tobacco; and iv) *S. densiflora,* wide spread in India and Indonesia occurring on sugarcane and cereals. *Striga* causes yield losses of 15 to 75% in India in sorghum, pearl millet, maize and sugarcane depending on the severity of infestation. The stimulants secreted from the host plants which causes germination of *Striga* are kinetin, zeatin, ethylene, Strigol, scopoletin, thiourea, allylthiourea, sulphuric acid and sodium hypochlorite. The *Striga* seeds lying within a few millimeters of host roots and receiving stimulants continuously for 24-28 h, will germinate and able to make attachment with host roots through haustoria. *Striga* emerges after 50-55 days of sowing of host crops and continues growth for another 50 to 70 days. Each shoot may produce seeds up to 50,000 to 75,000. Seeds can have dormancy up to 15- 20 years.

Control*:* Non-chemical methods such as deep tillage, uprooting and burning of shoots, use of clean seeds, avoid using seeds from infested areas, crop rotation, use of trap crops or inter cropping, and use of resistant crops/varieties may be useful in preventing and reducing the menace of *Striga*. It is generally agreed that for the subsistence farmers of the tropics, the development of resistant varieties of sorghum [N-13, No. 148/168 (CSV-5), Farmida, BH4-1-4], sugarcane (CO-290, CP-36-13, CP-36-105, CP-48-103), maize and pearl millet will be the final answer to the *Striga* menace. For instance, the new hybrids of pearl millet seem free from *Striga*.

Catch crops (*Striga*-susceptible, short duration crops to be planted and destroyed before planting the main crop) and trap crops (*Striga* germination stimulating crops with inherent attachment barriers), are often suggested as possible means to reduce *Striga* populations. Cotton, sunflower, cowpea, gram, redgram, sesamum, groundnut, castor and melons are considered suitable trap crops of *Striga*. Catch crops like *Setaria* and maize, may be taken up before main crop. Growing of intercrops of groundnut, cowpea and redgram along with sorghum can also lower the menace of *Striga*. Repeated hand-pulling around 50-55 days onwards before flowering and burning will help in lowering the menace of *Striga*, but it is impracticable and costly in situations of severe infestations. *Striga* infestation is usually less in the wet season, in adequately N fertilised plots, and in densely sown crops. Improving soil fertility through manures and fertilizers (application at higher than recommended level) also lowers the menace of *Striga* owing to higher osmotic concentrations of the host plant cell sap. Directed applications of 2,4-D (1.5 to 2.0 kg/ha) is a very practical alternative to reduce the seed bank of *Striga*. Alternatively, 2-3 applications of low doses of 2,4-D (0.5-0.75 kg/ha) during the crop season is also effective and destroy flushes of *Striga* in its vegetative phase. Use of stimulants like Strigol, GR 7, GR 45 and ethylene before sowing are effective in reducing 50% *Striga* population. The stimulants will be effective on moist soil for at least for 3-4 weeks and when the temperature is about 20 C. A successful ethylene and methyl bromide fumigation treatment achieve 90% reduction in *Striga* seed population, but it is not practicable for the arid farmers. Further efforts are needed from researches to develop chemical stimulants of varied strains of *Striga* are

needed. Thus, the timing of soil treatment with the stimulants and the planting of crops must be worked out properly. Isolated infestations of *Striga* growing on some host weeds species, outside the field boundaries, should also be destroyed with any contact herbicide to prevent its seed production.

Suitable legislation is required to restrict the movement of seeds of crops grown in these parasite infested areas to other areas. In the United States, "Witchweed" is the only weed seed whose movement is prohibited in every state.

Cuscuta

Cuscuta (dodder, strangle weed, Devil's guts, family Convolvulaceae) is an invasive, obnoxious, complete stem parasitic weed that attaches itself to stem and leaf of wide varieties of host plant species. There are about 175 species of genus *Cuscuta* and 12 species occur in India. *Cuscuta chinensis*, *C. reflexa* and *C. campestris* are more common in India. The *Cuscuta* is widely distributed in our country in cropped and non-cropped areas. This parasite poses a serious problem in Orissa, Chattisgarh, Madhya Pardesh, Andhra Pradesh, Tamil Nadu, Gujarat and Karnataka. It is also a major weed of lucerne and berseem, linseed, lentil, chickpea, greengram, blackgram, onion, sugarbeet, carrot, tomato, hina and citrus. In non-cropped areas, the weed is mostly found on hedges and shrubs.

Cuscuta can transmits tomato leaf curl virus from infested plants to healthy plants of tomato following establishment with haustorial connections. They also transmit the diseases to host plants. The yield reductions due to *Cuscuta* are reported to the tune of 30% in greengram and blackgram, 85% in lentil, chickpea and alfalfa depending upon severity of infestation. Seeds usually germinate on or near the soil surface. Germination of seed is completely independent of any influence from a host plant. Seedlings are rootless, leafless stem. After emergence, the seedlings twin around the leaf or stem of a suitable host plant. In the absence of suitable host, *Cuscuta* seedlings die within a week's time. Haustoria from the *Cuscuta* penetrate the host and establish a parasitic union. Once the *Cuscuta* is attached to a host plant, it remains parasitic until harvest. A well-established single plant of *Cuscuta* produces more than one lakh of seeds, which remain viable for many years. It reproduces mainly by seeds and to a lesser extent by shoot fragments. In India, *Cuscuta* occurs on forage legumes (alfalfa and clovers), pulses (chickpea, lentil, pea, blackgram, greengram and pigeonpea), oilseeds (niger, sesame, soybean and linseed), carrot and citrus.

Non-chemical methods such as use of *Cuscuta* free crop seeds, use of resistant crops/varieties, deep ploughing, burning, crop rotation and intercropping, stale-bed technique, mechanical weeding, etc. may be useful in preventing/reducing *Cuscuta* infestation. *Cuscuta* is one of very few weeds that can be controlled completely by crop rotation with members of the Poaceae, forage grasses or cereal grains. Without a host plant nearby, *Cuscuta* seedlings emerge and die. There are genotypic differences with regards to tolerance to *Cuscuta* infestation. Lucerne variety T9 was found to be highly sensitive, whereas LLC 6 and LLC 7 were moderately tolerant to *Cuscuta* infestation. Greengram cv. M2 and black gram cv. T9 are tolerant to *Cuscuta*. The shade from dense crop foliage suppresses *Cuscuta* sufficiently to control it almost completely.

Non-selective herbicides like paraquat (1%) and glyphosate (1%) and others like 2,4-D kill *Cuscuta* effectively in areas where it occurs in patches. Use of pre-emergence herbicides trifluralin or pendimethalin at 0.75 to 1.50 kg/ha (relevant to crops) will lower the menace of *Cuscuta* in addition to other weeds in niger, linseed, chickpea and lentil. In lucerne, early post-emergence (10 days after sowing) of pendimethalin at 0.50 kg/ha was also effective killing the emerging *Cuscuta*.

Mistletoes

Mistletoes (family Loranthaceae and Viscaceae) are obligate, semi stem parasite, most troublesome weeds of tree crops and bushes. In India 70 species of mistletoes have been reported attacking several hundreds of trees and shrubs extending from the sea level to about 3500 m in the Himalayan hills. These can attack numerous trees and shrubs of forests and plantations leading to untimely death of the host plant. In forests, they are reported to reduce the productivity of both timber and related forest products. Mistletoes affect host foliage, phenology, respiration, growth, yield, quality and increase operational and protection cost of plantation. In trees, the parasite enters the entophytic system, invades the bole/heartwood and thus affects wood quality. Wood quality is also affected by production of larger knots and other altered physical properties. They also alter the pattern of plant succession, and disturb the vegetation pattern of the landscape. Mango and cashew plantations are some of the most seriously affected ones.

The principal families of mistletoes are loranthaceae and viscaceae. Loranthaceae has 73 genera and 1000 species and Viscaceae has 11 genera and 450 species. Flowers in viscaceae are small and inconspicuous, whereas those of Loranthaceae are large, colourful and calyculus. Most problematic mistletoes are *Dendrophthoe falcata* (L.f.) Ethingsh. LC. *and Viscum* spp. The seeds of parasite are spread by birds to fresh tree branches. In many parts of India, it occurs on almost all forest trees, high value timbers (Teak, Rose, Sandalwood, Eucalyptus, Casuarina, Neem, Copperpod, Banyan, Ficus, Flame of the forest), fruit/commercial trees (Mango, Citrus, Sapota, Guava, Pomegranate, Cocoa, and Coffee). Occurrence of the parasite has not been observed on Tamarind.

Control: Scraping the bark of the parasite at the point of attachment of the haustoria on the tree and placement of cotton pads containing 1 g 2,4-D Na salt 80 WP dissolved in 20 ml water effectively control *Dendrophthoe falcata*. Directed spraying of ethrel (Ethephon 39 SL) 25 ml/l on the parasite causes complete defoliation without harming the host plants and regrowth do not occur for at least 6 months. Other method is to lop off the branch infested with *Dendrophthoe* to prevent further growth and spread in the initial stage itself.

Bioremediation – role of aquatic weeds

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Aquatic plants grow profusely in lakes and waterways all over the world and in recent decades their negative effects have been magnified by man's intensive use of water bodies. Eradication of the weeds has proved almost impossible and even reasonable control is difficult. Turning these weeds to productive use would be desirable if it would partly offset the costs involved in mechanical removal. Aquatic plants are also used for pollution control, that is accumulation of heavy metal ions by aquatic macrophytes from the water.

Water is a resource that supports life throughout the earth. Contamination of water resulting from anthropogenic activities is a matter of concern worldwide. Various forms of physical, chemical and biological contaminants are reported in polluted waters. Chemical pollutants mainly include inorganic, organic and gaseous pollutants depending upon the nature of anthropogenic activity and the chemicals used in various industrial processes. Discharge of municipal sewage and industrial activities deteriorate water quality in urban areas. Synthetic fertilizers, herbicides, insecticides and plant residues released from agricultural activities change the water quality in rural areas. Waste water emanated from various sources including municipal drains act as a pollutant if transported to surface water bodies or leached down to ground water. Besides this, high content of sodium, calcium, magnesium ions in such water contributes to high alkalinity and is favorable for enhancing aquatic weed infestation in fresh water bodies.

In India, most of peri-urban agriculture is subjected to waste water irrigation. In peri-urban areas, farmers usually adopt year round, intensive vegetable production systems or other perishable commodity like fodder and earn up to four times more from a unit land area compared to freshwater.

Bioremediation exploits the natural capability of living organisms to clean environment. It involves the use of microorganisms and other biological materials such as algae, fungi and bacteria to detoxify or remove pollutants from the environment owing to their diverse metabolic capabilities. Bioremediation aids in transformation and degradation of contaminants into non-hazardous or less hazardous substances like mitigating hydrocarbons, halogenated organic compounds, non-chlorinated pesticides and herbicides, nitrogen compounds, metals (lead, mercury, chromium) and radio nuclides. Bioremediation techniques, although requiring more time, usually require less capital than the physical and chemical treatment methods and has been listed among top ten technologies because of its potential for sustainable mitigation of environmental pollution and cost effectiveness.

Phytoremediation

Plants remove or degrade selected contaminants present in soil, sludge, sediment, groundwater, surface water and wastewater by utilizing their metabolic and hydraulic processes, thereby improving the environment quality that is termed as 'phytoremediation'.

The ideal plants for phytoremediation should possess the ability to tolerate and accumulate high levels of heavy metals in their harvestable parts, while producing high biomass. Several species of aquatic plants have been used for phytoremediation of wastewater. Over the time, green technology became a promising alternative for treating both organic and inorganic contaminants present in water and soil and hence can be an affordable technological solution for wastewater treatment. The high purification activity of the plants is due to a rapid growth in polluted wastewater and capacity to remove contaminants. Bioremediation technologies, including phytoremediation, have been estimated to be 4 - 1,000 times cheaper than current non-biological technologies.

Phytoremediation technology can be useful for removal/degradation/stablization of both organic and inorganic contaminants. Treatment of organic contaminants mainly involves phytostabilization, rhizodegradation, rhizofiltration, phytodegradation and phytovolatilization mechanisms, while phytostabilization, rhizofiltration, phytoaccumulation and phytovolatilization mechanisms are mainly involved in the treatment of inorganic contaminants.

Different phytoremediation processes

Phytoextraction: It is defined as uptake/absorption and translocation of contaminants by plant roots into the above ground portions of the plants (shoots) that can be harvested. Plant species absorb and hyper accumulate metal contaminants and/or excess nutrients in harvestable root and shoot tissue. This process is applicable for metals (Ag, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn), metalloids (As, Se), radionuclides (90 Sr, 137 Cs, 234 U, 238 U), non-metals (B, Mg) and organic contaminants present in soils, sediments and sludge.

Phytostabilization: It is defined as the use of plants to immobilize the contaminants in the soil and groundwater through absorption and accumulation in plant tissues, adsorption onto roots or precipitation within the root zone preventing their migration in soil. The plant root exudates stabilize, demobilize and bind the contaminants in the soil matrix, thereby reducing their bioavailability. This process is suitable for organic contaminants and metals present in soils, sediments and sludges. This technique does not require disposal of hazardous materials or biomass. Long-term maintenance of the vegetation is the limitation.

Rhizofiltration (Phytofiltration): It is the removal of contaminants in surface water by plant roots. It involves adsorption or precipitation onto plant roots or absorption followed by sequestration in the roots. This process is applicable for removal of metals (Pb, Cd, Cu, Fe, Ni, Mn, Zn, Cr), excess nutrients and radionuclide (90 Sr, 137 Cs, 238 U, 236 U) present in groundwater, surface water and wastewater

Phytovolatilization: It is defined as the plant's ability to absorb, metabolize and subsequently volatilize the contaminant into the atmosphere. Growing trees and other plants take up water along with the contaminants, pass them through the plants leaves and volatilize into the atmosphere at comparatively low concentrations. This process is used for removing metal contaminants present in groundwater, soils, sediments and sludge medium.

Phytodegradation (Phytotransformation): It is defined as the metabolization and degradation of contaminants within the plant or the degradation of contaminants in the soil, sediments, sludges, groundwater or surface water by enzymes produced and released by the plant. Organic compounds such as munitions (trinitrotoluene), chlorinated solvents, herbicides, insecticides and inorganic nutrients are reported to be removed by this technique.

Advantages of phytoremediation technique

Over the last few years, phytoremediation emerged as a publicly acceptable, aesthetically pleasing and solar-energy-driven cleanup technology with minimal environmental disruption as it possesses certain advantages such as:

- Capacity in reducing a wide range of contaminants both organic and inorganic
- Cost-effective technology as it does not require expensive biosorbent materials and highly specialized personnel and equipment. It effective for remediate large volumes of water having low concentrations of contaminants and for large areas having low to moderately contaminated surface soils.
- Can be applied *in situ* to remediate shallow soil, groundwater and surface water bodies
- Does not have adverse impact on environment and benefits the soil, leaving an improved functional soil ecosystem at costs estimated at approximately one-tenth of those currently adopted technologies.
- Can be used in much larger-scale cleanup operations
- Organic pollutants may be degraded in to safer compounds like CO_2 and H_2O

Realizing the potential of terrestrial species; aquatic plant species have been explored and studied extensively for their phytoremediation capacity. A number of aquatic plant species and their associated microorganisms have been used for more than a decade in constructed wetlands for municipal and industrial wastewater treatment. The aquatic plant biomass represents an abundantly available biological material. The features such as easy cultivation, high biomass production, faster growth rate, surplus availability and high tolerance to survive adverse environmental conditions together with higher bioaccumulation potential establish them as potential agents for phytotechnology.

Plant species used in phytoremediation technology

The aquatic and wetland plant species gained importance worldwide as they depict exorbitant efficiency to remove contaminants from wastewaters, though the degree of potential for removal varies from species to species. Aquatic macrophytes possess immense potential for removal/degradation of variety of contaminants, including heavy metals, inorganic/organic pollutants, radioactive wastes and explosives. Aquatic plants form a major part of the natural and constructed wetlands as they possess immense potential for removing variable contaminants from wastewaters/aqueous solutions. Realizing the exorbitant abilities of aquatic macrophytes, their role in environmental cleanup is highlighted.

Aquatic macrophytes are broadly classified into three types depending upon their habit of growth:

- Free-floating plant species like *Lemna*, *Eichhornia*, *Pistia*, *Salvinia*, *Azolla* and *Spirodela*
- Submerged plant species like *Potamogeton*, *Ceratophyllum* and *Myriophyllum*
- Emergent plant species like *Typha*, *Elodea*, *Phragmites* and *Scirpus*

Hyper-accumulators

Plants that possess the capacity to accumulate high quantities of metals than required for plant growth are termed as 'hyper-accumulators'. The concentration noted in these plants are about

10–100 fold higher than the levels noted in 'ordinary' or non-hyperaccumulator plants. For example, *Eichhornea crassipes* can accumulate and tolerate high concentrations cadmium and zinc.

Contaminants that can be removed by aquatic plants

I. Inorganic contaminants

Heavy metals: Heavy metals form one of the largest categories of contaminants that are efficiently being removed by aquatic plants. Living and non-living biomass of aquatic plants remove heavy metals in a sustainable way. Aquatic macrophytes (free floating, submerged or emergent plant species) sequester heavy metals. Free-floating aquatic plant species namely *Eichhornia crassipes* (water hyacinth), *Salvinia herzogii* and *Salvinia minima* (water ferns), *Pistia stratiotes* (water lettuce), *Nasturtium officinale* (watercress), *Spirodela intermedia*, *Lemna minor* (duckweeds) and *Azolla pinnata* (water velvet) possess potential to scavenge heavy metals and have been used in abatement of heavy metals. Submerged species including *Potamogeton crispus* (pondweed), *Potamogeton pectinatus* (American pondweed), *Ceratophyllum demersum* (coontail or hornwort), *Vallisneria spiralis*, *Mentha aquatica* (water mint) and *Myriophyllum spicatum* (Eurasian water milfoil) also bear the potential for extraction of metals from water as well as sediments. Semiaquatic/emergent plant species such as *Typha latifolia* (cattail), *Phragmites* spp. (common reed) and *Scirpus* spp. (bulrush) possess potential metal-removing abilities.

Explosives: Submerged and emergent aquatic plant species including *Elodea Michx* (elodea), *Phalaris* sp. (canary grass), *Ceratophyllum demersum*, *Potamogeton nodosus* and *Sagittaria latifolia* (arrow head) have demonstrated the capacity to remove explosives such as 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) and octahydro-1,3,5,7-tetranitro-1,3,5,7- tetrazocine (HMX) from contaminated groundwater.

Radionuclides: Removal of radionuclides such as 137 Cs, 60 Co and 54 Mn by submerged and emergent aquatic plant species including *Potamogeton lucens*, *Potamogeton perfoliatus*, *Nuphar lutea*, *Nitellopsis obtusa*, *Phragmites australis*, *Typha latifolia*, *Elodea canadensis*, *Ceratophyllum demersum* and *Myriophyllum spicatum* have been reported.

Ions/nutrients: Aquatic plant species such as *Ceratophyllum demersum*, *Potamogeton crispus, Eichhornia crassipes*, *Elodea nuttallii* and *Elodea canadensis* showed potential for effective removal of excess of inorganic nutrients such as nitrogen and phosphorus from hydroponic systems and microcosm.

II. Organic contaminants

Aquatic plant species possess potential to remove, sequester and transform organic contaminants like organophosphorus and organochlorine compounds, chlorinated solvents, hydrocarbons, explosives and pharmaceuticals by aquatic plants.

Limitations of phytoremediation technology

- It is generally considered as a time-consuming process and may take several growing seasons to cleanup a site
- Selection of faster growing plants and hyperaccumulators is a prerequisite
- Intermediates formed from organic and inorganic contaminants may be cytotoxic to plants
- Potential risk of horizontal gene transfer to related wild or cultivated plants is an important barrier associated with development of transgenic plants for bioremediation
- Depth of plant root is also a main factor that affects the plant's potential for uptake
- Technology can lose its effectiveness during winter or when damage occurs to the vegetation from weather, disease or pests
- Transfer of toxic contaminants to various components of food chain or bioconcentration of toxic contaminants by components of food chain and environment is an issue of major concern, especially if there is transformation of the contaminant into a more toxic, mobile or bioavailable form
- Efficacy for phytoremediation varies with species or varieties
- Amendments and cultivation practices might have unintended consequences on contaminants mobility

Conclusions and future developments

Phytoremediation is recognized as a cost-effective method for remediating sites contaminated with toxic metals, radionuclides and hazardous organics at a fraction of the cost of conventional technology. Research related to this relatively new technology needs to be promoted and emphasized and expanded in developing countries. In addition, environmental aesthetics should not be ignored. Under phytoextraction, the cost of processing and ultimate disposal of biomass generated is likely to account for a major percentage of overall costs. The use of plant roots as 'biocurtains' or 'biofilters' for the passive remediation of shallow groundwater is also an active area of research. The establishment of vegetation on a site also reduces soil erosion by wind and water, which helps to prevent the spread of contaminants and reduces exposure of humans and animals. Yet in many ways, this technology is still in its infancy. The public acceptance of technology depends upon the fact that field testing of genetically engineered plants is done. The application of phytoremediation is being driven by its technical and economic advantages over conventional approaches.

How successful is biological control of weeds?

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Biological control of weeds involves the use of living organisms (*i.e.* insects, pathogens, nematodes, parasitic plants and or other competitive plants) to keep population of a specific weed below the critical level. It includes the classical (inoculative), bioherbicides (inundative) approaches and herbivore management. The process involves collecting exotic natural enemies followed by importing, rearing, testing, and release from quarantine into target habitat for their establishment. Host specificity tests are conducted in artificial and field conditions, and combined with ecological and molecular evaluations. Australian scientists, Julien and Griffiths (1998) analyzed the total release of biocontrol agents on weeds and found that by 20th Centaury 1,120 releases of 365 species of biological control agents were made against 133 weeds in 75 countries predominantly in USA, Canada, Australia, South Africa and New Zealand. Recently in 2014, Suckling and Sforza (year), further analyzed the released world over and concluded that in 21st centaury upto 2012, a further 147 agents were released generating a new total of 512 organisms released for weed biological control world over. Be aware! Deliberate release of natural enemies is subject to necessary official approvals.

There is always discussion among the proponents and opponents about the success of biological control of weeds. Proponents of biological control advocate that biological control is aneffective method to control many problematic weeds besides being economical and eco-friendly. On the other hand, opponents believe that biological control is too slow, not able to control all weeds, involves costly and cumbersome process for import of a biocontrol agent, require test its host specificity, high rate of failure of bioagents, and may involve some degree of risk for non-target plants.

Success of biological weed management programmes

The history of biological control of weeds dates back to the seventeenth centaury and since then a great deal of progress has been achieved in biological methods of weed control. In fact, the first unintentional outstanding success of biological control of prickly pear (*Opuntia* sp.) in India from 1795 onwards by cochineal insect led the world to use natural enemies against exotic weeds. The success was followed in Sri Lanka (1865), and Australia (1912) and against lantana (*Lantana camara*) in Hawai'i in 1902.

There have been many successes world-wide in the biological control of weeds. McFadyen (1999) claimed successful management of 41 weeds using introduced agents (insects) and of three weeds using native fungi applied as mycoherbicides. Many of the successes have been repeated subsequently in different countries or continents.

McFadyenh as critically analyzed the definition of success of by biological control programme as given by Hoffman (1995). The success may be 'complete' when no other control method is required or used, at least in areas where the agent(s) is established; 'substantial' success means where other methods are needed but the effort required is reduced (*e.g.* less herbicide or less frequent application); and 'negligible', where despite damage inflicted by agents, control of the weed is still dependent on other control measures. Complete control does not mean that the weed is eradicated, but that control measures are no longer required solely against the target weed. "Substantial" control includes cases where control may be "complete" in some seasons and/ or over part of the weed's range, as well as situations where the control achieved is widespread and economically significant but the weed is still a major problem. Introductions of weed-feeding natural enemies have ranged from very successful (with a 99% reduction of the pest species) to complete failures. 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 in case of terrestrial weeds (23.8%).

Economic evaluation of biological control

Reported benefits in USA from the major weed biological programs in the 20th century resulted in benefits (net of research costs) in excess of US $180M per annum mainly from reduced ongoing costs of control using herbicides. Environmental benefits of replacing pesticides can be considered to be proportional in magnitude to market economy benefits. Biocontrol of weeds contributes to prevention of substantial losses to the economy over the decades, where it prevented the loss of ecosystem, environment and biodiversity that contribute to human well-being. The successful biocontrol of Noogoora burr (*Xanthium strumarium*) in Queensland resulted in annual benefits of US $720,000, a return of 2.3:1. Evaluations of the successful control of skeleton weed (*Chondrilla juncea*) and of tansy ragwort, have demonstrated benefit-cost ratio of 112 and 15. In South Africa, it is estimated that biocontrol programs have already saved US $276 million in weed control costs. Well known successful biological control programmes include management of tansy ragwort (*Senecio jacobaea*) in the USA, and nodding thistle (*Carduus nutans)* in Canada and the USA. Less known examples are the management of *Cordia curassavica* in Malaysia and Mauritius; annual weed Noogoora burr in Australia; *Harrisia cactus and Eriocereus martinii* in Australia; and annual weed *Mimosa invisa* in Australia, Papua New Guinea and the Cook Islands. The perennial shrub *Chromolaena odorata* has been successfully controlled in the Marianas and in large areas of Indonesia. The perennial shrubs *Hamakua pamakani, Ageratin ariparia,* and Klamath weed *Hypericum perforatum* are now well under control in Hawaii. The perennial trees type weeds, which were supposed not to be controlled by biological methods, like *Acacia saligna* and *Sesbania punicea* were successfully controlled in South Africa. Successful control of *Sida acuta* was also achieved in northern Australia.

The biological control programs against aquatic weeds may be viewed as excellent successes. Three water weeds namely, water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*), and water fern (*Salvinia molesta*) have been successfully controlled in the tropics and sub-tropics. Alligator weed (*Alternanthera philoxeroides*) has also been successfully controlled in aquatic habitats in sub-tropical climates. Benefits of biological control are enormous, if we calculate the financial, environmental and social cost. A case on point is the control of aquatic weeds. In general, water bodies are used for transport as well used for fisheries, irrigation and water supply. *Salvinia*, water hyacinth and alligator weeds are a known menace in water bodies. Control of these weeds in large areas by chemical or mechanical means is almost impossible and impractical. In India, release of the weevil *Crytobagous salvinae* led to successful control the *Salvinia* in Kerala in a large number of waterways and ponds within a reasonable time. The biological control of *Salvinia* also led to revival of the other aquatic flora similar to the pre-*Salvinia* days. Annually, thousands of hectares of water bodies regularly remain under control or at low level due to action of bioagent. Likewise, water hyacinth in many ponds and lakes in India has been controlled by the release of *Neochetina* spp.

After first release of *Zygogramma bicolorata* in India in 1984 for biological control of *Parthenium* and later due to its intensive introductions after 2000 to different parts of the country by Directorate of Weed Research (DWR), the bioagent has been established widely across the country. Incidence of *Z. bicolorata* has been recorded from mild to heavy in most of the states wherever it was introduced. Once a bioagent is established in one part of the country, its further release and augmentation can be achieved at negligible cost.

Why doubts about the chances of success?

Despite some great successes, many still doubt the potential of biological control of weeds. The absence of systematic studies on the impact of the technology adds credence to this view. Long term impact studies on economic, societal and environmental benefits are badly needed to support the successes of biological control of weeds. Although some of these assessments are easy, some are extremely difficult. The introduction of a biocontrol agent may not provide instant and complete control of weeds. But its effect on stopping the further spread of the weed to newer areas may be happening at a slow but steady pace leading to gradual restoration of the habitat. The introduction might be slowing down and stopping the extinction of natural flora and fauna. The assessments of such impacts are complicated and are not easy to perform. However, we should not forget the huge benefits some of the introductions of biological control agents have given to the society or the country. For example, the successful control of the prickly pear in India, Sri Lanka and Australia; successful control small tree *Cordia curassavica* in Mauritius and then Malaysia by a defoliating beetle. R.E. Cruttwell McFadyen, an Australian scientist justified that usually a success is quoted from time to time, but the community forgot the seriousness of that particular weed, and how much damage to ecosystems was being caused by the massive infestations of the weed. How many people are aware of seriousness of the *Salvinia* infestations in the Sepik river in PNG in the 1970s and 80s? And how rapidly they were controlled by the release of the *Crytobagous salviniae* weevil in 1982? Other examples are Klamath weed in the western USA and thistles in Canada and the USA, where most people no longer realize seriousness, spread and invasiveness of these weeds. Reports published at the time are seen as out of date and the success then questioned by later authors without realizing the seriousness of original infestations of the weed. In other instance, in the Brisbane river system in northern Australia, water hyacinth has been a problem since the early 1900s. The introduction and rapid establishment of the weevils *Neochetina eichhorniae* in 1975 and *N. bruchi* in 1990 resulted in the effective control of the weed in the areas where it used to proliferate.

What is failure of biological programme?

Failure in biological control of weed can be attributed to the failure of a biological agent in which the density of the target weed has not declined due to unsuccessful establishment and multiplication of biological agents. Such an example of well established but ineffective agents are the gall flies *Urophora quadrifasciata* and *U. affinis* introduced to North America on

Centaurea diffusa which became established and increased rapidly but could not reduce weed density. Cinnabar moth, *Tyria jacobaea* introduced as a control agent for *Senecio jacobaeae*, but had little impact on the weed density.

Failure of a whole program for biological control of a weed can occur when all the agents available for release do not measurably reduce the density of the target weed. In some cases the failure may be temporary and be the result of insufficient resources to identify, screen, or disseminate agents. For example, several bioagents have been released against *Lantana* in India but they did not bring about spectacular success. Likewise, *Chromolaena odorata* could not be controlled in India by the introduced bioagents. Another type of program failure that can occur in biological control is the attack on non-target hosts by the introduced agents. Failure may be due to poorly resourced programs; long time lag (20 years or more) and to record full extent of the pre-biocontrol weed infestations. If the probability of success is wrongly judged to be very low, the decision will be made to invest resources into other control methods, and biocontrol will not be attempted until the other methods have failed. Ignorance of past successes can also lead to untested theories becoming established dogma which again wrongly affect the decisions made. For example, it has been believed that biocontrol of trees is particularly difficult, yet, there are several examples of trees controlled by insects. Classical biocontrol has been seen as unsuitable for weeds of annual crops or other frequently disturbed environments despite of severalsuccessful examples.

Host specificity is one of the biggest fears in the mind of scientists and public as well. But it has been proved by rigorous analyses of past release that this is a wrongly justified fear. Recently, in 2014, Suckling and Sforza (year) from New Zeeland analyzed the risk magnitude of biological control agents on non-target organisms considering all the releases made world over so far to control weeds. They did not find significant risk magnitude and concluded that it was rare. The magnitude of direct impact of 43 biocontrol agents on 140 non-target plants was retrospectively categorized using a risk management framework for ecological impacts of invasive species (minimal, minor, moderate, major, massive). The majority of agents introduced for classical biological control of weeds (>99% of 512 agents released) have had no known significant adverse effects on non-target plants. Most direct non-target impacts on plants (91.6%) were categorized as minimal or minor in magnitude with no known adverse long-term impact on non-target plant populations, except a few cacti and thistles which were affected at moderate (in three cases), major (in seven cases) and massive (in one case) scale. The largest direct impacts are from two agents (*Cactoblastis cactorum* on native cacti and *Rhinocyllus conicus* on native thistles), but these introductions would not be permitted today as more balanced attitudes exist to plant biodiversity, driven by both society and the scientific community. Some impacts could have been overlooked, but this seems unlikely to change the basic distribution of very limited adverse effects. It is recommended that a simple five-step scale should be used for better communication of the risk of consequences from both action (classical biological control) and no action (ongoing impacts from invasive weeds).

Biological control agents or programme may also be considered as failure due to the technical hindrances during the production and dissemination of agent or release of misidentified agents. For example, release of agents on the wrong species of plant as occurred in the early stages of the leafy spurge program, at the wrong time of day, in wrong season where agents attain the potential to develop disease while being reared for release. Mixing of two species of agents prior to release may also be a cause of failure in some cases. This has occurred with the two *Urophora* species on knapweed and the two *Galerucella* species on *Lythrums alicaria.* Host testing mayalso be considered to be "technical failure" if agents are released that attack non-target hosts.

How to avoid failure of biological control programme?

Reducing the number and increasing the effectiveness of introduced biological control agents is a way to decrease the chances of failure. If progress can be made toward selecting agents that are more likely to be successful, non-anticipated side effects can be avoided. The successful control of the *Salvinia molesta* provides a good example for a retrospection. There are two species of weevil bioagents namely, *Cyrtobagous salviniae* and *C. singularis.* Grubs of *C. singularis* feed externally and have little impact on the plants, while *C. salviniae* grubs tunnel through plant rhizomes, nodes and leaves and cause internodes to turn brown and disintegrate. These slight differences in feeding behavior may turn a programme unsuccessful and failure if *C. singularis* is introduced against *Salvinia*. Biocontrol scientists need to publicize their successes so that biological control is appreciated as a truly successful, cost-effective and environmentally-sustainable method of weed control.

Failure may also be avoided through better communication, experimentation and evaluation as many weed problems are global. Through good screening of literature and communication, successes can be maximized. More indepth studies about the population dynamics of weeds and bioagents may help to find out the weak links with respect target weeds and bioagents. Biocontrol programme should be evaluated honestly as a whole for quantification of true impact of bioagent. Simply determining establishment or non-establishment, control or partial control, cannot really allow an accurate evaluation of biological control of weeds.

The future

The increasing incidence and impact of invasive species is widely recognized as a major threat to food and fiber production as well as ecosystem functioning. Therefore, need for classical biological control has been felt in order to mitigate increasing cost involved in control programme. Many analyses of success rates suffer from the inclusion of data from recent programs before equilibrium has been reached. Despite successful establishment of most of the bioagents in Australia, *Parthenium* weed remains a major problem and the programme is yet to be regarded as a success. However, field experiments involving insecticide-treated check plots have demonstrated reduction in *Parthenium* which accounted for increased pasture growth. Calculated over the 50 years since the program began, the cost/benefit ratio for even this partial success ranged between 2:1 and 3.7:1 as stated by Adamson and Bray (1999). In India, in spite of good establishment and continuous control by *Z. bicolorata*, *Parthenium* is still a major problem, which gives the impression that biological control by the beetle is a failure. However, it is worth considering the fact that absence of *Z. bicolorata* would have accentuated the problem now spread over, 8 Mha of land area. Based on the reports and past experiences, it would be appropriate to summarize that need for biological control programmes will increase in future owing to increased risks of pesticides and the awareness of public about non-chemical approaches of weed management.

Professor Jayashankar Telangana State Agricultural University : Profile

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Background

The Professor Jayashankar Telangana State Agricultural University (PJTSAU) was established on 31st July 2014 at Hyderabad and named in honour and memory of Professor Jayashankar, an eminent educationist and an ardent Telangana ideologue. It is the only Farm University of Telangana state which came into being in the event of the bifurcation from Acharya NG Ranga Agricultural University. This university was established as per the Telangana Govt's G.O. Ms No.7, Agricultural and Cooperation (Agri III) Department, Govt. of Telangana dated 31-07-2014 adapting the ANGRAU Act 1963 as "The ANGRAU Act of 1963 (Telangana Adaptation) order, 2014".

Mandate

Education:

- Train human resource needed for agricultural, home science and allied sectors for the development of the State of Telangana

Research:

- Constantly strive to generate technologies for increasing production in the agriculture and home science and allied sectors

Extension:

- Assist in the process of transfer of technology through the dissemination of knowledge in collaboration with the development departments of the Government

Mission and goals

In tune with the mandate, the university has set for itself the following goals:

- Provide opportunities for the citizens of the state and the country for education in the field of agriculture in its broad sense and to promote research, field and extension programmes in agriculture and allied sciences. Strengthen UG and PG teaching through periodic revision of syllabi
- Establish the required infrastructure to conduct location specific research in the field of agriculture and allied sciences
- Generate technologies to improve farm production and income to farmers
- Provide the needed assistance to the development departments of the Government and other agencies to test and disseminate the improved technologies developed
- Provide opportunities for rural youth and women for learning and adoption of improved agro-technologies

- Revitalize the extension activities through the creation of specific infrastructure in each district
- Adopt advancements in information technology and computers to improve the formal academic programmes and introduce non-formal distance and contact learning programmes for the benefit of farmers, rural youth and women

Institutional infrastructure and expansion of facilities

The Professor Jaya Shankar Telangana State Agricultural University has 7 Colleges (4 in Agriculture, 1 in Agricultural Engineering, 1 in Food Science and Technology and 1 in Home Science), 15 Research stations distributed in 3 Agro-climatic zones of the State, 13 Agricultural Polytechnics (11 for Diploma in Agriculture, 1 for Diploma in Seed Technology and 1 for Diploma in Agricultural Engineering), 9 District Agricultural Advisory and Transfer of Technology Centres (DAATTCs), 6 *Krishi Vigyan Kendras* (KVKs), one Agricultural Technology and Information Centre (ATIC) and Electronic Media Wing apart from one Extension Education Institute (EEI) and Agricultural Information and Communication Centre (AI&CC).

As far as basic infrastructure is concerned, the University had the support of the Government of Telangana State and the Indian Council of Agricultural Research (ICAR) for establishing a strong base. Therefore, the infrastructure, which was transferred to the University at the time of its establishment, has been further strengthened with addition of classrooms, farmlands, laboratories, computer facilities, workshops and hostels. The irrigation facilities in the teaching campuses have been improved through the installation of lift and micro irrigation facilities and sinking of bore wells. Staff quarters have also been built in most of the colleges. The present status of certain important infrastructural facilities existing in colleges is presented below:

The future emphasis is to maintain the strong infrastructure base, which has been developed, and to strengthen certain critical essentials such as hostels for boys in the three main campuses and additional hostel accommodation for girl students at the Rajendranagar campus. The University is also proposing to establish 'Centers of Excellence' and Advanced Research in areas such as Sustainable Agriculture, Integrated Pest Management, in addition to the existing Centre for Advance Studies in Foods and Nutrition under the Faculty of Home Science.

Library

The central library building with a carpet area of 4645 m^2 can accommodate over 2 lakhs books and sitting capacity of about 200 readers. Separate buildings/spacious and functional halls are available at other branch libraries. All the libraries are well furnished with a congenial atmosphere for in-house use of books and periodicals. CD-ROM facilities are available in all major campuses with a view to provide access to world agricultural literature. The University has total collection of over 2,00,000 books and subscribes to 500 Indian and foreign periodicals. The Agricultural Information and Documentation Centre (AGRIDOC) located in the Central Library takes care of information need of the scientists at all the 67 university research stations. The publications include union catalog of periodicals in PJTSAU libraries, agricultural dissertations index, agricultural dissertations abstracts, PJTSAU guidelines of presentation of thesis and "Current Agricultural Titles" backed-up with supply of free photocopies of papers from foreign and Indian periodicals.

Computer centre

The Computer centre at Rajendranagar, as a central computing facility of the university, was established in 1982. The centre is equipped with the latest generation computers and operating on various kinds of operating systems catering to all computing needs of the University. Recently, computer networking has been introduced in the university to gain access to latest scientific advances and related information across the globe. Almost all departments of the colleges were provided with computers for use by the staff and students. Installation of Local Area Network (LAN) is in progress in all the seven zonal headquarters, colleges as well as at headquarter. The computer center and central library at Rajendranagar are equipped with the latest facilities including Internet connectivity, to cater to the needs of the faculty and students.

University auditorium

The University has well-designed multipurpose auditorium of International standards constructed at Rajendranagar campus during the year 2001. It has sophisticated infrastructure to conduct meetings, seminars, symposia, and international conferences covering a plinth area of 5000 square meters. The main hall of the auditorium can accommodate 1000 delegates. It has two seminar halls with a seating capacity of 160 & 110 and a conference hall of 50 seating capacity. The auditorium is furnished with centralized AC facility of 90 ton capacity, and equipped with the latest audio video equipment such as projectors, DTS system, modern stage lighting system with computer controlled camera coverage and a 70 mm screen in the main hall.

Planning and monitoring cell

Individual officers do the planning of various activities of the university and it is then implemented with the approval of Competent Authority. However, during the past 40 years, the University grew very much in size and activities increased enormously. Besides these, the linkages among the universities, institutions and agencies at state, national and international levels have also increased leading to complex situations. All these necessitated to evolve a suitable mechanism not only for planning but also for monitoring the activities of the university, collecting required data and creating a data bank, programme appraisal, monitoring and evaluation of different schemes for functioning of the university and also suggest corrective measures for implementing the programmes from time to time. Functions of the cell include:

- Preparation of an overall perspective development plan of the university keeping in view the factors like student enrolment, staff requirement, developments of colleges and research departments, infrastructure needs at least for a long period of 15 years and subdividing it later into short term duration plans for five years and annual plans
- Sponsoring specific research studies on manpower requirements, admission policies, examination reforms, internal efficiency, pooling of resources etc., and to assess the status of the current programmes of higher education and research
- Appointing specific 'Task Forces' with experts to evaluate the works being carried out by departments, colleges etc. of the university
- Building up knowledge base, data base etc. for making proper projections of the future. To maintain linkages with state, national and international funding agencies and preparing feasibility reports of projects for the university

- The cell prepares the annual reports of the university incorporating the developments during the year in university administration, teaching, research, extension, finance, budget, and building programmes besides listing the awards and honours won by staff etc.
- The cell is handled by a coordinator of the rank of a Professor, who is under the direct control of the Vice-Chancellor

Research infrastructure

A Regional Agricultural Research Station (RARS) of the University is located in each of the nine identified agro-climatic zones of the state with a total number of 16 Research Stations spread all over the state, with at least one in each district.

Infrastructure of transfer of technology

The infrastructure for implementing extension activities of the university is mainly through the 9 District Agricultural Advisory and Transfer of Technology Centres (DAATTCs) functioning in all the district headquarters of the state. In addition, 6 *Krishi Vigyan Kendras,* ATIC Electronic wing, Agricultural Information and Communication Centre, Extension Education Institute and the Regional Biogas Development and Training Centre located at Rajendranagar, Hyderabad campus of the University are actively promoting the Transfer of Technology activities.

Institutional linkages

The university has developed close functional linkages with various organizations at regional, state, national and international levels in its endeavors to promote agricultural production and development in the country in general and State in particular.

International level

During 1964-1972, the University had linkages with Kansas State University (KSU) and United States Agency for International Development (USAID). Faculty members were deputed for advanced training in Agro forestry, Food and Nutrition, Child Development etc. During the recent years, it entered into Memorandum of Understanding (MOU) with several International institutions in countries like Brazil, Germany, Netherlands, UK, USA and Austria. The following Institutes have Memorandum of Understanding with PJTSAU for training scientists and handle research projects of mutual interest:

- Wageningen Agricultural University Research Centre (WUR), The Netherlands
- International Land Reclamation Institute (ILRI), The Netherlands
- Tuskegee University, USA
- USDA, USA
- International Research Institute for Climate Prediction, New York
- Universities of Londrina and North Parana, Brazil
- University of Cornell, Ithaca, USA
- University of California, USA

- Florida A & M University, USA
- IRRI, Philippines

Some of the research schemes were sponsored by International Organizations like Food and Agricultural Organization (FAO), IDRC, UNICEF, USAID, CARE, UNDP, International Foundation for Science, Ford Foundation for Science and US Wheat Associates. Exchange of technical data and plant materials were also taken up with International Rice Research Institute and International Crop Research Institute for Semi Arid Tropics.

National level

The University has developed close linkages with several National Organizations like, Indian Council of Agricultural Research (ICAR), University Grants Commission (UGC) and the Government of India. It is having collaborative research programmes with most of the All India Coordinated Research Projects (AICRP) for which funds are received from ICAR. Apart from research funding, ICAR also provides financial assistance for education, student amenities for equipping the existing laboratories etc. A number of workshops of the Coordinated Research Projects have been arranged by the University in collaboration with ICAR and other agencies. The University conducts summer institutes with the financial assistance from ICAR. The ICAR also provides funds for the frontline Extension/Transfer of Technology programmes like Operational Research Projects (ORP), National Demonstration Schemes (NDS), Lab to Land and Land to Lab etc.

The University undertakes specific projects funded by Government of India. The University has been implementing several extension education programmes sponsored by Government of India like Extension Education Institute (EEI), Regional Biogas Development and Training Centre (RBDTC), *Krishi Vigyan Kendras* (KVKs) etc.

The University has linkages with other agricultural universities in India and is a member of the Indian Agricultural Universities Association and Association of Indian Universities. This helps in exchange of printed material and information etc. The University invites External Examiners at PG level from other universities for conducting Post Graduate level examinations. Postgraduate students of this university have access to expertise and facilities present in local ICAR Institutes like Directorate of Rice Research (DRR), Indian Institute of Oilseeds Research (IIOR), National Research Centre for Sorghum (NRCS), Central Research Institute for Dryland Agriculture (CRIDA), National Remote Sensing Agency (NRSA), National Academy of Agricultural Research Management (NAARM), National Institute of Nutrition (NIN), Indian Institute of Chemical Technology (IICT) etc. The staff is receiving training from NAARM in some specific courses. Several senior staff members often deliver guest lectures at all these institutes at Hyderabad and other locations. The University has a Memorandum of Understanding with the Centre of DNA Finger printing and Diagnostics, Hyderabad besides ICRISAT.

State level

PJTS Agricultural University has established good linkages with State Departments of Agriculture, Horticulture, Animal Husbandry, Irrigation Command Area Development, Tribal Welfare, Forestry, Women Welfare etc., and Corporations like State Seed Corporation, Dairy Development Cooperative Federation, Meat and Poultry Corporation etc. The linkages between

Professor Jaya Shankar Telangana State Agricultural University and State Department of Agriculture (SDA) are at two levels:

(a) Research and Extension Coordination Committee

This Committee, with Director of Agriculture as Chairman, has Deans, Directors and Senior Scientists of Professor Jaya Shankar Telangana State Agricultural University and Senior Officials of State Department of Agriculture as members. It is responsible for promotion of research and extension programmes of the University.

(b) Research and Extension Advisory Council (REAC)

The Vice-Chancellor of Agricultural University is the Chairperson for this committee. Director of Extension, Director of Agriculture, Director of Animal Husbandry, three farmers, four members of Board of Management (BOM) of Agricultural University and all the Associate Directors of Research (ADRs) act as members of the REAC. This council suggests the research strategies based on feedback on the problems encountered by the farmers of the state.

Usually, before *Kharif* and *Rabi* seasons every year, the pre-seasonal workshops are held at district level and state level wherein the scientists of PJTSAU, ICAR and other institutions and officers of the SDA participate to discuss the production programmes for the districts.

At regional level

The Zonal Research and Extension Advisory Council (ZREAC) consisting of ADR, Scientists of the Zone, Officials of State Department of Agriculture like Joint Director, Deputy Director and Assistant Director of Agriculture and representatives of farmers of the zone meet and discuss the field problems of the zone during *Kharif* and *Rabi* seasons of the year and finalize the technical programmes of work. Apart from ZREAC meetings, Joint Diagnostic Teams are constituted from time to time for investigation of specific problems, which require immediate attention in the zone involving both scientists of the University and officials of State Department of Agriculture. The University also has established linkages with the non-governmental organizations (NGOs) in the state that are directly concerned with the Agricultural and Rural Development.

Directorate of Weed Research : Profile

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Weed control is as old as the agriculture itself. Primitive records show removal of weeds by hand and primitive tools. Later, during the period of 1000 BC, animal-drawn implements came into existence for removing weeds. During the first 2-3 decades of twentieth century, mechanically powered implements like cultivators, hoes and weeders were used for the purposes. Attempts to control weeds through biological agents started in 1930s. The earliest record of weed control in India through chemicals dates back to 1937 when sodium arsenite was used to control *Carthamus oxycantha* in Punjab. Later, the first herbicide used was 2,4-D with the development of its commercial formulation in 1940s. The research work on weed management is going on in our country for the past six decades since the initiation of a coordinated scheme in principal crops like rice, wheat and sugarcane in 1952 in 11 states, viz. Andhra Pradesh, Assam, Tamil Nadu, Madhya Pradesh, Maharashtra, Kerala, Punjab, West Bengal, Rajasthan, Uttar Pradesh and Jammu & Kashmir. In order to bring the researchers in weed science on a common platform, the Indian Society of Weed Science (ISWS) was established at Hisar in 1968 with Dr. M.K. Moolani of Haryana Agricultural University as its founder Secretary.

It was in 1978 that the weed research programme got a boost with the launching of the All India Coordinated Research Project on Weed Control by the ICAR in collaboration with the USDA. Initially, six centres were started at different SAUs for a period of six years. Later more centres were added during different phases, and presently there are 22 centres located in different agricultural universities. This project has assisted the farming community through the scientific technologies, which are effectively utilized for alleviating the yield losses due to weeds in field crops. In VII Plan, it was decided to establish a national centre for basic as well as applied research in weed science. A team comprising Dr. V.M. Bhan, Dr. S.K. Mukhopadhyay, Dr. S. Sankaran and Dr. V.N. Saraswat visited different states in the country and finalized the site at Jabalpur. Accordingly, the National Research Centre for Weed Science (NRCWS) was approved during the middle of VII Five Year Plan with a total outlay of Rs. 64 lakhs. Functioning of this Centre started with the joining of Dr. V.M. Bhan as its founder Director on 22 April, 1989. The office of NRCWS was initially established in a single room at the Department of Agronomy, College of Agriculture, JNKVV, Jabalpur. On 1 January, 1990, 61.5 ha farm land at *Khairi* village was acquired from JNKVV, and the Centre started functioning from rented premises at Adhartal. The first scientist joined in November 1990, and the research work started in 1991-92 with the joining of scientists in different disciplines.

The NRCWS was upgraded as Directorate of Weed Science Research (DWSR) in 2009, and further renamed as Directorate of Weed Research (DWR) in 2014. Major events over the last 25 years of establishment are given in Table 1.

Table 1. Chronology of major events at the Directorate of Weed Research

Year	Events
1989	National Research Centre for Weed Science (NRCWS) came into existence on 22 April, 1989. It started functioning from the Department of Agronomy, JNKVV, Jabalpur with the joining of Dr. V.M. Bhan, Director. Headquarter of AICRP on Weed Control was shifted to NRCWS, Jabalpur.
1990	Acquired 61.5 ha of land in *Khairi* farm which belonged to JNKVV, Jabalpur. NRCWS programmes organized into various sections and units. The centre was relocated to a private building at Ravindra Nagar, Adhartal. First experiments on weed management in wheat, rice, soybean, rice and on *Parthenium* were initiated.
1991	Multi-crop herbicide screening trials and on bioherbicidal effects of weeds were initiated. Experiment station advisory committee was constituted.
1992	Scientific research council, farm advisory committee, Institute joint staff council were constituted.
1993	Multi-crop herbicide screening trials were initiated. Institute Management Committee (IMC) was constituted.
1994	Research work on biological weed management was started. The centre was equipped with good library facility.
1995	Laboratory facilities were enriched with spectrophotometer, BOD incubators, leaf area meter, pH meter, seed germinator, laminar air flow, universal research microscope with photo-micrographic attachment, stereo-zoom research microscope, fine analytical balances, high speed refrigerated centrifuge, table top centrifuge, vacuum evaporator, hot air ovens, deep freezer, platform shakers etc. First Research Advisory Committee (RAC) was constituted. Post of Project Coordinator, AICRP-WC was abolished, and brought under the administrative control of Director.
1996	First Quinquennial Review Team (1989-1994) was constituted. Office was shifted to 5-HIG quarters purchased from M.P. Housing Board at Maharajpur. Workplan of administrative office-cum-laboratory building and farm block was approved.
1997	Local Area Network (LAN) was installed.
1999	Dr. V.N. Saraswat joined as Director on 13 July, 1999. Mexican beetle (*Zygogramma bicolorata)* was released for suppression of *Parthenium.*
2000	Dr. N.T. Yaduraju joined as Director on 5 September, 2000. Long-term studies on weed dynamics in cropping systems were initiated.
2001	Administrative-cum-Laboratory Building was inaugurated on 9 April, 2001 by Hon'ble Union Agriculture Minister, Shri Nitish Kumar. Parthenium awareness programme were launched. Weed News - newsletter of the centre was started.
2002	Poly house, net house and quarantine facilities were created. Large scale multiplication of Mexican beetle and their distribution started. Biennial workshop of AICRP on Weed Control was organized. First ICAR-sponsored winter school on Recent Advances in Weed Management organized. Extension work on weed management was initiated. First Kisan Mela was organized.

	Weed science museum/information centre was established. Development of weed seed identification kit with funding from ICAR was initiated.
2003	A Memorandum of Agreement (MoA) was signed with JNKVV, Jabalpur for collaboration in research, education and extension in weed science, and for seed production. A large number of extension folders on weed management in different crops were brought out. Developed national data base on weeds with funding from NATP.
2004	Controlled environment chambers were put into operation. Research on aquatic weeds under controlled conditions using polyurethane tanks was started. Main entrance gate of the Directorate was inaugurated. First *Parthenium* Awareness Week was organized.
2005	Research on climate change was started with Open Top Chambers (OTCs). Recreation club was inaugurated.
2006	Dr. Jay G. Varshney joined as Director on 10 May, 2006. Studies on weed management in prominent cropping systems were initiated.
2007	Containment facility with self-designed controlled environmental chambers was established for studying weather parameters on herbicide efficacy. Runoff plots with separate tanks were constructed for studying effect of herbicides in runoff water on non-target organisms. Lysimeters were constructed for studying herbicide movement at different depths. Research on horticultural, vegetable and medicinal crops was initiated. A village was adopted for transfer of technology for making it weed-free.
2008	National Invasive Weed Surveillance programme was launched. Open field research experiments on herbicide tolerant GM corn were initiated. Farm development was undertaken with development of farm office, wall fencing, watch towers, boundary plantation, lighting on the roads, drainage system etc.
2009	NRCWS was upgraded to Directorate of Weed Science Research. Free Air CO_2 Enrichment facility was installed for studies on crop-weed competition under elevated CO_2 in field conditions. Sophisticated laboratory instruments such as HPLC, IRGA, AAS, universal research microscope with photographic system, stereo zoom research microscope, nitrogen auto-analyzer, UV double beam spectrophotometer, high speed water purification assembly, multi-probe soil moisture meter, chlorophyll meter, line quantum sensor with data logger, gel documentation unit etc. were procured. All India weed maps were published. Headquarter of ISWS was shifted from CCSHAU, Hissar to DWSR, Jabalpur.
2010	An Interface meeting between the Planning Commission and ICAR institutes of central Zone chaired by Dr. K. Kasturirangan, Member (Science), Planning Commission. An Interface meeting between DWSR and other ICAR Institutes was organized and Chaired by Dr. S. Ayyappan, Secretary, DARE and DG, ICAR. LC-MSMS was procured for studying secondary and tertiary metabolites of the pesticides. Phyto-remediation model was developed. Facility for research on vermicomposting of weeds was established.
2011	Front gate was named as 'Dr. VM Bhan Dwar' in the memory of first Director, Dr. Bhan. Sports Complex was developed, and the first ever zonal tournament was organized. E-module for weed management in different crops was developed.

2012	Dr. A.R. Sharma joined as Director on 12 April, 2012. Research projects were reorganized and five focused research programmes on 'Sustainable weed management practices', 'Climate change', Herbicide resistance', 'Problem weeds', 'Environmental impact on herbicides' and 'On-farm research' were launched. A major initiative on weed management in conservation agriculture in rice-based cropping system was undertaken. On-farm research trials on improved weed management technologies were initiated in six localities around Jabalpur with involvement of all scientists of the Directorate. Quality seed production programme in collaboration with National Seeds Corporation was started. Dr. Sushil Kumar was conferred the 'ICAR Swami Sahajanand Saraswati Outstanding Extension Scientist Award'. Kisan Mobile Advisory Service was launched.
2013	Research programmes were undertaken in diversified cropping systems, including cotton, sugarcane, sunflower and gobhi sarson. Two new projects on weed utilization funded by NFBSFARA were launched. Laser land leveling was undertaken at the research farm. New generation farm machinery, such as, happy seeder and multi-crop zero-till seed-cum fertilizer drill, front loader, reaper etc. were procured. Technology park was developed to demonstrate different crops under improved weed management practices. Dr. VSGR Naidu and Dr. Chandra Bhanu were awarded "ICAR Rajendra Prasad Puraskar" for their Hindi Book on "Aushdhiya Kharpatwar". Agriculture Education Day, Industry Day and Farm Innovators Day were organized for the first time. 25^{th} Foundation Day was celebrated on 22 April, 2013. ISO 9001-2008 Registration Certificate was granted to the Directorate on 21 July, 2013.
2014	Silver Jubilee celebrations were organized throughout the year, and many publications were launched. On-farm research trials were reorganized and diversified considering the specific techniques / technologies developed and taken to new localities. Internal roads of the research farm were improved and plantation was undertaken on road sides. Research farm was made *Parthenium*-free, and developed as a 'Model' based on the principles of conservation agriculture. Renaming was done as 'Directorate of Weed Research' and AICRP on Weed Management. 26^{th} Foundation Day was graced by the presence of Dr. A.K. Sikka, DDG (NRM). Agro-biomass and composting unit was inaugurated.

Accomplishments

Founding Years (1989-1994)

In the initial years of establishment, major emphasis was on planning and development of basic infrastructure. The research farm was acquired and developed with underground irrigation facilities. Laboratories were set-up with the purchase of equipments for basic soil plant analysis work. Herbicide screening trials in major cereal crops and some work on biological control of problematic weeds was started. The first Institute Management Committee meeting was held in May 1993 to further consolidate infrastructural facilities in the centre. In the same year, the master plan of the new building prepared by the CPWD was approved by the Council.

During 1991-1994, the centre's research work was focused on developing weed management options in drilled rice, soybean, wheat, maize, chickpea etc. Chemical control of *Parthenium* was also studied. Work related to isolation of allelochemicals for weed control was initiated. The first QRT was constituted in 1995, which reviewed the performance for the period from 1989 to 1994. The team recommended filling-up of administrative, technical and scientific positions for efficient functioning and strengthening of infrastructure.

The All India Coordinated Research Project on Weed Control, which functioned from 1978 at the Central Rice Research Institute, Cuttack was shifted to the Centre in 1989. A separate coordinating cell was established to look after the work of 18 centers, viz. PAU, Ludhiana; JNKVV, Jabalpur (now at RVSKVV, Gwalior); UAS, Bengaluru; GBPUAT, Pantnagar; CSKHPKV, Palampur; TNAU, Coimbatore; MAU, Parbhani; GAU, Anand; AAU, Jorhat; NDUAT, Faizabad; ANGRAU, Hyderabad; CSAUAT, Kanpur; CCSHAU, Hisar; OUAT, Bhubaneswar; BAU, Ranchi; KAU, Thrissur; RAU, Pusa; and Viswa-Bharti, Sriniketan. Subsequently in 1992, the post of Project Coordinator was abolished and the AICRP-WC was merged with the NRCWS.

Research achievements:

- Application of butachlor @ 2.0 kg/ha, thiobencarb @ 2.0 kg/ha, 2,4-D @ 1.25 kg/ha and anilophos @ 0.3 kg/ha were quite effective in controlling weeds and increasing grain yield of direct-seeded rice under puddled condition. Pre-emergence application of anilophos @ 0.4 kg/ha and butachlor @ 2.0 kg/ha were effective for controlling weeds and significantly increasing grain yield of transplanted rice.
- Atrazine @ 1.5 kg/ha at 7 DAS proved effective in reducing weed density and resulting in higher yield of maize, which was comparable to weed-free situation.
- Herbicide combinations of tralkoxydim + 2,4-D (0.35 + 0.5 kg/ha) and fluroxypyr + isoproturon (150 g + 750 g/ha) were recommended for reducing weed management in wheat.
- Foliar spray of herbicides like metsulfuron @ 3.5 g/ha and chlorimuron @ 20 g/ha, 2,4-D @ 2.0 kg/ha and glyphosate @ 1.5 kg/ha were found to be effective in *Parthenium* control.
- *Parthenium* leaf powder from 0.25 to 1.25% (W/V) was found effective in killing *Salvinia, Hydrilla* and *Ceratophyllum.* Application of aqueous solution of dried powder of *Parthenium* leaf and flower at and above 0.5% (W/V), and of stem at 1% (W/V) killed water hyacinth plants in a month irrecoverably.
- Different bioagents like *Sclerotium rolfsii* and *Curvularia* sp. (from *Parthenium* infected plants), and *Fusarium* sp. and *Puccinia* sp. (water hyacinth) were isolated for their potential use for biological control of weeds.

Growing Years (1995-2000)

The first Research Advisory Committee of the Centre was constituted in 1995–96. AICRP on Weed Control was further strengthened by addition of four more centres, viz. SKRAU, Bikaner; IGKVV, Raipur; DBSKKV, Dapoli; and UAS, Dharwad in 1995. Organization of trainings programmes was initiated with a short-term course on "Weed management for improving crop production" in January 1996. To strengthen the research activities, various collaborative research projects were undertaken with ICAR institutes, funding agencies like DBT, and pesticide industry. Research farm was developed and facilities like information centre-cum-conference hall were created. The centre prepared the "Vision 2020" Perspective Plan to address the future issues in weed science. Biological control programme was further strengthened by the visits-cum-trainings of Dr. L.P. Kauraw at CABI, Ascot, UK in 1998 and to Montana State University, USA in 1999.

Research achievements:

- Application of anilofos @ 0.4 kg/ha coupled with one hand weeding at 30 DAS, and fenoxaprop at 28 DAS was found effective and provided good weed control in direct-seeded rice.
- In case of soybean-wheat/mustard cropping system, application of pendimethalin @ 1.25 kg/ha as PE in soybean and isoproturon @ 1.0 kg/ha POE in wheat and mustard was found effective with respect to weed control with significant increase in grain yield.
- In maize-pea cropping system, application of atrazine @ 1.0 kg/ha in maize and pendimethalin @ 1.25 kg/ha in pea provided good weed control with a significant increase in yield of maize (19.1%) and pea (15.6%). Pea cv. 'JP-885' was found to be competitive and suppressed weed growth.
- Soil solarization for 3-5 weeks gave excellent control of most annual weeds and resulted in significantly higher yield of soybean. Stale seedbed technique was also found to be effective in reducing weed biomass and obtaining higher grain yield. Fluchloralin @ 1 kg/ha, alachlor @ 2 kg/ha as PE and trifluralin @ 1.5 kg/ha resulted in higher grain yield of soybean. Herbicide combinations of lactofen @ 0.10 kg/ha + fluazifop-p-butyl/sethoxydim @ 0.25 kg/ha, fluazifop-p-butyl @ 0.50 kg/ha + sethoxydim @ 0.25 kg/ha, fluazifop-p-butyl @ 0.25 kg/ha + sethoxydim @ 0.50 kg/ha were found effective in controlling weeds with increased seed yield of soybean.
- Application of fluchloralin @ 1.0 kg/ha, pendimethalin @1.0 kg/ha and sethoxydim @ 0.25 kg/ha proved beneficial with respect to weed control and grain yield in chickpea.
- For integrated management of *Saccharum spontaneum*, application of glyphosate @ 1.5 kg/ha alone and in combination with summer ploughing was found effective.
- Phytotoxic activity of pure parthenin on *Cassia sericea* revealed significant reduction in plumule and radicle growth with 1000 and 2000 ppm parthenin with LD_{50} 5000 ppm and 3000 ppm, respectively.
- In vitro incubation of *Parthenium* seeds with *F. pallidoroseum* caused nearly 35% seed rot and 65% seedling mortality. Seed germination of *Parthenium* was found to be reduced from 57-100 % when *F. pallidoroseum* was sprayed 0-3 DAS. Inhibition of *Parthenium* seed germination (86.4%) and growth was observed with culture filtrate of *G. virens* + neem oil (10%).
- Marigold was found to be suppressive for *Parthenium* root and shoot growth and development. Reappearance of *Parthenium* in next season was completely suppressed when the ratio of *Parthenium* and marigold was kept at 1:4.

- Mexican beetle found effective in defoliation *Parthenium* in the patches depending on build-up of the population. High establishment of the beetle was during August and September, and lowest in December and January.
- A manually operated herbicide wick applicator for application of non-selective herbicides showed satisfactory performance in crops like mustard, soybean and maize. Twin-wheel hoe operation was found effective for weed control in soybean with a weed control efficiency ranging from 63-82%.

Maturing Years (2001-2005)

Administrative-cum-laboratory building was inaugurated on 9 April, 2001 by the Union Agriculture Minister, Shri Nitish Kumar in the presence of Dr. R.S. Paroda, Director General, ICAR. Facilities for herbicide residue analysis, poly and net houses for controlled experiments were developed. For the first time, a three day Biennial Workshop of All India Coordinated Research Programme on Weed Control was held. Several training programs were conducted during this period. Organization of *Kisan Mela* became a regular activity for disseminating the weed management technology among the farmers. A MoU was signed with JNKVV for collaboration in research, education and extension in weed science. One of the significant achievements of the centre is nationwide awareness programme on the ill-effects of *Parthenium* and its management. The successful campaigning of this programme created awareness among the people and policy makers throughout the country. Success of biological management of *Parthenium* through Mexican beetle gained momentum though the involvement of AICRP-WC centres.

Research achievements:

- Tank-mix application of cyhalofop + almix (70 + 20 g/ha) and fenoxaprop + almix (60 + 20 g/ha) at 25 DAS provided broad-spectrum weed control and higher grain yield in direct-seeded rice.
- Sulfosulfuron @ 25 g/ha and clodinafop-propargyl @ 60 g/ha followed by 2,4-D @ 0.5 kg/ha were found superior to isoproturon @ 1.0 kg/ha with respect to weed count and growth of dominant weeds in wheat. Herbicide mixture of metsulfuron @ 2 g/ha + isoproturon @ 500 g/ha was most effective and provided effective control broad-spectrum of weed flora in wheat.
- Application of imazethapyr @ 100 g/ha (post-emergence), tank-mix application of fenoxaprop [100 g/ha and chlorimuron-ethyl (6 g/ha)] effectively provided weed control throughout the growing duration of soybean. *Euphorbia geniculata* could be controlled by pre-emergence application of metribuzin @ 0.5 kg/ha, oxyfluorfen @ 0.2 kg/ha or post-emergence application of chlorimuron @ 0.01 kg/ha or imazethapyr @ 0.07 kg/ha.
- Application of oxyfluorfen @ 200 g/ha at 3 DAS *fb* oxyfluorfen @ 150 g/ha 30 DAS and oxyfluorfen @ 200 g/ha at 3 DAS *fb* pendimethalin @ 0.75 kg/ha 30 DAS provided broad-spectrum control of weeds and higher bulb yield in direct-seeded onion.
- Intercropping of cowpea as fodder or grain in maize integrated with pre-emergence application of pendimethalin @ 1.0 kg/ha and application of 100 kg N/ha was found most effective in suppressing weeds and obtaining higher productivity.

- Intercropping systems involving wheat + mustard and wheat + berseem (15/30 cm) were the best combinations for weed suppression and higher total crop productivity. Intercropping of berseem either in between two rows of mustard at 45 cm or as paired rows of 30/60 cm reduced the weeds effectively. The system produced comparable seed yields as of sole mustard crop with additional fodder and seed yield of berseem. Similarly, growing *dhaincha* along with rice for 30 days and killing it by applying 2,4-D @ 0.5 kg/ha followed by one HW controlled the weeds effectively.
- Soil solarization for 45 days was effective in controlling *Phyllanthus niruri*, *Echinochloa colona*, *Mollugo* sp., *Dinebra* sp., *C. communis, Cyperus iria*, and *Euphorbia geniculata* in sesame. More than 75% control of *Avena sterilis* and *Cichorium intybus* was achieved in tomato by soil solarization, but failed to check the emergence of *Medicago hispida* and *Vicia sativa*.
- In transplanted rice-wheat system, zero tillage reduced the population of *Phalaris minor* but increased the population of *Avena ludoviciana* as compared to conventional tillage.
- Soybean-wheat system reduced the population of almost all the winter season weeds as compared to soybean-linseed system. Zero tillage increased the population of *Echinochloa colona* and *Commelina* spp. but reduced the problem of *Phyllanthus* spp. and *Cyperus iria* in soybean. Zero tillage significantly reduced the population of *Chenopodium album* but increased the population of *Vicia sativa.* Pre-emergence application of pendimethalin @ 1.0 kg/ha gave effective control of *C. album* but was less effective against other dominant weeds like *Vicia sativa, Medicago hispida* and *Avena ludoviciana*.
- *Cuscuta* infestation even @ 1 plant/m^2 caused significant yield loss in niger (39.3%), summer greengram (27.7%), chickpea (54.7%), and lentil (49.1%). Niger was the most susceptible crop followed by greengram, sesame, soybean, blackgram, pigeonpea and groundnut. In winter, lentil was found to be the most susceptible crop followed by chickpea, linseed and pea. Weed species, viz. *Convolvulus arvensis*, *Amaranthus* spp., and *Medicago hispida* were also found to be susceptible for *Cuscuta infestation*. Pendimethalin @ 1.0 kg/ha as pre-emergence was found effective against *Cuscuta* in blackgram, niger, linseed, lentil and chickpea. However, in berseem and lucerne, pendimethalin @ 0.50 -1.0 kg/ha at 2 weeks after sowing was safe and effective as the pre-emergence application.
- High CO_2 increased the wheat grain yield due to increase in number of grains/spike and test weight. At competitive weed density, yield loss was 52, 43 and 35%, respectively due to competition *by Phalaris minor, Chenopodium album* and *Avena ludoviciana* under ambient condition. On the other hand, the yield loss at elevated CO_2 was reduced to 23, 22 and 7.0%.
- In pea, high CO_2 increased seed yield by 63% in pure culture. The yield loss was 32 and 60% due to competition with *L. sativus* and *A. viridis,* respectively under ambient conditions, and 0 and 8% under elevated CO_2condition.
- Wheat cultivars, viz. 'HD 2285', 'Sujata', 'WH-147', 'Raj 33765' and 'DL803-3' were found competitive against wild oat and produced higher yields under zero tillage condition. Upland rice varieties, viz. 'RR 151-3', 'Kalinga-III' and 'Vandana' also showed better weed competitive ability with a reasonable yield potential.
- Plant parts, viz. stem, root, leaf, petiole, green and ripe fruit pulp, and seeds of neem and tropical soda apple (*Solanum viarum*) showed phytotoxicity to different floating and submerged aquatic weeds at 0.1-2% (dry weight/volume).
- A combination of seed treatment (4 g/kg) + soil treatment (8 g/m^2) in wheat, and seed treatment (4 g/kg) + soil treatment @ 20 g/m^2 in rice with bioagents *T. viride* and *T. virens* was found effective for suppression of *Phalaris minor and Echinochloa colona*, respectively.
- Herbicide residues in rice, wheat, soybean, pulses and vegetables were found below the detection limit as well as maximum residue limit.
- Information on major and minor weeds of different crops of 435 districts of the country was collected and documented in the database which included the details of crops/cropping systems, growing situations and seasons. Weed distribution maps of the above districts was prepared using software (Arcview 3.1).

Transforming Years (2006-2012)

The centre earned appreciation for the work done on biological management of *Parthenium* through public participation in awareness campaigns. The premises of the centre attained a new look with organization of farm and other several facilities like FACE, LC-MS/MS, aquatic chambers, lysimeters, facility for residue-runoff studies, bioremediation unit, containment chambers etc. A major programme on "National Invasive Weed Surveillance" was launched in 10 states covering 267 districts for exhaustive surveillance of quarantine weeds which might have entered the country with the import of wheat in 2006. Another milestone was upgradation of the centre to the status of Directorate of Weed Science Research (DWSR) w.e.f. Jan 2009. Many events like the Interface meeting, National consultation on weed utilization, and biological control of weeds were also organised. Since 2010 four scientists were trained abroad under NAIP programme. The ICAR Zonal Sports meet (Central Zone) was successfully organized. In March 2012, Dr. A.R. Sharma joined as Director and took several initiatives for reorganizing the research projects at the Directorate and in AICRP-Weed Control, on-farm trails, strengthening of farm infrastructure, and launched a major programme on conservation agriculture.

Research achievements:

- Under organic weed management, stale seedbed along with reduced row spacing resulted in better weed control in wheat. The grain yield was the highest under 10 t FYM/ha with berseem as intercrop. In okra-tomato cropping system, the lowest weed dry biomass and significantly higher yield were recorded in okra and tomato under FYM @ 10 t/ha with black polythene mulch treatment.
- In System of Rice Intensification (SRI), the effective weed control was recorded with fenoxaprop @ 60 g/ha + almix @ 4 g/ha at 15 DAP, and pretilachlor @ 0.75 kg/ha + cono-weeder at 20 DAP and bispyribac-sodium @ 15 g/ha applied at 15 DAP. In transplanted rice, metsulfuron-methyl @ 4 g/ha, penoxsulum + cyhalofop @ 150 g/ha, combination of metsulfuron + carfentrazon @ 30 g/ha with non-ionic surfactant were effective against weeds. In direct-seeded rice, application of cyhalofop + penoxulum @ 150 g/ha as ready-mix controlled all the weeds and recorded higher grain yield.

- In wheat, pinoxaden, metsulfuron-methyl + carfentrazon-ethyl @ 22.5 g/ha with 0.2% non-ionic surfactant, metsulfuron and clodinafop were effective against grassy weeds, especially *Avena ludoviciana*.
- Application of imazethapyr @ 100 g/ha, penoxsulum @ 22.5 g/ha, propaquizafop @ 75 g/ha and quizalofop-ethyl @ 50 g/ha were found effective in reducing weeds, specially *Echinochloa colona*, *E. glabrescence*, *Dinebra retroflexa* and *Cynodon dactylon* in soybean.
- In niger-tomato cropping system, soil solarization for a period of 45 days either alone or in combination with FYM and crop residue provided season-long weed control by reducing the emergence of all weed species. Application of metribuzin @ 0.5 kg/ha reduced the emergence of all weed species, except *Phylanthus niruri* and *C. communis* in niger, and *Avena ludoviciana, Cichorium intybus* and *Medicago hispida* in tomato.
- In zero-till direct-seeded irrigated rice-wheat system, seeding of rice after receipt of first flush of monsoon and sequential application of pretilachlor at 0.75 kg/ha as pre-emergence followed by 2,4-D @ 0.50 kg/ha and fenoxaprop @ 0.07 kg/ha as post-emergence was recommended for obtaining higher yield and benefits.
- Cowpea-pea-cowpea and greengram-pea-greengram cropping systems with herbicide application significantly reduced the weed population and weed dry matter in mango and citrus orchards.
- Bioagents along with spray of glyphosate @ 1.5 kg/ha caused suppression of water hyacinth but the water quality was also affected adversely. No mortality of fish was observed due to glyphosate spray.
- About 7 lakh beetles of *Zygogramma bicolroata* were released throughout India involving colony residents, farmers, ICAR institutes, SAUs and Krishi Vigyan Kendras, which resulted in significant reduction in *Parthenium* density.
- Longevity of seeds of *Parthenium hysterophorus*, *Cassia sericea*, *Phalaris minor*, *Echinochloa glabrascence*, *Echiniochloa crusgalli*, *Medicago denticulata* and *Rumex dentatus* could be extended by immersing in liquid preservatives at ambient temperature.
- In wheat, *Chenopodium* caused 42% reduction in yield under ambient CO_2, while it was 46% under elevated CO_2. Early maturity was observed in wheat under elevated CO_2. The reduction in wheat yield was relatively higher due to competition by *Phalaris minor* as compared to *Chenopodium album*.
- Profuse tillering and prolific root growth was observed in *Phalaris minor* under elevated CO_2. The elevated CO_2 resulted in an increase in dry weight of chickpea (45%), *Lathyrus sativus* (151%), *Phalaris minor* (140%), *Medicago denticulata* (55%) and *Chenopodium album* (132%) as compared to ambient CO_2.
- Most effective herbicidal property of allelochemical crude of *Lantana* leaf was shown by the n-pentane soluble fraction. It was lethal to floating weed *Lemna* at 100 ppm, and the test plants were killed within about 5 days.

- A rust disease on *Lagascea mollis* was first observed at Hyderabad, and subsequently at Jabalpur and Bhopal. Growth and seed production of the weed were significantly reduced due to application of rust bioherbicide. In mustard crop, seed bank of Lagascea mollis was reduced by 91% in bioherbicide applied plots as compared to 98% reduction in imazethapyr applied plots.
- *Fusarium oxysporum* was found efficient for killing of water hyacinth within 15 days of inoculation provided with injury caused by *Neochetina*. There was rapid wilting and death of the plants when the beetles were applied 10 days in advance of the application of the fungus.
- *Pseudomonas fluorescens* and *Trichoderma viride* isolated from the native rhizosphere of chickpea were found to induce systemic resistance in chickpea against *Cuscuta*. Defence enzymes, viz. peroxidase, polyphenol oxidase and catalase were activated upon the application of microbes. *Trichoderma viride* activated more amounts of polyphenol oxidase, while *Pseudomonas fluorescens* was found to activate other two enzymes.
- Molecular tool based on 16S rRNA gene was standardized for characterization of heterotrophic bacteria in agricultural environment. Bacteria associated with aquatic and terrestrial weeds were isolated and characterized using biochemical tests and 16S rRNA gene approach. Gene sequences determined in this study have been deposited in the GenBank database, with accession numbers: 'JN638742' through 'JN638750', and 'JN944746' through 'JN944751'.
- *Aspergillus* found to be the most sensitive and *Penicillium* the most resistant to herbicides. Sulfosulfuron did not show any toxic effect to the PSFs, while clodinafop exhibited maximum toxicity.
- Degradation of applied butachlor was faster and residues remained in soil for three weeks under continuous field capacity. Alternate wetting-drying of soil increased the half-life of butachlor, pretilachlor and pendimethalin compared to soil that was continuously kept at field capacity.
- Residues of oxyfluorfen, butachlor and anilofos in pond water were 22 to 2.5 ng/ml, 137 to 3.6 ng/ml and 151 and 6.4 ng/ml, respectively between 0 and 90 days. The herbicides dissipated slowly in water as compared to soil.
- Persistence of herbicides revealed that 3.1 and 3.6 ng/g residues of oxyfluorfen, and 14 and 41 ng/g residues of butachlor were detected from grain and straw of rice, respectively.
- Cutin of *Phalaris* and *Avena* slowed down degradation process of isoproturon by quenching the photolysis and consequently increased the half-life (75.0 and 114.8 min, respectively) as compared to standard glass surface (52.8 min).
- Chloroform and dichloromethane were found to be the most suitable solvents for extraction of epicuticular waxes from rice, wheat, *E. colona*, *P. minor* and *A. ludoiviciana*

- Three major metabolites isolated from photodegradation of propaquizafop in the environment through LC-MS/MS analysis were identified as: 2-[4-[(6-chloro-2-quinoxalinyl)oxy] phenoxy]propanoic acid, 2-[[[[1-methylethylidene]amino]oxy] p-benzyl]-6-chloro-2-quinoxalinolate, and 2-[[[1-methylethylidene] amino]oxy]ethyl 2-[4-[(6-chloro-2-quinoxalinyl) oxy] phenoxy] propanoate.
- *Aspergillus niger* was screened from soil as chlorimuron degrading agent with two major routes. One route involved the cleavage of sulfonylurea bridge, resulting in the formation of two major metabolites, viz. ethyl-2-aminosulphonyl benzoate, and 4-methoxy-6-chloro-2-amino-pyrimidine. The other route was the cleavage of sulfonylamide linkage, which forms the metabolite *N*-(4-methoxy-6-chloropyrimidin-2-yl) urea. Two other metabolites, saccharin and *N*-methyl saccharin, formed from the major metabolite-II were also identified.
- Potential weedy species for phytoremediation of heavy metal contaminated sites were identified. Vermicompost unit was established for half-decomposed material from weed biomass and crop residues.

Silver Jubilee Year (2013-14)

On completing 25 years of establishment, the Directorate celebrated the year 2013-14 as the "Silver Jubilee Year". Several programmes and lectures by eminent scientists were organized at the Directorate. Annual Review Meeting of AICRP-Weed Control and Biennial Conference of ISWS were held. Dr. A.K. Sikka, Deputy Director General (NRM), ICAR visited the Directorate on the 26th Foundation Day on 22 April, 2014. He inaugurated the Agro-waste and Weed Biomass Composting Unit at the farm. The Directorate was renamed as 'Directorate of Weed Research' in November 2014. On recommendation of QRT, 5 centres of AICRP on Weed Control, viz. Kanpur, Bikaner, Parbhani, Dharwad and Sriniketan were closed, and new centres at Pasighat, Udaipur, Akola, Raichur and Jammu were added to the AICRP network.

Facilities

The Directorate is one of the best equipped institutes of the ICAR in terms of field and laboratory facilities. All the required facilities for high quality basic, applied and strategic research are available. Some of the special features are: (i) Small and beautiful campus, (ii) Excellent infrastructure, offices and laboratories, (iii) Model research farm, fully leveled, irrigated, just outside the door, (iv) Laboratories well furnished, equipped with all basic and some with most advanced equipments, (v) 24 x 7 electricity, (vi) 24 x 7 internet connectivity, (vii) All staff having computers, (viii) No constraint of labour, farm machinery and others, (ix) No dearth of funds – virtually everything available on demand, (x) Diversified crop resources – upland, lowland, ponds, aquatic, horticultural crops, (xi) Minimum workload on scientists of the non-scientific works, and (xii) Supportive and responsive administration.

Research farm

The research farm is equipped with modern farm machines like high power tractors, mini tractor, power weeders, tractor-driven sprayers, laser land-leveler, happy seeder, zero-till seed-cum-fertilizer drill, multi-crop seed-cum-fertilizer drill, disc bund former, dozer blade, front loader, bed maker, multi-crop thrashers, reaper, tube wells, underground irrigation pipelines and sprinkler system. The 'Model' farm has the following features:

- Well laid out laser-levelled fully-irrigated experimental farm (60 ha)
- Containment facility for conducting experiments under varied environmental conditions
- Open Top Chambers (OTCs) to assess the impact of climate change on crops and weeds
- Free Air CO_2 Enrichment (FACE) facility to study the effect of elevated CO_2 on crop-weed interaction
- Lysimeters to assess ground water contamination potential of herbicides
- Phytoremediation unit to study the bioremediation potential of weed species
- Setup to evaluate management practices for aquatic weeds
- Runoff tanks for studies on herbicides toxicity to non-target organisms
- Well equipped research laboratories
- Agro-waste and weed biomass composting unit
- Weed cafeteria for demonstration and conservation of weed germplasm
- Weed seed display containing germplasm of more than 100 species
- Technology park on weed management technologies
- Information centre displaying the world of weed science
- Net/poly-houses/containment chambers for quarantine weeds and multiplication of bio-agents

Laboratories

All the laboratories covering different disciplines, viz. agronomy, plant physiology, soils science, residue chemistry, biocontrol, biotechnology and environmental science are well equipped with most modern equipments, such as the following: (i) LC-MS/MS system, (ii) Vacuum evaporator, (iii) High performance liquid chromatography (HPLC), (iv) Lyophilizer, (v) Gas chromatography (GC) unit, (vi) UV-visible double beam spectrophotometer, (vii) Portable photosynthesis system (IRGA), (viii) Kjel-Tec unit for nitrogen analysis, (ix) Stereo zoom research microscope with photographic attachment, (x) Leaf area meter, (xi) Osmometer, (xi) Thermal cycler (PCR), (xii) Multi-probe soil moisture meter, (xiii) Gel documentation unit, (xiv) Root scanner, (xv) Atomic absorption spectrometer (AAS), (xvi) Ultra water purification unit, (xvii) Soil CO_2 flux analyser, (xviii) High speed centrifuge, (xix) Spectro-radiometer, and (xx) SPAD chlorophyll meter.

Other infrastructure

Agriculture Knowledge Management Unit (AKMU) is well equipped with computers, LAN facilities, colour xerox-cum-printer and A-0 plotter. Specialized software like ARC Info for GIS analysis and ERDAS Imagine for satellite image analysis are available. All the scientists are provided with internet connection through Lease Line. The main building of the Directorate is Wi-Fi enabled.

Library has a total collection of 3,057 books pertaining to weed science. It has modern facilities such as CAB-PEST and CAB-SAC CD-ROMs and Current Contents on Diskette (CCOD) on biological sciences, software for library automation and information retrieval. It has 60 Indian and 20 foreign journals in its subscription. Library is also a member of Consortium for e-Resources in Agriculture (CeRA). All the scientists have online access to more than 2000 e-journals in various fields of science. Reprographic and documentation facilities have also been created for the preparation of documents and reports.

Well developed Information Centre has been created with the aim of briefly informing farmers, dignitaries and other stakeholders about its mandate and thrust areas; history, importance, methodologies and tools of weed management; problematic and alien invasive weeds; weed utilization and environmental concerns in respect to chemical weed management using sophisticated display systems. Directorate's publications, prototypes of weed management tools and live specimen of weed seeds are also displayed.

Current research projects (2012–17)

Based on the recommendations of the 4th QRT, the following research projects were undertaken at the Directorate for the period 2012–17:

1. Development of sustainable weed management practices in diversified cropping systems
   - 1.1. Weed management under long-term conservation agriculture systems
   - 1.2. System-based approach to weed management
   - 1.3. Improving input use efficiency through efficient weed management
   - 1.4. Standardization of spraying techniques and mechanical tools for weed management
2. Weed dynamics and management under the regime of climate change and herbicide resistance
   - 2.1. Effect of climate change on crop-weed interactions, herbicide efficacy and bioagents
   - 2.2. Physiological and molecular basis of herbicide resistance development in weeds and evaluation of herbicide-tolerant crops
   - 2.3. Development of weed seed identification tools and weed risk analysis
3. Biology and management of problematic weeds in cropped and non-cropped areas
   - 3.1. Biology and management of problematic weeds in cropped areas
   - 3.2. Biology and management of problematic weeds in non-cropped areas
   - 3.3. Biology and management of aquatic weeds
4. Monitoring, degradation and mitigation of herbicide residues and other pollutants in the environment
   - 4.1. Impact of herbicides in soil, water and non targeted organisms and herbicide mitigation measures
   - 4.2. Degradation of herbicides in the environment
   - 4.3. Bio-remediation of pollutants using terrestrial / aquatic weeds

5. On-farm research and demonstration of weed management technologies and impact assessment
   - 5.1. On-farm research and demonstration of weed management technologies for higher productivity and income
   - 5.2. Impact assessment of weed management technologies on social upliftment and livelihood security

Emerging challenges and concerns

Weed problems are dynamic in nature and are likely to be more serious in the coming decades due to the following factors: (i) Adoption of dwarf HYVs and hybrids, (ii) High-input agriculture, (iii) Altered agronomy – zero-till, organic farming, (iv) Monocropping / fixed cropping systems – shift in weed flora, (v) Development of herbicide resistance in weeds, (vi) Herbicide residue hazards, (vii) Growing infestation of weedy rice, parasitic and other obnoxious weeds, (viii) Globalization and invasion of alien weeds, (ix) Implications of climate change, and (x) Lack of quality human resource in weed science. Stakeholders express serious concerns about weed management in real field situations. In fact the weed related problems have become the issues of common discussion in the meetings, seminars, trainings, workshops, *Kisan Mela* and *Sangosthis*. Following issues are raised by the stakeholders: (i) Non-availability of labour for weed control, (ii) Rising costs of manual weeding, (iii) Invasion of new weed species, (iv) Application techniques of herbicides, (v) Herbicide + other pesticide combinations, (vi) Non-availability of herbicides and mechanical tools, (vii) Spurious chemicals, costly herbicides, (ix) Large packings of herbicides, (x) Registration of new molecules, (xi) Lack of awareness / extension efforts, and (x) Weeds in no-man's lands.

Continuous refinement of weed management technologies is essential to cut down production costs, and also in the light of ever-changing socio-economic conditions of the farmers and international trade policies. Rapid expansion of weedy rice infestation, evolution of herbicide resistant weeds, introduction of alien invasive weeds, lack of low-cost environment-friendly weed management technologies for water bodies and for dryland farming systems are some of the burning issues requiring immediate attention. Herbicides are going to become increasingly popular in the coming years but the residue hazards and other environmental issues are also required to be suitably addressed. Development of suitable technologies to tackle the probable scenario that may emerge in the area of crop-weed competition due to increased atmospheric CO_2 concentration and subsequent global warming are some of the major future challenges. Herbicide-tolerant GM crops may be a possibility in the coming decades after the legitimate concerns are adequately addressed.

Way Forward

A great deal of change has occurred in weed management for the last few decades. In fact, serious research in weed science was undertaken in our country during 1970s when some herbicides like 2,4-D, butachlor, isoproturon, atrazine and a few others were found highly effective in major cereal crops. Some weeds in croplands and non-crop lands started becoming predominant in the 1990s, for which, effective control measures were developed. Studies on herbicide use in other crops like pulses and oilseeds were started with the availability of new herbicide molecules. Thereafter, issues related to herbicide residues and resistance development in weeds cropped-up and systems approach to weed management was emphasized. Aquatic weeds also gained attention due to their vast invasion in the water bodies. In the present times, low-dose high-potency herbicide molecules and mixtures have become available for major crops like rice, wheat and soybean. It is also feared that climate change will shift the behaviour of crop-weed competition. However, newer opportunities will also be available in the coming decades for tackling weed menace with the adoption of conservation agriculture, organic farming and precision farming systems.

A holistic approach with multi-disciplinary, multi-locational and multi-institutional involvement would be imperative to tackle future weed problems. More emphasis will be given on developing integrated weed management technologies involving non-chemical methods, use of cover crops, weed suppressing crop cultivars; mechanical weeding tools, etc. Basic research in areas like allelopathy and bioherbicides which have relevance for practical weed management will be undertaken through collaborative arrangements with other institutes. Research on biological control of important alien invasive weeds in non-cropped situations, aquatic bodies, etc. will be undertaken with the participation of all stakeholders. Scientists will also be encouraged to undertake on-farm research trials in participatory mode and take part in technology development, refinement and transfer. Technologies developed will be refined and fine-tuned for their suitability in actual farmers' situations through on-farm trials, awareness campaigns, farmers' fair, farmers' training, etc. The involvement and partnership of other line departments such as state departments of agriculture, NGOs, local administration, etc. will be ensured to achieve the goals. The sound technical programme for network research on management of aquatic and parasitic weeds, weed management in rainfed agriculture, horticultural and vegetable crops will be required after thorough interaction with collaborating organizations.

AICRP on Weed Management network functioning under the Directorate is a great strength and will continue to be immensely useful in this regard. There are AICRP-WM centres, each with a team of multidisciplinary scientists, situated in different SAUs under different agro-ecological regions. Efforts will be made to develop effective linkages with other sister institutions under ICAR as well as other scientific organizations like CSIR, DBT, DST, ISRO, etc. in formulating innovative research projects. Efforts are also needed to be made with IITs and IIITs to explore the possibility of utilizing the robotic and LASER technology for weed control. Linkages in research and technology development with SAUs and related ICAR/ other institutions will be strengthened not only to avoid duplication of work but also for effective utilization of resources and complementing research outputs. Scientists will be trained in new areas like weed risk analysis, precision farming, herbicide residue estimation, C-sequestration, crop-weed modeling, climate change, biotechnology, etc. Evaluation of new low-dose high-potency herbicide molecules and their methods of application for higher efficiency and other related issues will be addressed in collaboration with the herbicide industry.

Emphasis will be given to develop infrastructures like phytotron growth chambers, containment facilities and large-sized open top chambers with controlled CO_2, temperature and humidity components for climate change related studies, sophisticated laboratory facilities for molecular biology works, quarantine facilities for Weed Risk Analysis and biocontrol related studies, and a referral laboratory for herbicide residues study.