DWR Publication No. 18

DWR - Souvenir

Celebrating Silver Jubilee

(1989–2014)

ICAR - Directorate of Weed Research
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Preface

Considering the growing infestation of weeds in cropped and non–cropped lands, the Indian Council of Agricultural Research decided to establish the National Research Centre for Weed Science (NRCWS), which came into existence on 22 April, 1989 with the joining of its first Director, Late Dr. V.M. Bhan. This centre was upgraded as Directorate of Weed Science Research (DWSR) on 23 January, 2009; and further renamed as Directorate of Weed Reseach (DWR) on 27 November, 2014. This is a unique institute in the National Agricultural Research System, which is probably the only one of its own kind in the whole world dealing exclusively with weed science research. Besides, training, coordination, consultancy and collaborative programmes on weed management are also undertaken with various stakeholders.

Over the last 25 years, the institute has played a significant role in conducting weed survey and surveillance, development of weed management technologies for diversified cropping systems, herbicide resistance in weeds, biology and management of problem weeds in cropped and non–cropped areas, and environmental impact of herbicides. Adoption of these technologies has been promoted in large areas through on–farm research and demonstrations, which has raised agricultural productivity and livelihood security of the farmers. Training and awareness, and consultancy programmes organized by the Directorate have been found highly beneficial and appreciated by the stakeholders. All these activities have been further geared up to address the emerging challenges in weed management including threats posed by climate change, invasive weeds, herbicide resistance, herbicide residue hazards, and safety concerns about herbicide tolerant crops.

During the Silver Jubilee Year (2013-14), many programmes and initiatives have been undertaken at the Directorate. New publications based on the achievements made have been brought out. This Souvenir includes the goodwill messages from our leaders and administrators associated with the establishment and growth of this Directorate. Some articles on emerging issues in weed science from eminent scientists and experiences of the Directors have been included. The various activities organized during the year befitting the occasion are also highlighted in this publication.

The information in this publication has been compiled by Dr. R.P. Dubey and Dr. Meenal Rathore, whose efforts are appreciated. The help rendered by other staff members, especially Mr. Sandeep Dhagat is duly acknowledged.

I hope this publication will be useful to the past and present generation of staff members at the Directorate, and all those concerned with weed management in the country.

Date: 31 December, 2014

(A.R. Sharma)
Director

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भारत सरकार
MINISTER OF STATE
FOR AGRICULTURE &
FOOD PROCESSING INDUSTRIES
GOVERNMENT OF INDIA

7th April, 2014

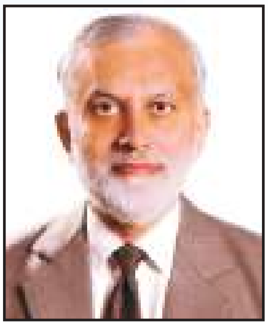
डमेंहम

It is heartening to know that Directorate of Weed Science Research, Jabalpur is celebrating its Silver Jubilee on 22nd April, 2014. Among all constraints in crop production, weeds cause huge economic losses and also affect human and animal health. It is happy to note that the Directorate has developed integrated weed management technologies for managing weeds in cropped as well as non-cropped lands for achieving higer agricultural production.

I extend my warm greetings and felicitations to all those associated with the institution and wish it a grand success.

(Dr. Charan Das Mahant)

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



सत्यमेव जयते

भारत सरकार
कृषि अनुसंधान और शिक्षा विभाग एवं
भारतीय कृषि अिनुसंधान परिषद्
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11th April 2014

डमेंहम

It gives me immense pleasure to know the Directorate of Weed Science Research is celebrating 2014 as the Silver Jubilee Year. During the last 25 years, DWSR has established itself as a research institute focused on weed mangement research. The Directorate has developed technologies for weed management for different agro-ecological zones. It has also developed the National Database on weeds and weed seed/seedling identification softwares, which have become very popular amongst stakeholders.

While there is immediate need to focus on managing weeds keeping in view the challenges in agricultural production and climate change, there is equal need to watch out for newly emerging and invasive weeds, not withstanding the beneficial uses of weeds.

I am sure the Directorate shall continue to progress and achieve greater heights in the times to come. I convey my heartiest congratulations to the entire DWSR family on this occasion.

(S. Ayyappan)

Dr. Mangala Rai
Agriculture Advisor to Chief Minister of Bihar

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15th April, 2014

डमेंहम

Weeds have been and will be a serious constraint in agricultural production. They are also a problem in aquatic bodies and interfere with human and animal activites. Hence, problem solving safe technologies are required to mange the menace.

The establishment of a National Research Centre/Directorate at Jabalpur has been thought to address the existing and emerging weed problems in different situations and systems. The institution, in its 25 years of useful existence, has moved forward but challenges on research and development fronts continue to be there. I hope the present leadership would concentrate far more on basic and strategic research at Jabalpur and use them effectively in location, situation and system specific technology development thorugh its coordinated networks.

With a happy note, I extend my greetings and best wishes to the Directorate of Weed Science Research on the occasion of its Silver Jubilee Celebrations.

(Mangla Rai)

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डा. गुरबचन सिंह
अध्यक्ष
Dr GURBACHAN SINGH
CHAIRMAN

9th April, 2014

Message

Weeds are a major concern in agricultural production as these cause up to one-third of total losses in yield, reduce produce quality and impose various hazards, to both health and environment. The Directorate of Weed Science Research is engaged in developing technologies for weed management in a sustainable way so as to not only improve crop production but also conserve the soil's health; managing weeds on non-arable lands, assessing residual effect of commercially available herbicides on soil, vermicomposting using agrowastes, identifying potential weed threats in changing climate and crop establishment regime, etc. The Directorate has emphasized on-farm research in a farmers participatory mode where all scientists are actively engaged in demonstrating technology to the farmers on their own field.

It is a matter of pleasure that the Directorate is celebrating Silver Jubilee on 22nd April, 2014. I am sure the technologies developed at DWSR shall continue to benefit farmers enabling better yield of crops and health of soil.

I wish the Directorate success in all its future endeavours.

(Gurbachan Singh)

Dr. C.D. MAYEE
M.Sc. (Agri.), Ph.D., D.Sc.
AVH Fellow (Germany), NAAS Fellow
ADJUNCT PROFESSOR (IARI, New Delhi)

Former :
Chairman, ASRB (ICAR), New Delhi
Agri. Commissioner, GOI, New Delhi
Director, CICR, Nagpur
Vice Chancellor, MAU, Parbhani

16^{th} April 2014

डमेंहम

Among all the pests, weeds cause about 33% loss in crop production. Besides crop losses, they also harm the non-crop situations, aquatic bodies and interfere with human activity. Weed management is a multi-disciplinary task. Understanding the weed biology, ecology and developing environment friendly control technologies are key to modern crop production. The Directorate at Jabalpur has been in the service of Nation by developing technologies to the farmers.

I congratulate and convey best wishes to the Directorate of Weed Science Research on the occasion of Silver Jubilee Year.

(C.D. Mayee)

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Additional Secretary, DARE &
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सत्यमेव जयते

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MINISTRY OF AGRICULTURE
DEPARTMENT OF
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KRISHI BHAVAN, NEW DELHI 110 001

11th April, 2014

डमेंहम

I extend my best wishes to the staff of Directorate of Weed Science Research for celebrating 2013-14 as its Silver Jubilee Year. The Directorate is a nodal centre for developing integrated weed management strategies for improving crop yield and reducting weed problems in varying ecosystems. The multi-disciplinary team engaged in basic and applied research in weed science has aptly given and entended improved weed management technologies to the farmers.

I am sure that the Directorate would march ahead with increased vigour to sustainably manage complex challenges in weed management for the welfare of farmers and other stakeholders. I extend my best wishes to the Directorate for its bright future.

(Arvind Kaushal)

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डॉ. अलोक कुमार सिक्का
उप महानिदेशक (प्रा सं प्र)
Dr. Alok K. Sikka
Deputy Director General (NRM)

22nd April, 2014

डमेंहम

It gives me immense pleasure to learn that Directorate of Weed Science Research, Jabalpur has completed 25 years of its existence in the service of Nation. This is a unique institute established by ICAR in 1989 to deal with all aspects of weed management under a single umbrella in a multi-disciplinary manner. Over the years, the Directorate has played a meaningful role in developing technologies for managing weeds in cropped and non-cropped areas, which have been adopted on large areas by the farmers and their stakeholders throughout the country.

Despite development and adoption of weed management technologies, weed problems are virtually on the rise. This is due to input intensive cropping systems and altered agronomy of crops, introduction of alien invasive weeds, and climate change. Research and development programmes of the Directorate have been reorganized to meet the emerging challenges. There is need to continuously monitor weed dynamics and refine the technologies, and also minimize adverse effects of herbicides on the environment.

I extend my greetings to all the staff of the Directorate, and wish success for further growth and achieving excellence in weed science research.

(Alok K. Sikka)

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dqyifr
Prof. Anil Kumar Singh
Vice - Chancellor

No./VC/2014-15/140 Dt. 16/04/12

डमेंहम

I am delighted to know the Directorate of Weed Science Research, Jabalpur, a constituent of ICAR, is celebrating its Silver Jubilee Year on 22nd April, 2014. Since its inception in 1989, the Directorate, then the National Research Centre for Weed Science, has been working on major weed problems of the country. Contribution of the Directorate in survey of the weed flora and development of weed management technologies for diversified cropping systems, weed management in the context of herbicide resistance, biology and management of problematic weeds in cropped and non-cropped areas, and environmental impact of herbicides is praiseworthy. Adoption of these technologies has been promoted on large areas through on-farm research and demonstration, which has raised the crop productivity and sustained income and livelihood security of farmers. It has developed many technologies which are widely accepted by the farmers of the country.

I am happy to know that a Souvenir is being published on this historic occasion. I compliment and congratulate the staff of the Directorate on completing 25 years of a very fruitful and meaningful period and wish their future endeavors a great success.

(A.K. Singh)

डॉ. जे.एस. सामरा
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15th April, 2014

डमेंहम

It gives me immense pleasure to learn that the Directorate of Weed Science Research, Jabalpur is celebrating its Silver Jubilee during 2013-14. It is a very unique R & D institution for investigating weed problems in their multi-dimensionalities with the involvement of post graduate students and young scholars. Weeds cause potential losses in crop production and harm to biodiversity and effect human and animal health. The Directorate has developed integrated weed management technologies for managing weeds in crop as well as non-crop lands.

On the occasion of Silver Jubilee year, I wish the Directorate and its staff all success in its future endeavours.

(J.S. SAMRA)

Prof. Vijay Singh Tomar
Vice Chancellor

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No. VC/TC/125-A
9th April, 2014

डमेंहम

Directorate of Weed Science at Jabalpur has been doing a commendable job of educating farmers and policy planners about the dangers of weeds in agriculture and society. The Directorate has developed weed managnement technologies under diverse cropping sytems, non-crop lands and aquatic bodies.

I extend my greetings and best wishes to the Directorate of Weed Science Research on the occasion of Silver Jubilee Year.

(V.S. Tomar)

SURESH C. MODGAL, Ph.D
Former Vice-Chancellor
G.B. Pant University of
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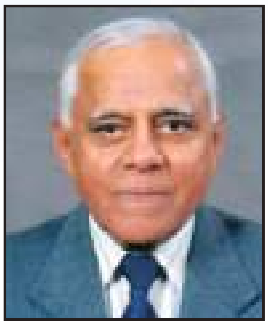

7th April, 2014

डमेंहम

Directorate of Weed Science Research through its 22 coordinating centres has provided practical solutions for managing weeds in different ecosystems and thus contributed immensely in the overall food production in the country.

I am very happy to learn that the Directorate is celebrating its Silver Jubilee on 22nd April, 2014. I congratulate the staff of DWSR and wish that it continues to provide leadership in weed science research in the country.

(S.C. MODGAL)

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Dr. B. Mohan Kumar
Assistant Director General
(Agronomy and Agroforestry)

9th April, 2014

डमेंहम

Weeds cause enormous losses in crop production besides causing health hazards to human beings and animal population. The Directorate of Weed Science Research has conducted research on weeds and developed weed management technologies for the benefit of farmers. It has also created awareness among farmers and policy planners about ill effects of weeds.

On completion of 25 years, I would like to congratulate the staff of the Directorate and wish all success in future.

(B. Mohan Kumar)

Dr. V.N. Saraswat
Former Director
Directorate of Weed Science Research
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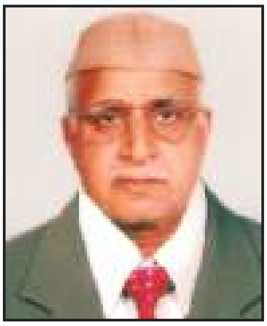

9th April, 2014

डमेंहम

It gives me immense pleasure to know that the Directorate is celebrating Silver Jubilee on 22nd April, 2014. During the past 25 years since its inception, the Directorate has established itself as a centre for weed research where both basic and applied science is undertaken in a multi-disciplinary mode. The Directorate has significantly contributed to development of efficient and sustainable weed management technologies, assessment of herbicide residues in soil, use of weeds for human welfare, identification of weeds, weed dynamics in different cropping systems and in the regime of climate change.

I wish success to the Directorate and its staff in their future endeavours.

(V.N. Saraswat)

Dr. N.T. Yaduraju
Former Director
Directorate of Weed Science Research
and President
Indian Society of Weed Science,
Jabalpur-482004
Madhya Pradesh

22nd April, 2014

डमेंहम

Directorate of Weed Science Research has come a long way since its inception in 1989. It has seen many ups and downs like many organizations face during their initial stages of establishment. Today it is counted as one of the major centres in the world engaged in weed science. In fact, it is the ONLY organization of its kind in the world. It has excellent facilities of all kinds to carry out both basic and strategic research, the results of which are used in solving local problems through its network programme involving AICRP centres spread across the length and breadth of the country. Besides creating awareness about weeds, the major contributions of the Directorate include: development of national database on weeds, long-term weed management trials, weed seedling and weed seed identification tools, and biological control of *Parthenium* to name a few. The Directorate will have a key role to play in the immediate future in the light of critical importance the weeds and weed management have assumed in sustainable crop production and conservation of biodiversity and environment.

I take this opportunity to express my best wishes on the occasion of the Silver Jubilee celebrations of the Directorate. I congratulate and compliment the Director and staff of the Directorate for their commitment and dedication.

I wish the Directorate a great future.

(N.T. Yaduraju)

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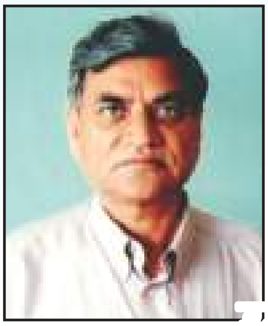

7th April, 2014

डमेंहम

The Directorate of Weed Science Research is a sole and unique institution, not only in India but globally, dedicated towards undertaking research on sustainable weed management. The institute has done excellent work for managing weeds under crop and non-crop situations. The recommendations generated by the institute at its headquarter as well as centres under All India Coordinated Research Project on Weed Control are adopted by farmers vigorously. The institute has excellent field and laboratory facilities and is also addressing well the new challenges such as effect of climate change on crop-weed interaction, early detection of establishment of invasive weeds, phytoremediation of free radicals in irrigation and drainage water, understanding the occurrence of weedy rice, soil and water pollution through herbicides and their secondary metabolites, biocontrol of prominent weeds and herbicide resistance and GM technology etc.

The Directorate is undertaking transfer of technology to farmers and creating awareness about ill effects of different types of weeds amongst the farmers and public at large.

The Directorate with which I have been associated for a period of five years during 2006-2011, is celebrating its Silver Jubilee year during 2014. I feel immense pleasure on the occasion and extend my heartiest wishes to Director, scientists and staff for further excelling in their endeavors for solving problems of farmers in the field of weed management.

(Dr. Jay G. Varshney)

Weed management research in India – an analysis of past and outlook for future

Adusumilli Narayana Rao, Suhas P. Wani and J.K. Ladha

Agriculture is a critical sector of the Indian economy. Though agriculture's contribution to the overall Gross Domestic Product (GDP) of the country has fallen from about 30% in 1990–91 to <15% in 2011–12, agriculture yet forms the backbone of development. Achieving an 8–9% rate of growth in overall GDP would help in poverty reduction and in providing food and nutritional security to all Indians, only when agricultural growth accelerates. In the last two Five Year Plans, it was mentioned that for the economy to grow at 9%, it is important that agriculture should grow at least by 4% per annum. The average growth in agriculture and allied sectors in the XI Plan is around 3.3–3.5% per year against a target of 4%. Despite a virtual ceiling on cultivable area of 140±2 M t, India's foodgrain production increased from 198 million tonnes (M t) in 2004–05 to 259 M t by 2011–12, at an average of about 6 M t per annum due to enhanced growth rates in yield of different crops. However, we need to produce more to meet the demands of 1.66 billion people (of 9.16 billion people of the world) to be inhabited in India by 2050. Further enhancement of crop productivity for the achievement of food and nutritional security and alleviation of poverty and unemployment on a sustainable basis depends on the efficient and judicious use of natural resources. Efficient use of natural resources, enhancing food and feed production to meet the demands (Table 1) of increasing population is possible only when biological constraints such as weeds are understood properly and alleviated by evolving and implementing appropriate management strategies.

Table 1. Production and future requirement of foodgrains in India

Crop	Production 2010–11 (M t)	Demand 2021 (M t)
Rice	103	120
Wheat	90	100
Coarse cereals	42	40
Pulses	17	25
Total	252	285

Source: www.epsoweb.org/file/853

Weeds are one of the major biological constraints that compete with crops for natural resources as well as added inputs, and are limiting agricultural production and productivity in India (Rao and Nagamani, 2010, 2013). Despite continuous research and extension efforts made in weed science, weeds continue to cause considerable losses to farming. As per the available estimates, weeds cause up to one–third of the total losses in yield, besides impairing produce quality and various kinds of health and environmental hazards (DWR, 2014). In their response to the survey carried out for the present chapter, Indian weed scientists estimated losses due to weeds from 10–80% (Table 2). Even the lowest estimate of 10% loss would amount to a loss of about 25 M t of foodgrains, currently valued at approximately US$ 13 billion (Yaduraju, 2012). Losses of similar magnitude may occur in plantation crops, fruits, vegetables, grass lands, forestry and aquatic environment. Thus, the total economic losses will be much higher if indirect effects of weeds on health, loss of biodiversity, nutrient depletion, grain quality etc. are taken into consideration.

Table 2. Possible yield loss due to weeds in different major crops of India, as expressed by the Indian weed scientists in the survey

Crop	Yield loss (%)	Crop	Yield loss (%)
Chickpea	10–50	Pea	10–50
Cotton	40–60	Pearlmillet	16–65
Finger millet	50	Pigeonpea	20–30
Greengram	10–45	Potato	20–30
Groundnut	30–80	Rice*	10–100
Horsegram	30	Sorghum	45–69
Jute	30–70	Soybean	10–100
Lentil	30–35	Sugarcane	25–50
Maize	30–40	Vegetables	30–40
Mustard	20–30	Wheat	10–60
Niger	35		

*Yield losses could be up to 100% if weeds are not controlled

As weeds are dynamic, continuous monitoring and refinement in management strategies is essential for alleviating adverse effects of weeds on agricultural productivity and environmental health (Rao and Nagamani, 2013). Currently, weed scientists of India have the challenge of evolving effective weed management technologies that are economical and have least impact on environment and non–target organisms (Rao and Nagamani, 2010). For the research efforts to be more effective and target based, it is essential to review, from time to time, the research work carried out and identify the research needs based on: (a) impact of research results attained and extended to farming community, and (b) new emerging weed problems that farmers are facing in response to adoption of improved weed and crop management technologies.

The present paper aims at understanding and analyzing the weed management research carried out in India in the past, being carried out at present and suggests future research needs based on current farmers needs.

Methodology

The first assumption made for this study was that the research carried out in India is mostly published by the Indian weed scientists in the Indian Journal of Weed Science (IJWS). Hence, for the purpose of this paper, publications of Indian Journal of Weed Science have been considered as the criteria of research carried out in India during different periods of time. We have considered:

Past:

(i) Far–past: IJWS publications from the year 1980–1989

(ii) Past: IJWS publications from the year 1990–1999

(iii) Immediate past: IJWS publications from the year 2000–2009

Present: IJWS publications from the year 2010–2013

The publications were categorized into different sub-disciplines of weed science, analysed and discussed. Future research needs, as we felt important, are discussed in this paper. The short communications during the period of 2000–2009 were not considered in this analysis (due to time constraint). For the rest of the years, they too were included. The research findings as presented in "Proceedings of the Annual Group Meeting of All India Coordinated Research Project on Weed Control" from 2010–2013 were also referred and summarized.

A survey was conducted, using structured questionnaire, among Indian weed scientists on relevant aspects of weed management in India. Twenty-four scientists responded and the summary of their response was used at appropriate places with due acknowledgement.

Weed management research in India

In the past, hand weeding was synonymous to weed management due to abundant labour availability, cheaper cost of labor and the nature of agriculture as major occupation. Hence manual and mechanical methods were used by the farmers. During 1990s, the nominal farm wages grew at a rate of 11.6% per annum, while in 2000s the growth rate was 8.9% per annum. Within 2000s, the growth was only 1.8% during 2001–2002 to 2006–2007 and 17.8% during 2007–2008 and 2010–2011 (Source: Labour Bureau, Shimla, India). Increased labour wages lead to adoption of chemical weed control alone or as a component of integrated weed management by the farmers in India during recent times.

Earliest attempts in India to control weeds by herbicides were made in 1937 in Punjab for controlling *Carthamus oxycantha* by using sodium arsenite. After the discovery of 2,4-D as plant growth regulator (Zimmerman and Hitchcock, 1942), it was first tested in India in 1946 (Mukhopadhyay, 1993). Since then a number of herbicides have been imported and tested for their effectiveness in controlling many weed species. In 1952, ICAR initiated a scheme for testing the field performance of herbicides in rice, wheat and sugarcane in different states of

India. Maximum amount of herbicides (50–60%) were used in the tea plantation. ICAR recognized the need for strengthening weed research in India by setting up in 1978 an All India Co-coordinated Research Project on Weed Control (AICRP–WC) in collaboration with United States Department of Agriculture (USDA), which is continued and now being implemented through 22 centres all over the country. National Research Centre for Weed Science was set-up in 1989 at Jabalpur and was upgraded as Directorate of Weed Science Research in 2009. Prior to establishment of AICRP–WC, weed science was considered as sub–discipline of Agronomy and is still considered in many agricultural universities of India.

Rice and wheat were the major crops of weed management research in India during past as well as current period (Table 3). The research efforts on these crops increased from 1980 to 2009. However, during present period (2010 to 2013), percentage papers on rice and wheat decreased as relatively more results were reported on crops such as sugarcane, maize and other crops. Research papers with studies on weed management in cropping systems perspective remained less throughout.

Table 3. Research publications on different crops (% of total papers published) in IJWS across years

Crop	Percentage of published papers in IJWS			
	1980–1989	1990–1999	2000–2009	2010–2013
Rice	14	20	26	21
Wheat	13	14	20	16
Cropping systems	5	7	9	6
Maize	4	3	3	3
Soybean	3	7	5	6
Greengram	3	2	< 1%	1
Blackgram	2	< 1%	2	1
Groundnut	3	3	< 1%	1
Potato	2	1	1	< 1%
Tomato	2	1	< 1%	–
Mustard	1	1	1	1
Sorghum	3	< 1%	–	1
Sugarcane	2	1	2	3
Chickpea	2	1	3	1
Fingermillet	2	< 1%	–	1
Onion	2	1	2	2
Cotton	1	2	2	< 1%
Brinjal	1	–	< 1%	< 1%
Cauliflower	1	< 1%	–	
Cowpea	1	1	–	< 1%
Barley	1	1	< 1%	< 1%
Chillies	1	< 1%	–	
Garlic	1	< 1%	< 1%	1
Jute	1	< 1%	–	< 1%
Mint	1	< 1%	–	
Pea	2	1	–	–
Pigeonpea	1	1	< 1%	1
Lentil	< 1%	1	1	2
Sunflower	–	1	1	1
Mulberry	–	1	< 1%	–
Rajmash	–	1	< 1%	
Sesame	–	1	1	< 1%
Coriander	–	–	1	–
Cumin	< 1%	–	1	< 1%
Okra	< 1%	< 1%	1	1
Sweet corn	–	–	–	1
Cluster bean	–	< 1%	< 1%	1
< 1%	Chickpea, radish, tobacco, bamboo, banana, bell pepper, *Brassica capsularis*, carrot, fenugreek, field peas, french bean, greengram, fodder, isabgul, orchards, peach, plum orchard, ramie , safflower, urd bean, winter vegetables, vegetable pea	Flax, ber, kinnow, linseed, pearlmillet, lemon, saffron, toria, bell pepper, carrot, cassava, citrus, faba bean, fenugreek, field bean, fodder maize, French bean, *Citronella*, mandarin, opium poppy, pointed gourd, roses, runner bean, safflower, tobacco, tomato, toria, urdbean, vegetable nurseries	Garden pea, pea, pearlmillet, shaftal, aswagandha, baby corn, blond psyllium, fenugreek, berseem as fodder, chicory, chamomile, cabbage, cocoa, rubber, coconut, teak, banana and pineapple, dwarf pea, fenugreek, niger, linseed, niger, onion, opium poppy, Persian clover, pointed gourd, seed potato, *Setaria*, sweet potato, tea.	*Jujube*, strawberry, baby corn, bhalia plantation, berseem, Egyptian clover, ginger, grapes, *Gladiolus*, isabgul, Lucerne, tapioca, urdbean, greengram, pearlimilllet, toria.

Contd..

Analysis of the past

Far past period (1980–1989)

During far past period, major emphasis was on utilisation of herbicides for weed management. Out of 333 papers published, 69% were on herbicides (such as alachlor, atrazine, bifenox, butachlor, 2,4-D, dicamba, diquat, fluchloralin, fluroxypyr, glyphosate, methabenzthiazuron, metoxuron, nitrofen, paraquat, propanil, simazine, terbutryne, and sethoxydim) and on herbicide related aspects of weed science (Table 4). Efficacy of herbicides in managing weeds in different crops, herbicide efficacy interaction with irrigation, fertilisers, effect of herbicides sprayed in one crop on the succeeding crops, tolerance of crop cultivars to herbicides were certain aspects of herbicide based studies. Only 9% of research papers were on integrated weed management (IWM) and all these were herbicide based.

Table 4. Broad research areas of publications in Indian Journal of Weed Science across thirty three years

Research area	Percentage of papers published in IJWS			
	1980–1989	1990–1999	2000–2009	2010–2013
Herbicides	69	57	53	41
IWM	9	20	30	35
Ecology	16	15	11	10
Cultural	2	3	3	4
Genomics	0	0	1	0
Physiology	1	1	1	3
Allelopathy	3	1	1	1
Biocontrol	1	< 1	1	1
Weed use	0	< 1	< 1	2
Economics	0	1	< 1	< 1
Review	1	1	< 1	2
Modelling	0	0	1	< 1
Decision support	0	0	< 1	0
Total publications referred to by author	333	560	424	277

A considerable number of papers were published on weed ecology (16%) during the period. Weed ecological research focussed on assessing critical period of crop weed competition (rice under different methods of establishment, brinjal, finger millet, groundnut, maize and sugarcane) and weed flora surveys (in the states of Andhra Pradesh, Punjab, Madhya Pradesh, Maharashtra, higher hills of Nilgiris, Kashmir, West Bengal, Western Himalayas and Tarai region) during the far past period. Results of research on ecology of *Parthenium hysterophorus* (Tiwari and Bisen, 1984) and biology and control of *Oxalis latifolia* were reported (Muniyappa *et al.*, 1983). Allelopathy studies were focussed on effects of weed leachates on germination of crop seeds. The concept of utilising competitive crops for managing *Cyperus rotundus* was put forward (Kondap *et al.*, 1982). Only one publication on the biocontrol was published on the role of *Teleonemia scrupulosa* in controlling *Lantana* (Gupta and Pawar, 1984).

Past period (1990–1999)

During the past period, a significant increase in research papers on integrated weed management was observed while papers on herbicides alone slightly decreased.

During this period, resistance of isoproturon against *Phalaris minor* had posed a severe threat in wheat production in India (Malik and Singh, 1993, 1995; Bhan, 1994). Until the early 1990s, *Phalaris minor* could be effectively controlled by isoproturon, a substituted urea herbicide first recommended in 1977–78 and widely used since the early 1980s. But continuous use of this single herbicide for 10–15 years coupled with mono cropping of rice–wheat led to the evolution of resistance in this weed. By 1993, the resistance affected area ranged between 0.8–1.0 M ha in North West India and it also affected other *tarai* areas. Screening for alternative herbicides (Walia and Brar, 1996; Balyan *et al.*, 1999) and varieties tolerant to those herbicides (Yaduraju *et al.*, 1999) were initiated and reported.

In this period, reviews on biology and control of *Parthenium* (Tripathi *et al.*, 1991; Garg *et al.*, 1999) and usefulness of the weed, *Blumea lacera* (Oudhia and Tripathi, 1999) were published. Several publications on critical period of crop weed competition also appeared during this period in addition to results on herbicide evaluations, IWM, and weed flora surveys. Interesting publications of this period include identification of suitable crop species and plant density to suppress growth of *Cyperus rotundus* (Murthy *et al.*, 1995) and efficacy of crop residue management on herbicide efficacy in the rice–wheat sequence (Brar *et al.*, 1998).

Immediate past (2000–2009)

During this period, research papers on herbicide evaluation in different crops and weed ecology studies decreased in comparison to past period and those of IWM increased considerably. Increase was also observed in reports of studies on cultural weed management.Use of biotechnology for understanding molecular diversity of *Phalaris minor* populations in wheat (Dhawan *et al.*, 2008) and mechanism of resistance of *Phalaris* to isoproturon (Dhawan *et al*, 2004; Singh *et al.*, 2004) were initiated during this period. Methodology to study crop weed competition was reviewed by Singh *et al.*, (2002). Possible utilisation of weeds such as *Lantana* and *Eupatorium* as green manure in rainfed maize–wheat system (Mankotia *et al.*, 2006) and weed biomass for nitrogen substitution in rice–rice system (Rajkhowa, 2008) were published. An attempt to understand the technological gap in adoption of weed management technology in rice–wheat system of Uttaranchal was made (Singh and Lall, 2001). Cultural practices like use of smother crops in sugarcane (Rana *et al.*, 2004); soil solarisation alone in sunflower (Chandrakumar *et al.*, 2002) and soil solarisation along with crop husbandry practices like tillage with and without irrigation, wheat straw incorporation (e.g. Das and Yaduraju, 2008); irrigation and nitrogen in wheat (Das and Yaduraju, 2007) etc. were evaluated for their weed management efficacy and reported in the journal. Evaluation of varieties and hybrids in rice (e.g. Dhawan *et al.*, 2003; Kumar *et al.*, 2000) for response to fertilizers and herbicides and reports on varieties and herbicides in wheat (Verma *et al.*, 2007) were published. Publications on integrated weed management included combination of herbicides with manual weeding (e.g. Singh and Singh, 2004), trash burning (e.g. Singh and Rana, 2003), intercultivation (e.g. Subramanian and James, 2006), tillage (Sharma and Gautam, 2006), rotation (Singh, 2006), and several other combinations in several crops. Herbicide studies involved herbicide evaluation in different crops, their degradation (Amarjeet *et al.*, 2003), resistance in weeds (Mahajan and Brar, 2001); and herbicide residue effect on crops grown in rotation (Yadav *et al.*, 2004). The importance of decision making tools was brought to light (Babu *et al.*, 2000).

Present (2010 - 2013)

During the present period 277 research papers have been published in IJWS as Volumes 42 to 45. Supplementary volumes published from Jabalpur during these years were also considered in this analysis. Majority of the studies published during present period were herbicide based (41%). Integrated weed management studies and its percentage increased from 30–35%. Studies on weed use and cultural weed management increased slightly. But the studies on weed ecology decreased. Reviews on aspects such as integrated weed management (Rao and Nagamani, 2010); aquatic weed problems and management in India (Sushil Kumar, 2011); impact of climate change on weeds and weed management (Singh *et al.*, 2011); weed management approaches for dry-seeded rice (Chauhan and Yadav, 2013); zero tillage in weed management (Singh *et al.*, 2010) and cost of *Parthenium* and its management (Sushilkumar and Varshney, 2010) were published. In addition to studies on weed management with recently available herbicides, some of the interesting papers that appeared during this period were on shifts in weed flora due to tillage and weed management practices (Singh *et al.*, 2010); threshold level of horse purslane in irrigated cowpea and onion (Chinnuswamy *et al.*, 2010, 2010a); non-chemical methods for managing weeds in rice (Deshmukh, 2012); screening rice genotypes against weeds in direct-seeded rice (Walia *et al.*, 2010); evaluation of cultivars and herbicides for control of barnyard grass and nutsedge in rice (Kumar *et al.* 2013); evaluation of toxins of phyto-pathogenic fungus for eco-friendly management of *Parthenium* (Singh *et al.*, 2011); management strategies for rehabilitation of *Lantana* infested forest pastures in Jammu & Kashmir (Sharma *et al.*, 2012); and solarization for reducing weed seed bank in soil (Arora and Tomer, 2012).

Present day weeds and weed management practices used by farmers (as revealed by Indian weed scientists)

Dominance in weed flora and increase / decrease of weed dominance across years varied at different locations in India (Table 5). Majority of the crops, the scientists observed that hand weeding prevailed as the method of weed management in past and currently, herbicides are being used to manage crops associated weeds (Table 6). Labour wages for weeding have increase from 20 (20 years back) to 100 (3 years back) of the past to 120 to 300 of the present day. The increased labour wages are forcing farmers to adopt herbicides as a component of integrated weed management. Reported percentage of farmers using integrated weed management ranged from 10–30% in wheat; 10–70% in rice; 10–60% in soybean; 15–60% in chickpea; 5–40% in mustard and 20–50% in maize. Variation in the herbicides used in the past and present has also been observed. In the past, herbicides largely used were isoproturon and 2,4-D. Currently, sulfosulfuron, clodinafop, metsulfuron, mesosulfuron + iodosulfuron and isoproturon + 2,4-D were reported to be used by the wheat farmers. In rice thiobencarb, butachlor and 2,4-D, anilophos were used in the past. Currently, bispyribac sodium,

fenoxaprop, chlorimuron + metsulfuron, oxadiargyl, ethoxysulfuron, pyrazosulfuron, butachlor, pretilachlor and 2,4 D are being used by the farmers. However, in Haryana, it was reported that many grassy weeds like *Leptochloa chinensis*, *Eragrostis* spp. and *Dactyloctenium* were not controlled by any of the herbicides used (AICRP–WC, 2013).

Based on research work carried out in India, DWSR has published books on: i) AICRP–WC recommendations on weed management, ii) Herbicide use in field crops, iii) Hand book on herbicide recommendations (http://www.nrcws.org/ Listpublication.html). Hence, details of herbicides and their recommendations are not summarised in this paper.

Table 5. Summary of major weeds, new weeds, decrease and increase in weed species occurrence in India at different locations as reported in recent AICRP–WC meetings

Location	Weeds with decreased incidence	Weeds with increased incidence	Major weed problem / new weeds	References
Andhra Pradesh			*Vicoa indica* and *Cassytha filiformus* (parasitic weed) (new weeds in Ananthapur district)	AICRP–WC (2013)
Assam			*Eichhornia crassipes* followed by *Ipomoea carnea* (In aquatic situations of Dibrugarh district)	AICRP–WC (2013)
Assam (Jhum cultivation)	*Biophytum reinwardtii, Desmodium gangaticum, Mollugo pentaphylla, Passiflora foetida, Smilax perfoliata, Sonchus asper, Stephania japonica, Digitaria setigera, Echinochloa colona* and *Phragmites karka*			AICRP–WC (2012)
Bihar			Dominant weeds: *Cyperus rotundus, Cynodon dactylon, Echinochloa colona* and *Eleusine indica,*in initial stages and at later stages, *Caesulia axillaris* (in rice);	AICRP–WC (2013)

			weedy rice (New weed in direct-seeded deep water rice in Darbhanga and Madhubani districts)	
Chhattisgarh		*Alternanthera triandra* (DSR); *Malwa pusila* (replacing *Parthenium* on road sides);	Major weed: *Phalaris minor* (in wheat)	AICRP-WC (2013)
		Alternanthera triandra (in direct-seeded rice)		AICRP-WC (2011)
			Malwa pusilla is replacing *Parthenium hysterophorus* (in crop fields); *Alternanthera triandra*	AICRP-WC (2012)
Haryana (North-eastern)		*Medicago denticulata*, *Chenopodium album*, *Rumex dentatus* (in Hisar- wheat field due to continuous use of clodinafop)		AICRP-WC (2010)
		Solanum nigrum and *Malwa parviflora* (zero tilled wheat fields)		AICRP-WC (2011)
	Avena ludoviciana (disappeared in wheat)	*Ammania baccifera* (in transplanted rice)		AICRP-WC (2012)
			Avena ludoviciana (in wheat of southern Haryana); *Orobanche* spp. (in tomato)	AICRP-WC (2013)

Himachal Pradesh		*Commelina benghalensis* and *Brachiaria ramose* (due to continuous use of atrazine)	*Syndrella viallis* (new weed in maize at Palampur)	AICRP-WC (2010)
		Ageratum conyzoides, *Commelina benghalensis* and *Brachiaria ramosa*		AICRP-WC (2012)
			Ageratum conyzoides, *Commelina benghalensis* and *Brachiaria ramosa* (in Kangra district); *Parthenium hysterophorus* (started invading the upland *kharif* crops in the mid-hill conditions)	AICRP-WC (2013)
Jharkhand			*Hyptis suaveolens*	AICRP-WC (2012)
Karnataka			*Tithonia diversifolia* ; *Mikania micrantha* and *Ipomoea triloba* (new weeds); *Ambrosia psilostachya* (new quarantine weed recorded at Turevekare taluk of Tumkur district)	AICRP-WC (2013)
			Solanum carolinense, *Solanum trilobatum* (Solanaceae), *Cenchrus tribuloides/ biflorus*, (Poaceae), *Verbesina encelioides* Cav., *Echinops echinatus* Roxb. (Asteraceae), *Ipomoea hederifolia*, *Ipomoea quamoclit* (Convolvulaceae), *Anoda cristata* (Malvaceae) (New weeds noticed on cropped fields and road sides	AICRP-WC (2011)

Kerala		*Alternanthera philoxeroides* (Alligator weed) (spreading in the low lands in the Kuttanad and Koleland regions, where one crop is rice is taken during summer)		AICRP–WC (2012)
		Weedy rice (*Oryza* spp.) (rice growing tracts of Kerala, viz. Kuttanad, Thrissur Kole and Palakad regions)		AICRP–WC (2012)
			Leptochloa chinensis (rice in the Kole lands and Kuttanad)	AICRP–WC (2012)
Madhya Pradesh			Dominant weeds: *Orobanche aegyptica* (in mustard of Bhind, Datia, Shivpuri and Sheopur districts) *Orobanche aegyptiaca* and *Asphodelus tenuifolius* (in Gwalior and Morena districts)	AICRP–WC (2013)
			Alternanthera sessilis	AICRP–WC (2012)
Odisha			Major weeds: *Mikania micrantha, Parthenium hysterophorus, Eichhornia crassipes, Alternanthera philoxeroides, Orobanche aegyptica* (In East and South Eastern Coastal Plain Zone); *Celosia*	AICRP–WC (2013)
Punjab		*Poa annua* (increasing in Ludhiana		AICRP–WC (2010)

		wheat field due to continuous use of clodinafop and sulfosulfuron)		
		Eleusine spp. and *Leptochloa* (as they escape bispyribac in rice)		AICRP–WC (2012)
		Phalaris minor (showed signs of cross resistance to pinoxaden, sulfosulfuron, mesosulfuron + iodosulfuron and clodinafop)	Likely to be dominant: *Poa annua* (in wheat, berseem and oats); *Ipomoea* (in berseem); weedy rice (in transplanted rice), and *Dactyloctenium* spp., *Leptochloa spp* , and *Eragrostis spp.*, (in direct–seeded rice)	AICRP–WC (2013)
Tamil Nadu	*Tridax procumbens*	*Parthenium hysterophorus* (in cropped and non–cropped area)		AICRP–WC (2013)
Uttar Pradesh (Eastern)	*Avena fatua*		*Poa annua, Stellaria media; Solanum nigrum* and *Rumex acetosella* (new weeds)	AICRP–WC (2012)
			Polypogon monspliensis and *Poa annua, Rumex* spp. and *Medicago denticulata* (new weeds in wheat) and weedy rice (New weed in lowlying rice)	AICRP–WC (2013)
		Solanum sysimbrifolium (in potato, cabbage and cauliflower)		AICRP–WC (2013)

West Bengal			*Echinochloa glabrescens*, *Echinochloa crusgalli* both (in *boro* and *Kharif* rice) and *Oryza nivara*, *Oryza minuta*, *Oryza barthii* and *Oryza rufipogon* (in *Kharif* rice)	AICRP–WC (2012)

Table 6. Weeds of economic significance (in order of significance) in certain crops as reported by Indian weed scientists

Wheat	Rice	Soybean	Chickpea	Maize
Phalaris minor	*Echinochloa colona*	*Echinochloa colona*	*Chenopodium album*	*Echinochloa colona*
Avena ludoviciana	*Echinochola crusgalli*	*Cyperus rotundus*	*Avena fatua*	*Celosia argentia*
Chenopodium album	*Cyperus* spp.	*Euphorbia geniculata*	*Medicago denticulata*	*Cynotis axillaris*
Avena fatua	*Alternanthera* spp.	*Commelina communis*	*Chicorium intybus*	*Euphorbia hirta*
Cichorium intybus	*Cyperus rotundus*	*Dinebra retroflexa*	*Convolvulus arvensis*	*Melochia carchorifolia*
Medicago denticulata	*Commelina benghalensis*	*Physalis minima*	*Lathyrus aphaca/sativa*	*Cyperus* spp.
Parthenium hysterophorus	*Caesulia axillaris.*	*Trianthema* spp.	*Vicia sativa*	*Spilanthes acmella*
Vicia sativa	*Ammannia* sp.	*Alternanthera sessilis*	*Cyperus rotundus*	*Blainvillea acmella*
Convolvulus arvensis	*Dinebra* sp.	*Chenopodium album*	*Orabanche*	*Euphorbia geniculata*
Melilotus alba	*Eclipta alba*	*Convolvulus arvensis*	*Phalaris minor*	*Digera* spp.
Melilotus indica	*Fimbristylis millicea*	*Cynodon dactylon*	*Avena ludoricium*	*Ageratum* spp.
Rumex dentatus	*Dactyloctenium aegyptium*	*Digera arvensis*	*Euphorbia geniculata*	*Cyperus iria*

Majority of the scientists reported *Parthenium hysterophorus* as the most invasive weed species as it invaded soybean, vegetable, wheat, upland rice, sorghum and fruit orchards posing a severe threat during both *kharif* and *rabi* seasons. Weedy rice was the next problematic weed that had invaded both direct–seeded and transplanted rice fields in India. *Lantana camara* was reported as most invasive weed of non–cropped areas. Other weeds that were reported to invade cropped and non-cropped areas during recent years include: *Ageratum* sp., *Alternanthera triandra*, *Argemone mexicana*, *Avena* sp., *Cenchrus ciliaris, Elatine triandra*, *Celosia argentia* and *Tithonia rotundifolia* in upland crops; *Hyptis suaveolens* in moist land; *Leptochloa chinensis* in paddy; *Medicago denticulata*, *Malva* spp., *Mikania micrantha, Hyptis suaveolens*, *Lantana camara*, *Chromolaena odorata* in off fields; *Rumex* spp., *Solanum* sp., parasitic weeds and water hyacinth.

Outlook for the future

Adoption of integrated weed management (IWM) is essential for economic management of weeds, management of herbicide resistance, and it also helps in minimising the size of weed seed banks over time, and has clear benefits for managing the risk of weed control

failure due to adverse seasonal conditions that may prevail in the era of climate change. Using different components in an IWM plan is essential for the effective, long-term management of weeds. Some components of IWM that require emphasis on future research include:

Preventive control measures: Majority of the serious weeds are not native, but exotic and naturalised species. Trends of trade globalisation and global warming have potential to increase invasive plants dominance in agro-ecosystems of India. International cooperative efforts among weed scientists can be useful to prevent negative impact of invasive weeds. Considerable weed management can be achieved by adopting preventive weed control measures (Rao and Moody, 1988). Stricter introduction and implementation of seed laws (Rao and Moody, 1988a) and stricter enforcement of quarantine measures to prevent introduction would help in preventing new weed species into our country. Identification and popularisation of the preventive control measures for their use in arable and non–arable lands would be a low monitory input.

Mechanical weed management methods: Efforts to improve the efficacy of traditional implements and introduction of power operated mechanical implements to save labour hours and reduce drudgery to labour are essential.

Biocontrol: The first success in biological suppression of weeds was achieved in India with *Dactylopius ceyloniclus,* which was introduced from Brazil in 1795 for producing dye from a cactus species. It eradicated the problematic cactus species *Opuntia vulgaris* Mill. from India (Sushilkumar, 1993). Research on biological control of weeds was initially carried out at the erstwhile Commonwealth Institute of Biological Control at Bangalore which was known as Project Directorate of Biological Control and is now the National Bureau of Agriculturally Important Insects and the All India Co-ordinated Research Programme on Biological Control of Crop Pests and Weeds (AICRP–BCCPW).

Insect species such as *Neochetina* spp., *Cyrtobagolls salvallaie* and *Zygogramma bicolorata* were imported to India in earlier eighties, for controlling water hyacinth, water fern and *Parthenium*, respectively. Efforts have been successful and considerable control of respective weeds has been achieved by these insects. However few incidences of *Zygogramma bicolorata* feeding on sunf1ower were reported. Efforts in use of pathogens in managing weeds still remain in experimental stage.

Biocontrol may serve as a component of integrated weed management in future, inspite of several practical difficulties.

Habitat management: Research efforts in weed management through creation of unfavourable environment for weeds through habitat management has a lot of scope and greater future research efforts are needed here. Use of soil solarisation, manipulation in cultural practices such as change in time of seeding, seed rate, row spacing, tillage, time and dose of fertilizer application of different cropping systems adoption, selection of competitive crop varieties, allelopathic crops and their varieties and intercropping systems can serve as components of habitat management that can be integrated with other methods of weed management. Understanding weed ecology and biology is a prerequisite to effectively use habitat management of weeds and very little work has been done on weed ecology in India (Table 7). Greater efforts are needed to understand weed ecology particularly for the weeds such as weedy rice, *Parthenium* and others that were reported by Indian weed scientists as major weeds of economic significance (Table 5 and 6).

Table 7. Weeds whose ecological aspects were published in the IJWS

Weed	Aspect studied	State of India	References
Ageratum houstonianum	Seed germination	Himachal Pradesh	Angiras and Kumar (1995)
Avena ludoviciana	Germination and emergence	Himachal Pradesh	Singh and Ghosh (1992)
Celosia argentea	Germination and emergence	Asia	Chauhan and Johnson (2007)
Cleome viscosa	Seed viability	Tamil Nadu	Sivasubramaniam and Vijayalakshmi (2012)
Convolvulus arvensis	Germination	Haryana	Kumari *et al.* (2010)
Cuscuta species	Biology and management – review	Madhya Pradesh	Mishra (2009)
Cyperus rotundus	Autecology	Andhra Pradesh	Raju and Reddy (1999)
E. colona, E. glabrescens and *E. crusgalli*	Autecology and biology	Andhra Pradesh	Raju and Reddy (1999a)
Eclipta alba	Germination and growth	Haryana	Dhawan (2007)
Eupatorium adenophorum	Biology and control	Himachal Pradesh	Singh *et al.* (1992)
Euphorbia geniculata	Seed biology	J&K	Araf Mohd. *et al.* (2009)
Ischaemum rugosum	Growth, competition	Punjab	Singh and Singh (1992)
Ischaemum rugosum	Emergence	Punjab	Singh *et al.* (1991)
Lathyrus aphaca	Germination	Haryana	Kumari *et al.* (2010)
Leptochloa chinensis	Germination	Punjab	Aulakh *et al.* (2006)
Malva neglecta	Biology	Punjab	Kaur *et al.* (2008)
Malva parviflora, Rumex dentatus and *R. spinosus*	Emergence	Haryana	Singh and Punia (2008)
Melilotus indica	Germination, emergence and establishment	Haryana	Dhawan (2009)
Oxalis lalifolia	Biology	Karnataka	Pratibha *et al.* (1994)
Oxalis latifolia	Biology and control	Karnataka	Muniyappa *et al.* (1983)
Oxalis latifolia and *Ageratum conyzoides*		Himachal Pradesh	Kumar and Singh (1990)
Parthenium hysterophorus	Ecology	Madhya Pradesh	Tiwari and Bisen (1984)
Parthenium hysterophorus	Ecology and control	Tamil Nadu	Kathiresan (2008)
Parthenium hysterophorus	Germination	Uttar Pradesh	Maurya and Sharma (2010)
Phalaris minor	Germination	Haryana	Chhokar and Malik (1999); Chhokar *et al.* (1999)
Phalaris minor	Emergence	Haryana	Yadav and Singh (2005)
Sidarhombifolia	Dormancy, germination and emergence	Asia	Chauhan and Johnson (2008)
Trianthema	Soil seed bank	Tamil Nadu	Sivasubramaniam (1996)
Trianthema portulacastrum	Dormancy and germination	Tamil Nadu	Umarani and Selvaraj (1994)

Weed use: Many weed species have been utilized by mankind as food, medicinal plants, animal feed, housing material, handicraft material, ornaments, manure, etc. Systematic studies on possible economical use of weeds may be conducted to include weed usage as a component of IWM, where ever feasible.

Herbicides: About three-fourth of the available herbicides in India are used in plantation crops. It has been estimated that herbicides are currently being used on >20 M ha, which constitute about 10% of the total cropped area in the country (Yaduraju *et al*., 2006). Herbicides are also used in field crops like sugarcane, wheat, rice, maize, chillies, vegetable etc.

They will play a major role as component of IWM, especially when labour wages are increasing, labour availability is decreasing, hard work in fields is not preferred and zero tillage is gaining momentum in India. Research emphasis is needed to identify economic ways of herbicide use to reduce the cost of herbicide without affecting its efficacy and possible ways of integrating herbicides with other weed management practices. Educating farmers and popularizing safe and effective use of herbicides among farming community is essential (Rao *et al*., 2014). With growing concern and the increased public interest in environmental conservation, efforts to popularize methods of minimizing adverse environmental effects of herbicides and development of herbicide resistance among weeds in India are to be strengthened. Monitoring herbicide residues in environment (soil, air, water) and food chain should be strengthened.

Biotechnological tools: Genetically engineered (GE) varieties with pest management traits became commercially available for major crops in 1996. Despite the rapid increase in adoption of corn, soybean, and cotton GE varieties by farmers of the world and cotton farmers in India, questions persist regarding their economic and environmental impacts, evolution of weed resistance, and consumer acceptance (Rao *et al*., 2007; Rao and Ladha, 2013).

Herbicide-tolerant (HT) crops have traits that allow them to tolerate more effective herbicides, such as glyphosate, helping adopters to control pervasive weeds more effectively. HT seed–based production programs allow growers to use one product to control a wide range of both broadleaf and grass weeds instead of using several herbicides to achieve adequate weed control. Herbicide–tolerant crops also complement ongoing trends toward post-emergence weed control, adoption of conservation tillage practices, and use of narrow row spacing. The simplicity and flexibility of weed control programs for HT seeds requires less management attention, freeing valuable management time for other activities. In certain countries, adoption of HT crops has enabled farmers to substitute glyphosate for more toxic and persistent herbicides (Fernandez–Cornejo and McBride, 2002). However, over reliance on glyphosate and a reduction in diversity of weed management practices adopted by crop producers have contributed to the evolution of glyphosate resistance in weed species and biotypes. Thus weed resistance may be reducing use of the economic and environmental advantages of HT crop adoption regarding herbicide use.

In India the HT crops are yet to be tested and released. In our survey, majority (83%) of respondent Indian weed scientists were of the opinion that it is very unlikely (33%) and likely (50%) that HT crops have a role to play in future weed management in India (Figure 2). Genetic engineering and HT crops would be an important option in the future efforts towards sustainable weed management and agricultural production in India.

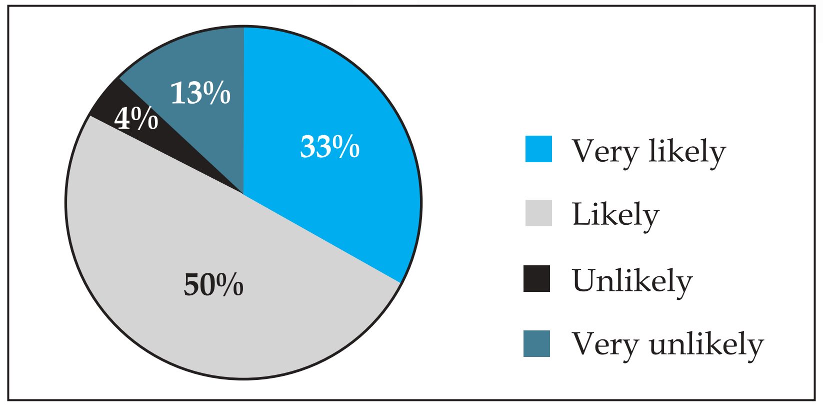

Figure 2. Response of current day Indian weed scientists on the role of genetically modified herbicide tolerant crops in future weed management in India

Climate resilient weed management options

Climate change is now a reality and bound to influence the ecology of weeds with possible implications for their management. It is important to have tools with which to assess likely impacts of climate change on potential future distribution and relative abundance of different weed species.

Fourteen of the world's worst weeds are C_4 plants. Seventy six per cent of the harvested crop area is with C_3 crops. The research carried out so far indicates that: (a) C_3 crops would benefit more from elevated CO_2 than C_4 weeds, losses due to C_4 weeds might decrease; (b) temperature increase /drought in combination with elevated CO_2 trends are not clear; (c) optimal temperatures for growth in C_4 plants are generally higher than optimal temperatures for C_3 plants, but with higher CO_2 the optimum temperature of many C_3 plants also increases; (d) in drought situations C_4 weeds might also have advantages over C_3 crops under elevated CO_2 (Yaduraju and Rao, 2013). However, in India, very little efforts been made to study the impact of climate change on weeds, weed ecology and their response to weed management practices including herbicides. Future research efforts must be intensified on these aspects to evolve climate resilient weed management approaches.

In the survey, 88% of Indian weed scientists have responded that in coming 25 years the change in weed flora is very likely (Figure 3).

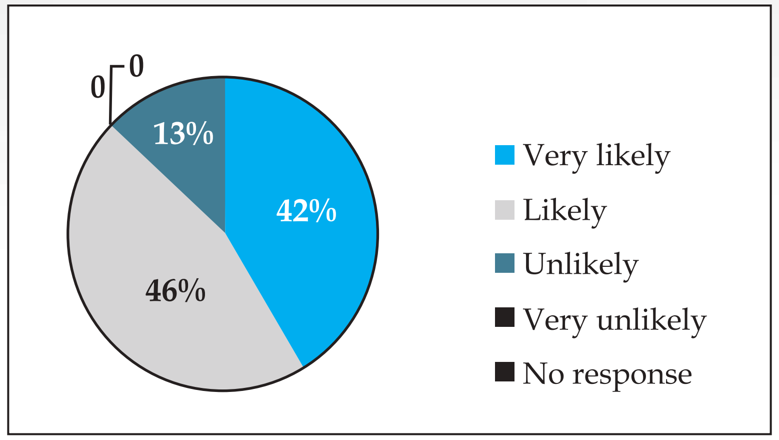

Figure 3. Response of weed scientists on the possibility of change in weed flora in coming 25 years

For managing weeds effectively in future, it is essential to adopt best management practices (BMPs) which include applying multiple herbicides with different modes of action, rotating crops, adopting best cultural weed management practices, planting weed–free seed, scouting fields routinely, cleaning equipment to reduce the transmission of weeds to other fields, and maintaining field borders. BMPs to control weeds may help delay the evolution of herbicide resistance. Location specific BMPs for different agro–ecological regions of India need to be developed and popularized. 88% Indian weed scientists expressed that funding for research is inadequate (Figure 4), any future effort to evolve best weed management options for different agro-ecological zones needs adequate funding.

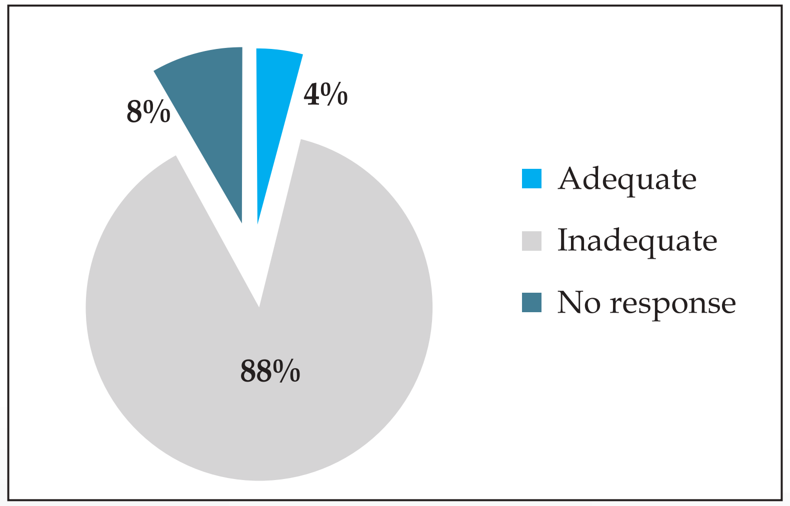

Figure 4. Response of Indian weed scientists on the adequacy of funds to weed science research in India

The present centers of All India Coordinated Research Project on Weed Control in different states of India must be upgraded as respective, "State Directorates of Weed Management Research" in the same pattern as DWSR to effectively evolve location-specific BMP for managing weeds effectively, economically and in an environmentally safe manner.

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References

AICRP-WC. 2010. *Proceedings of XIX Biennial Workshop of Directorate of Weed Science Research Coordinating Centres* held during 23–24 February, 2010 at Indira Gandhi Krishi Vishva Vidyalaya, Raipur, Chhattisgarh.

AICRP-WC. 2011. *Proceedings of the Annual Group Meeting of All India Coordinated Research Project on Weed Control* held during 28th February – 1 March, 2011 at Anand Agricultural University, Anand, Gujarat.

AICRP-WC. 2012. *Proceedings of XX Biennial Workshop of All India Coordinated Research Project on Weed Control* held during 17–18 April, 2012 at Kerala Agricultural University, Thrissur, Kerala.

AICRP-WC. 2013. *Proceedings of Annual Group Meeting of All India Coordinated Research Project on Weed Control* held during 26–27 April, 2013 at Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh.

Amarjeet, Punia, S.S., Yadav, Ashok and Malik, R.K. 2003. Effect of pH on degradation of chlorsulfuron in soil. *Indian Journal of Weed Science* **35**: 97–99.

Angiras, N.N. and Kumar, A. 1995. Effect of temperature and periods of storage on seed germination of *Ageratum houstonianum* Mill. *Indian Journal of Weed Science* **27**: 183–185.

Araf Mohd., Kumar, S., Parihar, J. and Hamal, A. 2009. Seed biology of an invasive weed – *Euphorbia geniculata* Ortega from north-west Himalaya (India). *Indian Journal of Weed Science* **41**: 85–87.

Arora, A. and Tomar, S.S. 2012. Effect of soil solarization on weed seed bank in soil. *Indian Journal of Weed Science* **44**: 122–123.

Aulakh, C.S., Mehra, S.P. and Bhatia, R.K. 2006. Effect of temperature, submergence and seed placement depths on germination behaviour of red sprangletop [*Leptochloa chinensis* (L.) Nees]. *Indian Journal of Weed Science* **38**: 108–111.

Babu, M.B.B. and Yaduraju, N.T. 2000. Decision support systems: A tool for sustainable weed management. *Indian Journal of Weed Science* **32**: 119–128.

Balyan, R.S., Yadav, A., Pahwa, S.K. and Malik, R.K. 1999. Response of fenoxaprop and other herbicides on isoproturon resistant and susceptible biotypes of little seed canary grass and other weeds in Wheat. *Indian Journal of Weed Science* **31**: 38–43.

Bhan, V.M. 1994. Herbicidcs resistance against weeds – a growing menace in India. *Weed News* **1**: 7–9.

Brar, S.S., Kumar, S., Brar, L.S. and Walia, S.S. 1998. Effect of crop residue management systems on the grain yield and efficacy of herbicides in rice–wheat sequence. *Indian Journal of Weed Science* **30**: 39–43.

Chandrakumar, S.S., Nanjappa, H.V., Ramachandrappa, B.K. and Kumar, H.M. Prasad. 2002. Weed management through soil solarization in sunflower. *Indian Journal of Weed Science* **34**: 231–235.

Chauhan, B.S. and Yadav, A. 2013. Weed management approaches for dry–seeded rice in India: a review. *Indian Journal of Weed Science* **5**: 1–6.

Chauhan, B.S. and Johnson, D.E. 2008. Dormancy, germination and emergence of *Sida rhombifolia* L. *Indian Journal of Weed Science* **40**: 6–10.

Chauhan, B.S. and Johnson, D.E. 2007. Effect of light, burial depth and osmotic potential on germination and emergence of *Celosia argentea* L. *Indian Journal of Weed Science* **39**: 151–154.

Chinnusamy, C., Senthil, A., Kumar, G.P. and Prabhakaran, N.K. 2010. Identification of threshold level of horse purslane in irrigated cowpea. *Indian Journal of Weed Science* **42**: 91–92.

Chinnusamy, C., Senthil, A., Bhuvaneswari, J. and Prabhakaran, N.K. 2010a. Studies on the threshold values of horse purslane in onion. *Indian Journal of Weed Science* **42**: 109–111.

Chhokar, R.S. and Malik, R.K. 1999. Effect of temperature on germination of *Phalaris minor* Retz. *Indian Journal of Weed Science* **31**: 73–74.

Chhokar, R.S., Malik, R.K. and Balyan, R.S. 1999. Effect of moisture stress and seeding depth on germination of littleseed canary grass (*Phalaris minor* Retz.). *Indian Journal of Weed Science* **31**: 78–79.

Das, T.K. and Yaduraju, N.T. 2008. Effect of soil solarization and crop husbandry practices on weed species competition and dynamics in soybean–wheat cropping system. *Indian Journal of Weed Science* **40**: 1–5.

Das, T.K. and Yaduraju, N.T. 2007. Effect of irrigation and nitrogen levels on grassy weed competition in wheat and comparative eco-physiology of *Phalaris minor* Retz. and *Avena ludoviciana* Dur. in wheat. *Indian Journal of Weed Science* **39**: 178–184

Deshmukh, G. 2012. Rotary weeder for drudgery reduction of women during weeding in rice field. *Indian Journal of Weed Science* **44**: 132–134.

Dhawan, R.S. 2009. Factors affecting germination, emergence and establishment of *Melilotus indica* (L.) All. *Indian Journal of Weed Science* **41**: 127–133.

Dhawan, R.S. 2007. Germination potential and growth behaviour of *Eclipta alba*. *Indian Journal of Weed Science* **39**: 116–119.

Dhawan, R.S., Singh, R., Punia, S.S., Dhawan, A.K. and Dudeja, S.S. 2008. Molecular diversity of little seed canary grass (*Phalaris minor* Retz.) populations from wheat growing belts of India. *Indian Journal of Weed Science* **40**: 101–108.

Dhawan, R.S., Dhawan, A.K. and Kajla, S. 2004. Protein profiles of some isoproturon susceptible and resistant biotypes of *Phalaris minor* Retz. *Indian Journal of Weed Science* **36**: 38–40.

Dhawan, R.S., Singh, S. and Malik, R.K. 2003. Growth response of *Echinochloa crusgalli* in association with rice genotypes. *Indian Journal of Weed Science* **35**: 197–200

Fernandez–Cornejo, J. and McBride, W.D. 2002. *Adoption of Bioengineered Crops*. AER–810, Economic Research Service, U.S. Department of Agriculture.

Singh, D.V., Gaur, A.K. and Mishra, D.P. 2004. Biochemical and molecular mechanisms of resistance against isoproturon in *Phalaris minor*: Variations in protein and RAPD profiles of isoproturon resistant and sensitive *Phalaris minor* biotypes. *Indian Journal of Weed Science* **36**: 256–259.

DWSR. 2014. *Vision 2050,* 30 p. Directorate of Weed Research, Jabalpur, M.P.

Garg, V.K., Gupta, R. and Balyan, R.S. 1999. Biology and control of carrot weed – A Review. *Indian Journal of Weed Science* **31**: 124–129.

Gupta, M. and Pawar, A.D. 1984. Role of *Teleonemi aserupuloa* Stal. in controlling *Lantana*. *Indian Journal of Weed Science* **16**: 221–226.

Kathiresan, R.M. 2008. Ecology and control of *Parthenium hysterophorus* invasion in Veeranum command area. *Indian Journal of Weed Science* **40**: 78–80.

Kaur, C., Mehra, S.P. and Bhatia, R.K. 2008. Studies on the biology of new emerging broadleaf weed Malva neglecta Wallr. *Indian Journal of Weed Science* **40**: 172–177.

Kondap, S.M., Ramakrishna, K., Reddy, G.B. and Rao, A.N. 1982. Investigations on the competitive ability of certain crops against purple Nutsedge (*Cyperus rotundus* L.). *Indian Journal of Weed Science* **14**: 124–126.

Kumar, S. and Singh, C.M. 1990. Studies on ecology of *Oxalis latifolia* and *Ageratum conyzoides*. *Indian Journal of Weed Science* **22**: 78–82.

Kumar, P., Singh, Y. and Singh, U.P. 2013. Evaluation of cultivars and herbicides for control of barnyard grass and nutsedge in boro rice. *Indian Journal of Weed Science* **45**: 76–79.

Kumar, S., Malik, R.S., Yadav, A. and Malik, R.K. 2007. Performance of cultivars and sulfosulfuron against weeds in wheat. *Indian Journal of Weed Science* **39**: 44–47.

Kumar, R.M., Subbaiah, S.V. and Singh, S.P. 2000. Effect of weed competition and level of nitrogen on performance of rice hybrids. *Indian Journal of Weed Science* **32**: 51–54.

Kumari, A., Singh. K., Yadav, A. and Singh, S. 2010. Factors affecting seed germination of *Convolvulus arvensis* and *Lathyrus aphaca*. *Indian Journal of Weed Science* **42**: 203–211.

Mahajan, G. and Brar, L.S. 2001. Studies on herbicide resistance in *Phalaris minor* under Punjab conditions. *Indian Journal of Weed Science* **33**: 1–4.

Malik, R.K. and Singh, S. 1995. Little seed canary grass *(Phalaris minor)* resistance to isoproturon in India. *Weed Technoloogy* **9**: 419–25.

Malik, R.K. and Singh, S. 1993. Evolving strategies for herbicides usc in wheat: Resistance and integrated weed management, pp. 225–38.. In: *Proceedings International Symposium*, Indian Society of Weed Science held during November 1993, Vol. 1.

Mankotia, B.S., Thakur, R.C., Kumar, J. and Kumar, S. 2006. Use of *Lantana* and *Eupatorium* as green manure in rainfed maize–wheat system in north–west Himalayas. *Indian Journal of Weed Science* **38**: 263–266.

Mishra, J.S. 2009. Biology and management of *Cuscuta* species. *Indian Journal of Weed Science* **41**: 1–11.

Maurya, B.R. and Sharma, P.K. 2010. Studies on the germination and viability of *Parthenium hysterophorus* L. in its compost. *Indian Journal of Weed Science* **42**: 244–245.

Mukhopadhyay, S.K. 1993. Weed research in India and future thoughts, pp. 104–109. In: *Proceedings 10th Australian Weeds Conference / 14th Asian–Pacific Weed Science Society Conference*. Brisbane, Queensland, Australia held during 6–10 September, 1993. Published by Weed Society of Queensland, Australia.

Muniyappa, T.V., Ramachandra Prasad, T.V. and Krishnamurthy, K. 1983. Biology and chemical control of *Oxalis latifolia* Linn. *Indian Journal of Weed Science* **15**: 182–187.

Murthy, M.M., Devendra, M. and Viswanath, R. 1995. Identification of suitable crop species and plant density to suppress growth of *Cyperus rotundus*. *Indian Journal of Weed Science* **27**: 222–223.

Oudhia, P. and Tripathi, R.S. 1999. A useful weed *Blumea lacera* L. – A review. *Indian Journal of Weed Science* **31**: 108–109.

Pratibha, N.C., Muniyappa, T.V., Murthy, B.G. and Shivakumar, H.R. 1994. Study on biology of *Oxalis lalifolia*. *Indian Journal of Weed Science* **26**: 132–134.

Rao, A.N., Malik, R.K., Yadav, A. and Ladha, J.K. 2014. Strengthening farmers' knowledge for better weed management in developing countries, pp. 991-405. In: Chauhan, B.S. and Mahajan, G. (eds.). *Recent Advances in Weed Management*. Springer, USA. (in press)

Rao, A.N. and Ladha, J.K. 2013. Economic weed management approaches for rice in Asia, pp. 500–509. In: Baki Hj. Bakar, Kurniadie, D. and Tjitrosoedirdjo (eds.). *Proceedings of the 24th Asian–Pacific Weed Science Society Conference* held during 22–25 October, 2013, Bandung Indonesia.

Rao, Adusumilli N. and Nagamani, A. 2013. Eco–efficient weed management approaches for rice in tropical Asia, pp. 78–87. In: *Proceedings of the 4th Tropical Weed Science Conference* 2013. Weed Management and Utilization in the Tropics held during January 23–25, 2013, The Empress Hotel, Chiang Mai, Thailand.

Rao, Adusumilli N. and Nagamani, A. 2010. Integrated weed management in India – Revisited. *Indian Journal of Weed Science* **42**(3): 1–10.

Rao, Adusumilli N. and Moody, Keith. 1988. Dissemination of weeds in rice seedlings. *Tropical Pest Management* **34**(3): 288–290.

Rao, Adusumilli N. and Moody, Keith. 1988a. Weed seed contamination in rice seed. *Seed Science and Technology* **18**: 139–146.

Rao, A.N., Mortimer, A.M., Johnson, D.E., Sivaprasad, B. and Ladha, J.K. 2007. Weed management in direct–seeded rice. *Advances in Agronomy* **93**: 155–257.

Raju, R.A. and Reddy, M.N. 1999. Autecology of purple nutsedge (*Cyperus rotundus* L.) in sub–humid Godavari delta. *Indian Journal of Weed Science* **31**: 47–49.

Raju, R.A. and Reddy, M.N. 1999a. Autecology and biology of barnyard grass (*Echinochloa* spp.) in wetland rice fields. *Indian Journal of Weed Science* **31**: 167–171.

Rajkhowa, D.J. 2008. Utilization of weed biomass for nitrogen substitution in rice (*Oryza sativa*) – rice system. *Indian Journal of Weed Science* **40**: 27–32.

Rana, N.S., Kumar, S. and Saini, S.K. 2004. Weed management in spring sugarcane-based intercropping systems. *Indian Journal of Weed Science* **36**: 68–72.

Sharma, C.K. and Gautam, R.C. 2006. Effect of tillage, seed rate and weed control methods on weeds and maize (*Zea mays* L.). *Indian Journal of Weed Science* **38**: 58–61.

Sharma, B.C., Kumar, A. and Gupta, S.K. 2012. Management strategies for rehabilitation of *Lantana* infested forest pastures in Shivalik foothills of Jammu & Kashmir. *Indian Journal of Weed Science* **44**: 38–42.

Singh, R. 2006. Effect of cropping sequence, seed rate and weed management on weed growth and yield of Indian mustard in Western Rajasthan. *Indian Journal of Weed Science* **38**: 69–72.

Singh, S. and Punia, S.S. 2008. Effect of seeding depth and flooding on emergence of *Malva parviflora*, *Rumex dentatus* and *R. spinosus*. *Indian Journal of Weed Science* **40**: 178–186.

Singh, R.D. and Ghosh, A.K. 1992. Effect of temperatore and sowing date on germination and infestation of wild oats. *Indian Journal of Weed Science* **24**: 42–48.

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

Singh, B. and Rana, N.S. 2003. Effect of weed management practices on weeds, soil micro flora and yield of sugarcane ratoon. *Indian Journal of Weed Science* **35**: 77–81.

Singh, S. and Lall, A.C. 2001. Studies on technological gaps and constraints in adoption of weed management practices for rice–wheat cropping system. *Indian Journal of Weed Science* **33**: 116–119.

Singh, T. and Singh, K.S. 1992. Growth behaviour of *Ischaemum rugosum* Salisb. (Wrinkle grass) in competition with transplanted paddy. *Indian Journal of Weed Science* **24**: 59–61.

Singh, R.P., Singh, R.K. and Singh, M.K. 2011. Impact of climate and carbon dioxide change on weeds and their management – A review. *Indian Journal of Weed Science* **43**: 1–11.

Singh, V.P., Kumar, A. and Banga, B. 2010. Current status of zero tillage in weed management. *Indian Journal of Weed Science* **42** (Supplement): 1–9.

Singh, M.K., Singh, R.P. and Singh, N.P. 2002. Methods to study crop weed competition experiments – A review. *Indian Journal of Weed Science* **34**: 264–268.

Singh, C.M., Mohanty, R.K. and Kumar, S. 1992. Biology and control *Eupatorium adenophorum* in Himachal Pradesh. *Indian Journal of Weed Science* **24**: 62–64.

Singh, T., Kolar, J.S. and Bhatia, R.K. 1991. Emergence behaviours of *Ischaemum rugosum* (Wrinkle Grass) as affected by variable temperature, submergence period and depth of seed placement in the soil. *Indian Journal of Weed Science* **23**: 56–60.

Sivasubramaniam, K. and Vijayalakshmi, V. 2012. H_2O_2 induced seed viability assessment of Asian spider flower. *Indian Journal of Weed Science* **44**: 191–192.

Subramanian, E. and James, M.G. 2006. Effect of chemical, cultural and mechanical methods of weed control on wet seeded rice. *Indian Journal of Weed Science* **38**: 218–220.

Sivasubramaniam, K. 1996. Determination of *Trianthema* soil seed bank using tetrazolium staining pattern. *Indian Journal of Weed Science* **28**: 107–108.

Sushilkumar. 2011. Aquatic weeds problems and management in India. *Indian Journal of Weed Science* **43**: 118–138

Sushilkumar. 1993. Biological control of problematic weeds of forests and wastelands in India. *Annals of Entomology* **11**: 77–97.

Sushilkumar and Varshney, Jay G. 2010. *Parthenium* infestation and its estimated cost management in India. *Indian Journal of Weed Science* **42** (Supplement): 73–77.

Tiwari, J.P. and Bisen, C.R. 1984. Ecology of *Parthenium hysterophorus*. *Indian Journal of Weed Science* **16**: 203–206.

Tripathi, B., Barla, A. and Singh, C.M. 1991. Carrot weed *P. hysterophorus* (L.) – overview of the problems and strategy for its control in India. *Indian Journal of Weed Science* **23**: 61–71.

Umarani, R. and Selvaraj, J.A. 1994. Studies on dormancy and germination of *Trianthema portulacastrum*. *Indian Journal of Weed Science* **26**: 82–88.

Verma, S.K., Singh, R.P. and Singh, R.K. 2007. Performance of varieties and herbicides on production potential of wheat (*Triticum aestivum* L.) and associated weeds. *Indian Journal of Weed Science* **39**: 197–200.

Walia, U.S., Gill G., Walia, S.S. and Sidhu, A.S. 2010. Competitive ability of rice genotypes against weeds in direct seeding production system. *Indian Journal of Weed Science* **42**: 32–34.

Walia, U.S. and Brar, L.S. 1996. Performance of new herbicides for controlling wild canary grass (*Phalaris minor*) in wheat. *Indian Journal of Weed Science* **28**: 70–73.

Yadav, S.K. and Singh, G. 2005. Studies on the depth and periodicity of *Phalaris minor* emergence in wheat under different crop establishment methods. *Indian Journal of Weed Science* **37**: 29–32.

Yadav, R.S., Sharma, S.K., Poonia, B.L. and Dahama, A.K. 2004. Selectivity and phytotoxicity of oxadiargyl on cumin and weeds and its residual effect on succeeding mothbean and pearlmillet. *Indian Journal of Weed Science* **36**: 83–85.

Yaduraju, N.T. 2012**.** Weed management perspectives for India in the changing agriculture scenario in the country**.** *Pakistan Journal of Weed Science Research* **18**: 703–710.

Yaduraju, N.T. and Rao, Adusumilli N. 2013. Implications of weeds and weed management on food security and safety in the Asia–Pacific region, pp. 13–30. In: Baki Hj. Bakar, Kurniadie, D. and Tjitrosoedirdjo, S. (Eds). *Proceedings of the 24th Asian–Pacific Weed Science Society Conference* held during 22–25 October, 2013, Bandung Indonesia.

Yaduraju, N.T., Prasad Babu, M.B.B. and Chandla, P. 2006. Herbicide use, pp. 192–210. In: Swaminathan, M.S. and Chadha, K.L. (Eds.). *Agriculture and Environment*. Malhotra Publishing House, New Delhi, India.

Yaduraju, N.T., Ahuja, K.N., Das T.K., Singh, D.K., Seema, Tomar, Savita and Kumar Sudhir. 1999. Screening wheat cultivars against post-emergence herbicides used for controlling herbicide resistant population of *Phalaris minor*. *Indian Journal of Weed Science* **31**: 93–94.

Zimmerman, P.W. and Hitchcock, A.E. 1942. Substituted phenoxy and benzoic acid growth substances and the relation to physiological activity. *Contribution from the Boyee Thompson Institute* 12: 321–343.

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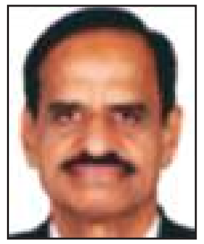

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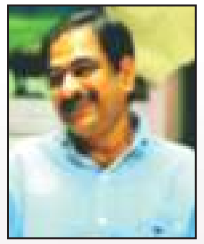

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Development of weed management research in India – retrospect and prospect

V.N. Saraswat

The concept of weed management developed with the efforts man made to cultivate food crops. It was soon realized that the crops grown in weed–free conditions produced higher yield in contrast to those grown in mixed population, and thus system of monocropping was developed. The undesirable plants were considered weeds. In the beginning, cultivation of crops comprised of collecting foodgrains from the mixed population and eliminating undesirable vegetation by hand pulling from naturally growing food crops. The practice of collecting foodgrains, especially rice, from mixed population in lowland conditions still exists in certain parts of India. The system of scattering seeds both on marginally tilled lands before rains and harvesting the crops at maturity, irrespective of food and fibre crops is also practiced under certain conditions. However, man's struggle continued to combat weeds from crop fields from the dawn of civilization for higher production. Macreist (1964) has indicated that the history of crop–weed association and efforts to eliminate the weeds from crop field was as old as the human civilization. Since 10,000 BC, Hay (1974) identified the stages in evaluation of weed management practices as: (i) 10,000 BC – removing weeds by hand, (ii) 6,000 BC – the use of primitive hand tools to till the land and destroy the weeds, (iii) 1000 BC– animal powered drawn implements i.e. hoes, harrows, ploughs etc., (iv) 1820 AD – mechanically – powered implements like blades, different types of improved ploughs cultivators etc., (v) 1920 A.D. biological control, and (vi) 1947 AD – chemical weed control, with commercial development of organic herbicides like 2,4–D and MCPA.

The use of herbicides has revolutionized agriculture in several western countries. The impact is also seen in India, especially in north and north–western states and in plantation crops, where labour is scarce and costly. However, a combination of cultural, mechanical or chemical methods may make the operation more effective, less cumbersome and economical, irrespective of field and plantation crops or different water bodies. The practice of weed management includes not only the control measures but also preventive measures, to reduce weed infestation. A successful weed management system takes into consideration various crops in rotation and the centre or surrounding area to combat the problem effectively.

The system of weed management is more relevant to agriculture in India and other developing countries where efforts are being made to adopt intensive agriculture and avoid hazards due to excessive use of chemical control measures. The success of system depends on preventive and cultural practices, viz. good land preparation, use of weed free crop seeds, quick and fast growing crops, genotypes having better canopy than weeds so that it may not allow weed to establish, proper placement of fertilizers and correct time of irrigation to give advantage to crops, higher plant population, check production of weed seed both in cropped and uncropped lands and use of pre–plant and pre–emergence herbicides followed by post–emergence operations, *viz.* mechanical or chemical weeding or manual weeding or growing intercrops, wherever possible for suppressing further emergence of weeds. However, in special cases viz. deep rooted perennial weeds, or other problem weeds, the operations like cheeling, mowing, burning, flooding, mulching or growing competitive crops and/or changing crop rotations may be adopted. The idea of weed management is to shift the balance in favour of crops by suppressing weed right from land preparation and sowing of crops till it is harvested, for higher production and reducing the cost on cultivation.

Integrated weed management is not new in agriculture; the farmers have used combination of some methods since man first started growing the crops. New methods have been introduced and old methods have been improved but none have been discarded. The farmer has to choose which combination under what situation suits him better to get maximum benefit in terms of effectiveness, economics and crop yields. In the weed management system, the concept is to maintain crop surroundings free from weeds by employing both preventive and control measures through a combination of suitable methods. This is to be taken up in a coordinated basis on a single species or a complex of weed flora (Rao, 1989). Integrated weed management (IWM) strategy relies on different control measures. The fundamental principle is to deprive weeds of the possibilities of developing strong points. The practical steps taken in the field, whether in the growing crop or in fallow period between crops, should be adjusted to actual situation to obtain optimal effect on weeds to the benefit of the crop with minimum risk to the farmers, as well as the environment. Here, efforts have been made to review the developments made in the weed management research in India during the last 50 years.

Development of weed management technology in India

As weed infestation began to reduce crop production, methods were developed to combat these unwanted plants through preparatory cultivation, crop rotation, intercropping, growing leguminous crops and interculture practices. In eighteenth century, Jethro Tull (1731) introduced row-crop culture which enabled growing crops successfully in weed free environment. In eighteenth and nineteenth centuries, early mechanization in agriculture, enabled man to keep up food production with increasing population, especially in the western countries.

The use of chemicals such as salts and various industrial byproducts have been used to control weeds on road sides and path ways. However, the use of chemical weed control started in 1886 when Bordeaux mixture was used. Later, sulphate of ammonia, zinc, iron and other metals were used by Bonnet, a French grape grower. Copper sulphate was introduced as selective weed killer in cereal crops, in quick succession in 1887 by a French farmer. Martin of Port d'Andres and Duclos in same year used sulphuric acid, ferrous sulphate and copper nitrate with good results (Bissey and Butler, 1930). Bolley (1908) compared copper sulphate, sodium arsenate and arsenate and found that copper sulphate and sodium arsenate were more useful but sodium arsenate was used extensively for many years in sugarcane and other crops in a number of countries. However, due to high mammalian toxicity, its use was discontinued.

The introduction of first organic chemical, DNOC (2–methyl 4–6–dinitrophenol) in 1932 and a few years later the important discovery of 2,4-D brought revolution in selective control of weeds in several crops and have been used now for many years. Non–selective and later selective residual herbicides such as substituted phenylurea and triazines and non–residual chemicals like diquat and paraquat are being used widely all over the world.

The history of success of biological control begins with control of weeds with certain bioagents. In Australia, prickly pears infested area was cleared using *Cactoblastis cactorum*. At present in Australia only occasional plants and few longer patches of prickly pear can be seen. Other good examples of control of weeds through bioagents is of alligator weed (*Alternanthera philoxeroides*) using flee beetle larvae (*Agasicle hygrophyla*) which has cleared larger aquatic bodices in USA.

In India, manual and mechanical methods of weed control have continued to be the mainstay irrespective of field, orchard, plantation or vegetable crops till recently. However, with the advent of line sowing in 1955–56, a number of mechanical devices and bullock drawn implements are being used for interculture and weeding operation throughout India. In recent years, due to literacy, migration from village to urban areas and change in socio–economic system, there has been scarcity of labour for timely weed control. Further, rise in price and near impossibility of distinguishing morphologically identical crop and weed plants, herbicides like isoproturon, butachlor and 2,4–D have become mainstay of wheat and rice cultivation not only in Punjab and Haryana but also in Jammu & Kashmir, western Uttar Pradesh, Karnataka, Rajasthan, Tamil Nadu etc.

A number of herbicides like triazines, ureas, phenoxy compounds have been tested as far back as in 1952 at Tocklai Experimental Station, Jorhat (Assam) and paraquat was introduced commercially in mid–sixties for controlling weeds in tea gardens. This gave the necessary impetus for growth of herbicide use till 1977 (Rao, 1986). Later, MSMA and DSMA were largely used in tea gardens till year 2000. The use of glyphosate in tea gardens and other perennial crops to control problematic weeds has become mainstay all over India. However, use of herbicides got its momentum only after 1971 when farmers of Punjab and Haryana began using herbicides like metoxuron, methabenzthiazuron and triallate to control problem weeds like canary grass (*Phalaris minor*) in wheat and butachlor to control *Echinochloa crusgalli* / *E. colona* in rice. The national market of herbicides was around 2,430 metric tons of technical material (5.9 million kg/litres of formulation) in 1984–85 with a total value of about Rs 610 million. However, consumption has increased to 4730 metric tons during 1989–90 and to 7620 m t in 1994–95. The crops which account for 95% of the market are wheat, rice and tea in that order.

Not much work was done in India on biological control of weeds before 1980. However, during nineties about 40,000 weevils of *Cyrtobagous salviniae* were released in different parts of *Salvinia* infested sites in Kerala. The weevils established itself at all sites of release and a number of ponds and canals have been cleared in 14 months after release. It has also spread into the nearby rice fields and is controlling weeds. A total number of 5000 exotic weevils of *Neochetina* *eichhorniae* and *N. bruchi* were released in different ponds in Bangalore for controlling Water hyacinth (*Eichhornia crassipes*). An exotic beetle, *Zygogramma bicolorata*, involving the use of large cages for mass production of beetle has also been released for controlling weeds from arable lands in some parts of India (Annual Reports, AICRP BCC P&W and NRCWS).

The grass carp (*Ctenopherygodons idella*) is commonly used for clearing weed in ponds in India. The silver carp (*Hypophthalmichthys molitrix*) and common carp (*Cyprinus carpio*) are also great consumers of blooming phyto-planktons and scummy algaes and are used in different aquatic situations.

Recently, the integrated methods of weed management in different crops and cropping systems developed under the All India Coordinated Research Programme on Weed Control at various agricultural universities, and crop institutes and Directorate of Weed Science Research are being passed on to the farmers through different extension agencies for adoption. Besides, the chemical weed control schedule is being developed and tested at various locations throughout the country for different cereals, fibres, oilseeds, pulses, vegetables and also plantation crops. These have been recommended for adoption by the farmers throughout the country and are in use.

Development of Weed Science Research

The history of modern weed science research started way back in 1908, when selective action of copper sulphate as herbicide was recognized. The prophecy came true with the discovery of 2,4-D and its field application in 1944, which revolutionized agriculture. Prior to that, there was not much attention given towards this multidisciplinary science involving disciplines like taxonomy, ecology, agronomy, physiology, microbiology, biochemistry, residue chemistry and engineering. Though the science is at its beginning, however, a spectacular progress has been made through scientific research as evidenced by the availability of wide spectrum of herbicides and technology for weed management.

In India, chemical weed control can be said to have begun in 1937 in Punjab, when sodium arsenate was first used to control *Carthamus oxyacantha*. In 1948, 2,4-D was introduced in India, and since then a number of herbicides have been introduced and tried and some of them were quite effective in controlling certain weeds (Mani, 1977). A number of herbicides like triazines, urea and phenoxy compounds have been tested far back in 1952 at Tocklai Tea Experimental Station, Jorhat (Assam). In the same year, the Indian Council of Agricultural Research sanctioned a total number of thirteen schemes for testing field performance of weed killers in crops like rice, wheat and sugarcane in the first instance. The states covered in this programme were Tamil Nadu, West Bengal, Punjab, Maharashtra, Andhra Pradesh, Rajasthan, Kerala, Madhya Pradesh, Uttar Pradesh, Jammu and Kashmir, and Assam. The main objective of this scheme was to investigate the weed flora of a region in the major crops, relative efficiency of herbicides and economics in their use in terms of increase in yield and their superiority or otherwise over manual and mechanical methods. The overall impact of the scheme in Indian agriculture remained marginal.

The different agriculture departments of the states, agricultural universities and crop institutes of ICAR have carried out research with a numbers of herbicides despite their being unavailable commercially in the country. However, surveying weed flora and screening and testing of herbicides for individual crops, remained the main concern of the Institutes for about 25 years till 1978. This also lacked the follow up action as the state governments did not realize the importance of herbicides in agriculture production in the country. The use of herbicides for weed management got its momentum only after 1970, when the farmers of Punjab and Haryana began using more herbicides.

With growing interest in weed research, the Indian Society of Weed Science was founded in 1968 at Haryana Agricultural University, Hisar by collective efforts of many Professors, especially by Dr. M.K. Moolani and Dr. Jai Prakash from HAU, Hisar and with a limited number of other scientists to advance the development of weed science in India. Individuals like Dr. H.R. Arakari, former Vice–Chancellor, UAS, Bangalore, from very beginning took active interest in weed control and contributed as a founder member which led to early development of weed science. In early eighties, the work on weed ecology and control which included extensive survey of weed flora and the ecology of jute and screening and testing of herbicides in collaboration with USDA by Dr. Bibhas Ray and Dr. V.N. Saraswat. In the year 1932, in South India a manual on weeds was published. Later Dr. C. Thakur (1953) published a book on Weed in Indian Agriculture. Amongst the latter publications the book "Weed Science" by Dr. C. Thakur, Dr. O.P. Gupta, Dr. N.C. Joshi and Dr. V.S. Rao, and lately "Weed Management" by Dr. Saraswat *et al.* are worth mentioning.

With the modest progress of weed science, education and research, the historical conference of weed science was held in 1977 at Andhra Pradesh Agricultural University, Hyderabad. The main objective of the conference was to review the advances made in weed science and to define future work priorities to meet the new challenges of increasing food production. It was also aimed to develop a weed science curriculum in Agricultural Universities. A number of scientists and teachers from various Universities and Institutions presented technical papers which included Prof V.S. Mani, Dr. K.C. Gautam and Dr. (Mrs.) Geeta Kulshrestha from IARI, New Delhi; Dr. P.S. Lamba from Rajasthan University, Udaipur; Dr. K. Krishnamoorti, UAS, Bangalore; Dr. N.C. Joshi, Central Plant Protection Training Institute, Hyderabad; Dr. H.R. Arakari and Dr. M.K. Hosmani, UAS, Bangalore; Dr. H.S. Gill, PAU, Ludhiana; Dr. V.S. Rao, Tocklai Experimental Station, Jorhat; Dr. S.K. Mukhopadhayay, Vishwa Bharati, Sriniketan; Dr. S. Sankaran, Tamilnadu Agricultural University, Coimbatore; Dr. K.C. Sharma and Dr. V.M. Bhan, GBPAU&T, Pantnagar; Dr. V.N. Saraswat and Dr. D.K. Biswas from Agricultural Research Institute, Barrackpore; Dr. Bibhas Ray, from Chemicals Ltd. Bombay etc. The foreign delegates who presented lead papers were: Dr. C. Parker, ARC–WRO, Oxford, U.K.; Dr. B.A. Krantiz, ICRISAT, Hyderabad; and Dr. S.S. Obien, FAO Agriculture office, CPPTI, Hyderabad.

Recommendations made by the workshop in the curriculum for B.Sc. (Ag.), M.Sc. (Ag.) and Ph.D. level were accepted by many agricultural universities and future directions given for weed research were adopted by many researchers working in different ICAR Institutions and other organizations. It was also proposed that ICAR should establish a National Research Institute for Weed Science at the earliest to take up research on basic aspects of weed science and monitor research programmes in the country.

Weed research, however was not fully developed up to 1978 in India. It lacked studies on various aspects of weed science viz. weed biology and ecology, herbicides physiology, residue estimation and management herbicide application devices, adjuvant and antidotes etc. The research programme on weed control, however was strengthened through the All India Coordinated Research Project on Weed Control through a negotiation between Indian Council of Agricultural Research and United States Department of Agriculture at six coordinating centres, viz. PAU, Ludhiana (Punjab); HPKV, Palampur (H.P.); JNKVV, Jabalpur (M.P.); UAS, Bangalore (Karnataka) and IIT, Kharagpur (W.B.) and the coordinating cell was attached with Central Rice Research Institute, Cuttack (Odisha). The work was initially supervised by Dr. H.K. Pandey, Director, CRRI, Cuttack as Project Coordinator. The technical guidance was provided by Dr. Robert N. Anderson and Dr. R.D. Comes both weed specialists for USDA. Later Dr. V.N. Saraswat, Project Coordinator was directed to monitor the programme in the initial stages, the thrust given was on surveying weed flora of different regions and evolving effective, economical and safe weed control measures for various field and vegetable crops and improving fertilizer efficiency through pre–plant and pre–emergence herbicides.

Based on excellent performance of the first phase centres, the activities of the project were further extended during 1982 at seven more centers, viz. AAU, Jorhat (Assam); MAU, Parbhani (M.S.); GAU, Anand (Gujarat); NDUA&T, Faizabad (U.P.); IIHR, Bangalore (Karnataka); IGFRI, Jhansi (U.P.) and TNAU, Coimbatore (T.N.) to take up research on vegetable and fodder crops besides cereals, pulse and oilseed crops, for a period of 5 years.

Based on the gaps identified and information generated in the initial stage of the project relatively greater emphasis was laid on integrated weed management in (i) lowland rice and rice based cropping systems, (ii) vegetable crops, (iii) fodder–pasture cropping system, and (iv) the inter/mixed and multiple cropping system. Each of these aspects, besides typical problems of the concerned regions, was also dealt by each of the first and second phase centres of the project. The first and second phase centres, however, were strengthened during VII Plan by providing specialists in agronomy, weed ecology and taxonomy, residue estimation and management and weed physiology to take up research programmes in their respective disciplines. While the Indian Institute of Technology, Khargpur was provided additional scientific staff and technical positions of engineering to take up more work on designing and development of weed control tools/implements both for terrestrial crops and aquatic systems, provisions were also made to provide sufficient funds to each centre for purchasing essential equipments. The activities were further extended covering nine more centres, viz. BAU, Ranchi Bihar; HAU, Hisar (Haryana); V.B. Srinikatan (W.B.); RAU, Pusa (Bihar); CSAUA&T, Kanpur (U.P.); KAU, Trichur (Kerala); OUA&T, Bhubaneswar (Odisha); ANGRAU, Hyderabad (A.P.)

and ICAR Research Complex, Shillong (Meghalaya), with a fresh negotiations with USDA for a period of four years – 1986 to 1990 to take up research on programmes identified in different multi crops.

During the period from 1984 to 1992, the annual workshops of the AICRP–Weed Control and conferences of the Indian Society of Weed Science were arranged to review the progress of research done during the preceding years on different aspects of weed science and to work out the technical programme for the ensuing years. The emphasis, however, was given to compile the whole work done as weed survey in various agro–climatic zones, integrated weed management in different crops/cropping systems and intercropping systems, studies on biology and control of problem weeds, herbicide residue estimation and management, physiological aspects i.e. allelopathic effect of weeds on weed and crops, and to design and develop different types of weed control tools/implements, spraying equipments, power operated aquatic weeders etc. A number of training programmes were also arranged to impart training in herbicide residue estimation at Coromandal Indag, Madras. Central Rice Research Institute, Cuttack and Tamil Nadu Agriculture University, Coimbatore (T.N.). One international workshop i.e. Indo–Pak–U.S. workshop was arranged at Agricultural Experimental Station, Jaipur during 1986 and another at Pakistan Agriculture Research Council, Islamabad during 1987 with the assistance from FERRO, USDA to interact with the scientists of other countries and to improve the research programme in weed science and in turn to develop best technology for the country. The expert assistance from USA was given by Dr. Robert N. Anderson and Dr. R.D. Comes. Amongst the other important scientists who participated in both the programmes were Dr. O.P. Gupta, Dr. V.M. Bhan, Dr. S.K. Mukhopadhyay and Dr. K.C. Gautam. The entire programme was monitored by Dr. V.N. Saraswat, Project Coordinator, AICRP–Weed Control, based at Central Rice Research Institute, Cuttack (Odisha).

Later in the VII Plan, a National Research Centre for Weed Science was proposed, which ICAR approved. A team of scientists, *viz.* Dr. O.P. Gupta, Dr. S. Sankaran, Dr. S.K. Mukhopadhyay, Dr. V.M. Bhan and Dr. V.N. Saraswat as its Member–Secretary was approved by ICAR to finalize a suitable site to establish the centre. The team visited different states to find out the best location for establishment of the centre to take up basic research on different aspects of weed science and to coordinate the research programme operating in different states. The team visited Uttar Pradesh, West Bengal, Orissa, Tamil Nadu, Rajasthan, Madhya Pradesh etc. The present site was recommended by the committee and the land of 160 acres was taken over from Jawaharlal Nehru Krishi Vishva Vidyalaya on 1st January, 1990 to establish National Research Centre on Weed Science. The centre initially operated in hired or temporary buildings till the new building was occupied on 1st January, 2000. Later, the formal inaugural function was held. During this period, Dr. V.M. Bhan, Dr. V.N. Saraswat, Dr. N.T. Yaduraju and Dr. Jay G. Varshney, supervised and guided the research programmes as its Directors. Presently, Dr. A.R. Sharma is guiding the research activities of the Directorate. The Directorate, today is having well–established laboratories to take up basic research programmes on residue estimation and management, weed ecology/biology, taxonomy, agronomic research, workshop to design and develop weed control tools and implements, biological control of weeds, extension activities and competent scientists to impart training in above disciplines.

Research achievements

During this long period stated above, research activities on weed science in a coordinated manner were initiated in three phases with assistance from USDA. The work done on different aspects of weed science viz. weed surveys, weed biology, standardizing weed management practices were compiled and printed in consolidated reports for that period i.e. 1st phase 1975–1984; 2nd phase 1982–1987 and third phase 1986–1990. The major weeds identified, region wise and the weed management practices developed were passed on to farmers through different extension agencies of the Agricultural Universities and State Departments. The scientific papers were published in different journals by individual scientists all over the country. However, based on data generated during 1978–1987 on different aspects of weed management both under AICRP–Weed Control and elsewhere losses in yield in cereal, pulse, oilseed, fibre and other commercial crops were computed. Results indicated that yield losses were maximum is unweeded crop which varied from 16.9% in transplanted rice to 56.5% in pearlmillet, which was very less in manual weeded and chemical weeded crops as compared to completely weed free conditions (Table 1). The losses in other crops like oilseeds were up to 71.2%, pulses 38.8% and commercial crops 50.4% (Sahoo and Saraswat, 1988).

Table 1. Average yield (t/ha) under different weed management practices in major cereal crops

Crop	Weed free	Chemical control	Manual weeding once or twice	Unweeded	Integrated chemical manual and/ or mechanical
Wheat	3.76	3.47	3.54	2.78	3.74
Rice (Transplanted)	4.37	4.41	4.41	3.74	4.52
Rice (Direct-seeded)	1.78	1.22	1.50	0.94	1.74
Maize	4.12	4.43	4.06	2.45	4.12
Sorghum	1.85	1.66	1.72	1.02	1.86
Pearlmillet	1.12	1.10	1.12	4.88	1.13

The complete data on distribution of weeds generated during 25 years in the All India Coordinated Project on Weed Control has been complied region-wise separately for *Kharif / Rabi* season crops, orchard and plantation crops, waste and vacant land and other problematic weeds were identified (Saraswat, 1993 and 1998).

The exhaustive work done both at the Directorate and at different coordinating centres on evaluation of herbicides has been published separately region wise by individual scientists. However, the complied information is given in Table 2.

Table 2. Herbicides for different field, vegetables, orchard and plantation crops during 1978

Crop	Herbicides identified
Rice (upland)	Thiobencarb, oxadiazon, butachlor, benthiocarb, pendimethalin, propanil, butachlor, 2,4-DEE, nitrofen, monilate and piperophos
Rice (lowland / transplanted)	Butachlor, piperophos, butachlor + 2,4-DEE, pendimethalin, oxadiazon, benthiocarb, propanil, nitrofen and anilophos + 2,4-D
Wheat	Isoproturon, metaxuron, trillate, chlorobutron, 2,4-D Na salt, methabenzthiazuron, fluroxypyr, tralkoxydim and tralkoxydim + 2,4-D
Maize	Simazime, cynazine, atrazine, pendimethalin and metolachlor
Pearlmillet / sorghum	Atrazine, simazine and cynazine, , fluazifop–p–butyl, imazethapyr, pendimethalin, alachlor, oxyfluorfen, butachlor, phenoxy propethyl and terbutyn
Groundnut	fluchloralin, nitrofen, alachlor
Soybean	Metolachlor, fluchloralin, metribuzin, dimethazon, sethoxydim, haloxyfop–methyl, butachlor, oxyfluorfen and fluazifop–p–butyl
Sesamum	Alachlor, fluchloralim, butachlor, thiobencarb and nitrofen
Sunflower	Pendimethalin, fluchloralin, oxadiazon and metolachlor
Castor	Pendimethalin, metolachlor and fluchloralin
Linseed	Isoproturon, methabenzthiauron, diclofop–methyl and alachlor
Rapeseed and mustard	Isoproturon, metoxuron, alachlor, pendimethalin, haloxyfop–methyl, biofenox and oxadiazon
Lentil and gram	Oxyfluorfen, fluchloralin, pendimethalin, isoproturon, metribuzin, linuron, trifluralin and terbutryn
Cowpea, chickpea, pea and cotton	Bentazon, fluchloralin, prometryn, metribuzin, metoalachlor and linuron, fluchloralin, oxyfluorfen, oxadiazon and pendimethalin
Jute and mesta	Fluchloralin, MSMA (directed application), tetraprion, dalapon, dalapon + MSMA and fluazifop–p–butyl
Sugarcane	Atrazine, metribuzin, diuron, butachlor + 2,4-D
Coffee and tea	Dalapon, paraquat, glyphosate, dalapon + 2,4-D, glyphosate + diuron, haloxyfop–methyl, glyphosate + uphar (surfactant)
Potato	Oxyfluorfen, metolachlor + atrazine, fluchloralin, alachlor, methabenthiazuron, linuron and metribuzin

Besides the annual reports of the Directorate, AICRP–Weed Control reports were published each year giving details of the work done and achievements made for general information and adoption by the farmers for its use. A monograph of major weeds was also developed by the Directorate.

A summary of events governing growth of the weed management research in India since 1901 is given in Table 3.

Table 3. Events governing the growth of weed management research

Year	Events
1901–36	Manual weeding in most broadcast sown crops.
1937	Sodium arsenate, an inorganic compound was used to control *Carthamus oxycantha* in Punjab.
1947–48	2,4–D was introduced in India for selective weed control in different cereal crops.
1952	A number of herbicides like triazines, urea and phenoxy compounds were used at Tocklai Experimental station, Jorhat (Assam) and paraquat was introduced in mid-sixties to control weeds in tea.
1952–53	ICAR sponsored thirteen research schemes for testing 2,4-D for control of weeds in rice, wheat and sugarcane in Tamil Nadu, Bose Institute of Calcutta, Punjab, Maharashtra, Andhra Pradesh, Rajasthan, Uttar Pradesh, Madhya Pradesh, Kerala, Jammu& Kashmir and Assam.
1955_56	Advent of line sowing resulted in use of manual and bullock drawn mechanical devices for intercultural practice.
1953–78	Most ICAR crop Institutes and SAUs were engaged for about 25 years in screening and testing of different new herbicides despite their being non-available commercially in the market.
1966	Indian Society of Weed Science was founded at Haryana Agricultural University, Hisar
1970	The use of herbicides for weed management got momentum, when farmers of Punjab and Haryana began using more herbicides like metoxuron, methabenzthiazuron and triallate to control problem weeds like canary grass (*Phalaris minor*) in wheat and butachlor and 2,4-D to control barnyard grass (*Echinochloa colonum* and *E. crusgalli*) in rice .
1978	ICAR in collaboration with FERRO, USDA set up the All India coordinated Research Project on Weed Control at six SAUs and the coordinating unit was attached with CRRI, Cuttack to take up research on applied aspects of weed science viz. weed survey and to develop weed management practices which are acceptable to the farmers.
1980	Research work on biological control of weeds was initiated under AICRP–BCCP &W and a number a number of exotic beetles were released to control *Salvinia* sp., *Parthenium hysterophorus* and *Eichhornia crassipes* in Karnataka .
1984–87	AICRP–Weed Control was strengthened by providing specialists in agronomy, weed biology/ ecology/taxonomy, residue chemistry, weed physiology and agricultural engineering to take up research in their respective field Dr. V.N. Saraswat joined as regular Project Coordinator to monitor and guide the research programmes .
1986	Arranged International weed control workshop cum Conference viz. INDO–PAK–US workshop to expose Indian Scientists to scientists of other countries at Agricultural Experimental Station, Jaipur, Rajasthan.
1987	Indian weed scientists led by Dr. V.N. Saraswat, Project Coordinator, AICRP-WC attended PAK –INDO–US workshop–cum–conference at PARC, Islamabad, Pakistan .
1986–90	Nine more centres in different SAUs were added with assistance from USDA in the AICRP-Weed control to take up location specific research on weed management.
1987	AICRP–Weed Control becomes a regular project of ICAR with all the centres mentioned above. A National Research Centre for Weed Science was also set up by ICAR to take up research on basic research on basic aspects of weed science and to coordinate the activities of the AICRP-WC based in different agricultural universities. A total number of 84 positions of scientist, technician, supporting and ministerial staff was sanctioned, of which, 27 positions were of scientists only.
1986–87	A team, viz. Dr. O.P. Gupta, Dr. S. Sankaran, Dr. S.K. Mukhopadhyay, Dr. V.M. Bhan and Dr. V.N. Saraswat visited different states to finalize suitable locations for the establishment of the NRCWS. The team after visiting all the states finally gave recommendation for the present site.

1989–90	The present site was taken over from Jawaharlal Nehru Krishi Vishwa Vidyalaya on 1 January, 1990 in presence of Dr. V.N. Saraswat and Dr. V.M.Bhan and the research activities were initiated in hired/ temporary buildings till the new building was occupied on 1 January, 2000, when Dr. V.N. Saraswat was the Director. The building was later officially inaugurated.
1990	Dr. V.M. Bhan, Dr. V.N. Saraswat, Dr. N.T. Yaduraju and Dr. Jay G. Varshney remained Directors and presently Dr. A.R. Sharma is working as Director to guide and monitor research activities of the Institution. The centre was upgraded to Directorate in 2009. The annual report of both NRCWS/ DWSR and AICRP-WC were separately published during this period.
2000	Based on the work done on weed control, a number of publications on weed science, recommendations for weed management practices, etc. were published regularly.

References

Bissey, R. and Butler, O. 1930. *Journal of American Society of Agronomy* **22**: 124–135.

Consolidated Report (1st Phase). 1978–84 of All India Coordinated Research Project on Weed Control, AICRP–Weed Control. CRRI, Cuttack.

Consolidated Report (2nd Phase). 1982–87 of All India Coordinated Research Project on Weed Control, NRCWS. Jabalpur.

Consolidated Report (3rd Phase). 1986–90 of All India Coordinated Research Project on Weed Control, NRCWS. Jabalpur.

Hay, J.R. 1974. Grain to grower. *Weed Science* **22**: 439–442.

Jethro, Tull. 1731. *Horse Hoeing Husbandry*. Berkshire, MDCC. 33.

Mani, V.S. 1977. Weed research in India – status, problem and strategies, pp. 27–36. *Proceedings of Weed Science Conference*, ISWS.

Macreist, R.S. 1964. The origin of new world civilization. *Scientific American* **211**: 29–37.

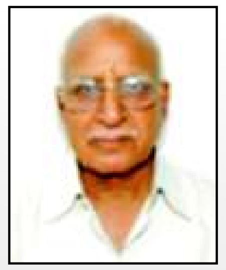
Rao, V.S. 1986. *Herbicide technology in India - retrospect and prospect*. Joint INDO–PAK–US. Workshop Conf. AES, Durgapur, Rajasthan.

Saraswat, V.N. 1993. Major weeds of Indian Agriculture, their distribution and ecology In: *Proceedings of the International Symposium on Integrated Pest Management and Sustainable Agriculture*, HAU, Hissar.

Saraswat, V.N. and Mishra, J.S. 1998. Status of weed management research in wheat. *Pestology* **XXII**(5): 5–13.

Thakur, C. 1954. *Weeds of Indian agriculture*. Motilal Banarsi Das, Patna.

About the Author



Dr. V.N. Saraswat is a reputed scientist with notable research contributions in weed management in jute and several field crops. He has been Project Coordinator, All India Coordinated Research Project on Weed Control and also served as Director, National Research Centre for Weed Science, Jabalpur during 1999-2000.

Transgenic herbicide resistance in crops: a review

V.S. Rao

Two of the greatest scientific inventions that have transformed global agriculture are the discovery of auxinic herbicides in the early 1940s and development of herbicide-resistant crops five decades later. While herbicide discovery has undoubtedly helped farmers mitigate weed problems, it challenged farmers and weed scientists by posing newer problems by way of herbicide-resistant weeds. On the other hand, development of transgenic herbicide-resistant crops has created contentious and controversial issues stemming from fierce debates on the benefits, both real and perceived, by proponents of genetically engineered crops and foods derived from them in solving world hunger as well as risks and issues that the antagonists and consumer activists point out in regard to their safety to consumers and environment. These two aspects that envelop the field of weed science are discussed in this review.

Herbicide resistance

Within four years of the widespread usage of phenoxy herbicides, beginning in 1946, Blackman [1950] had warned "…..repeated spraying with one type of herbicide will sort out resistant strains within the weed population.". This and a few other warnings were largely ignored until the first confirmed report of herbicide resistance against simazine and atrazine which failed to control *Senicio vulgaris* in 1968 (Ryan, 1970). Since then, herbicide resistance problems have accelerated, and consequently, management of weeds has become increasingly difficult and complex, and sometimes impossible.

Although herbicides have enabled farmers to raise crop yields by significantly lowering production costs, they did not make weeds extinct. Rather they, along with other influencing factors, caused a continuous selection of plants to occur and this enabled them both to survive and reproduce. Consequently, these resistant plants with survival properties were able to become dominant and be distributed over increasingly large areas worldwide.

The relatively steady increase in number of new cases of resistance since 1980 accounts for the increasing importance of herbicide resistance in weeds. During the period between 1970 to 1990, most documented cases of resistance were concerned with triazines. The introduction of new classes of herbicides such as acetolactate synthase and acetyl–CoA carboxylase inhibitors with different sites of action caused a significant shift. Additionally, rapid adoption of glyphosate-resistant transgenic crops in Australia, North America and South America, and the use of glyphosate as a pre-emergence herbicide in different cropping systems have resulted in increasing cases of resistance to this herbicide (Menne and Köcher, 2012). The probability of resistance development to glyphosate had been expressed as being likely, but underestimated. (Heap and Le Baron, 2001).

As of 16th December 2013, 412 unique cases (species x site of action) of herbicide resistant weeds, with 221 species (130 dicots and 91 monocots), from over 630,000 fields spread across 66 crops and cropping and non-crop situations in 61 countries have been identified to develop resistance to at least one of the 21 of the 25 known sites of action of 148 different herbicides worldwide (Figure 1) (Heap, International Survey of Herbicide Resistant Weeds, 2013). This phenomenon does not seem to end in the near future. Instead, it will continue to become a problem as newer areas and crops are brought under herbicide usage.

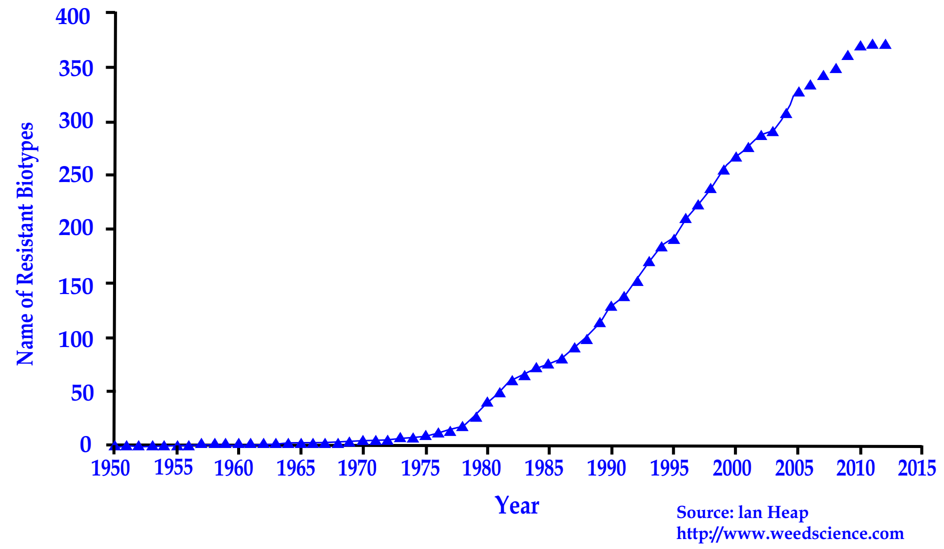


Figure 1. Worldwide rise of herbicide-resistant weeds from 1950
Source: Heap (2013)

Herbicides do not induce resistance, but they select for resistant individuals that naturally occur within the weed population. The more a herbicide is used, the greater the likelihood of encountering a resistant individual in a field. Once a resistant plant is selected, repeated use of this herbicide over multiple generations allows resistant plants to proliferate as and when susceptible plants are eliminated. Once a resistance gene has occurred within a population, failure of the herbicide can be rapid.

The two pre-requisites for evolution of herbicide resistance in plant populations include (a) occurrence of heritable variation in genetic composition for herbicide resistance and (b) natural selection for increased resistance to herbicides (Rao, 2000).

In response to repeated treatment with a particular herbicide or class (family) of herbicides, weed populations change in genetic composition such that the frequency of resistance alleles and resistant individuals increase (Jasieniuk *et al.*, 1996). In this way, weed populations become adapted to the intense selection pressure imposed by herbicides. The evolution of resistance under continuous application of a herbicide may be considered as an example of recurrent selection in which there is a progressive and sometimes rapid shift in average fitness of populations of weeds exposed to it (herbicide). This shift in fitness, a genetic trait, is directly related to an increase in frequency of the resistance trait (phenotype) in the population.

Selection intensity in response to herbicide application is a measure of the relative mortality in target weed populations and/or the relative reduction in seed production of survivors; this will be proportional, in some manner, to herbicide dose (Maxwell *et al.*, 1990). The duration of selection is a measure of the period of time over which phytotoxicity is imposed by the herbicide. Both intensity and duration will interact to give seasonal variation in the process of selection which will, in turn, depend upon the phenology and growth of a weed species. For example, in the case of pre–emergence application of a herbicide that inhibits seedling emergence over a time period, the intensity of selection may be much higher on weed seedlings emerging early in the life of a crop than those emerging later. The occurrence and speed of evolution of herbicide resistance are determined by: (a) number of alleles involved in the expression of functional resistance, (b) frequency of resistance alleles in natural (unselected) populations of weed species, (c) mode of inheritance of the resistant alleles, (d) reproductive and breeding characters of the weed species, e) longevity of weed seeds in the soil, (f) intensity of selection which differentiates resistant biotypes from susceptible ones, and (g) absolute fitness of resistance and susceptible genotypes (Rao, 2000).

There are several factors that lead to, or stimulate and accelerate, the evolution of herbicide resistance. These include biological characteristics of the weed species, characteristics and time of application of the herbicide, and cultural practices adopted for weed control.

Mechanism of herbicide resistance

The most common and important mechanisms of herbicide resistance are those which interrupt the transport of herbicides to biochemical sites of action, reduce the sensitivity of target sites, and detoxify the chemical or enhance repair that can potentially confer resistance. These include the following (Rao, 2000) :

- Sequestration or compartmentalization of the herbicide in apoplast: some plants restrict the movement of herbicides within the cells or tissues and prevent them from causing harmful effects. In this case, the herbicide may be inactivated either through binding (often to sugar moiety) or removed from metabolically active regions of the cell to inactive regions where it exerts no effect.
- Altered target site: the herbicide has a specific site of action where it acts to disrupt a particular plant process or function. If the target site is altered, it no longer binds to the site, thus becoming unable to exert its phytotoxic effect. This is the most common herbicide resistance mechanism.
- Differential uptake and translocation: in resistant biotypes, herbicides are not taken up readily due to abnormal production of foliage waxes, reduced leaf area, etc. Similarly, in resistant biotypes the apoplastic and symplastic transport of herbicide is reduced due to differential modifications.
- Enhanced metabolism: weeds that have the ability to quickly degrade a herbicide may potentially inactivate it before it reaches its site of action within the plant, thus enhancing metabolism.

- Over–expression of the target protein: If the target protein on which the herbicide acts is produced in large quantities by the plant, then the effect of herbicide becomes insignificant.
- Enhanced production of the target site: When production of the target site is enhanced, the herbicide will be unable to inactivate the enzyme. Thus, the enzyme spared by the herbicide will carry on the normal plant metabolic activities.
- Modification of cell membrane function and structure.
- Altered sensitivity of the key target enzyme caused by mutation(s).
- Enhanced metabolic breakdown and conjugation of the herbicide.
- Enhanced degradation of herbicide–generated toxic products.

These mechanisms, and consequently the expression of resistance, are controlled by genetic loci.

Inheritance of herbicide resistance

There are three modes of inheritance of herbicide resistance: nuclear inheritance, cytoplasmic inheritance, and quantitative inheritance.

Nuclear inheritance

In nuclear inheritance, the resistance–conferring alleles are transmitted through pollen and ovules. Adaptive evolution is achieved by the selection of phenotypes encoded by many genes (i.e., polygenes), each with a small additive effect. Generally, herbicide resistance is conferred by major genes present in weeds. In majority of cases where the number of genes has been determined, resistance is controlled by a single, major gene (Jasieniuk *et al.*, 1995). Resistance to most classes of herbicides is caused by nuclear inheritance. These include auxinic herbicides, aryloxyphenoxypropionics, benzoics, bipyridiliums, dinitroanilines, sulfonylureas, substituted ureas, glycines, etc.

Cytoplasmic inheritance

Cytoplasmic inheritance of resistance occurs with triazine herbicides in several weed species, the gene conferring resistance is located in the chloroplast genome (Hirschberg and McIntosh, 1983). Transmission of the chloroplast resistant gene mostly occurs by pollen, the paternal parent. For example, the mutation that confers maternally inherited triazine resistance involves a single base substitution in the *psbA* chloroplast gene which codes for a photosystem II (PS II) membrane protein to which triazine herbicides bind.

Quantitative inheritance

Quantitative patterns of inheritance occur where relative resistance is controlled by polygenes. In this, the additive action of numerous genes, perhaps minor, results in a trait (e.g., height, seed production, etc.) showing continuous variability. The different minor genes that affect several processes will rapidly add up to a high level of resistance (Neve and Powels, 2005). For instance, one gene may limit translocation of the herbicide, another may cause rapid metabolism, and yet another may affect the target site slightly (Gressel, 2009). Generally, differential resistance is quantitatively inherited.

Types of herbicide resistance

Herbicides target attack at one or more locations. These include enzyme proteins, non–enzyme proteins, cell division path, etc. For example, acetolactate synthase (ALS) enzyme is required for the first step in the synthesis of branched chain amino acids (valine, leucine, isoleucine). Herbicide families such as imidazolinones, pyrimidinyl oxybenzoates, sulfonylamino carbonyl triazolinones, sulfonylureas, triazolopyrimidines, etc., bind to this enzyme and prevent amino acid synthesis. When this happens, it leads to protein deficiency followed by death of the plant. Although the chemical structures of the above–mentioned herbicide families are different, their target site is the same. The plant that resists ALS herbicides has altered the enzyme in such a way that it does not bind with the herbicide. Now, the resistant weed biotype that has evolved by selection pressure from one ALS–attacking herbicide will be resistant to all herbicides that act on this particular site.

There are different types of herbicide resistance. These include: single resistance, multiple resistance, cross resistance, target–site resistance, and non–target site resistance.

When resistance is confined to only one herbicide or one with single site of action, it is called single resistance. In multiple–resistance, weed or crop biotype evolves resistance to two or more herbicides with different mechanisms of action and resistance. Commonly, after resistance to one herbicide chemistry has developed, the population is exposed to, and develops resistance to, a different herbicide.

In cross–resistance, plant population develops simultaneous resistance to more than one class of herbicide with similar mechanisms and sites of action. In this, herbicides of dissimilar chemistry bind to identical or overlapping domains of the same target site. Cross–resistance occurs when mutations within the target enzyme endow resistance to herbicides from various chemical classes that inhibit the target site.

When a plant becomes resistant to one herbicide, other physiological changes may occur that result in increased sensitivity to other herbicide families. The mutated, resistant plant that is more susceptible to the second herbicide displays the characteristic of negative cross–resistance. The second herbicide targets different functions of the plant. Negative cross–resistance can be a most useful preemptive, cost–effective tool for delaying the evolution of resistance as well as for resistance management, after resistant populations evolved.

On the other hand, target-site resistance to a herbicide is achieved if changes in a gene encode a structural change in its gene product (enzyme), such that the herbicide no longer binds in an inhibitory manner. Such structural change in the enzyme of a weed, occurring in target-site resistance, involves either modification by a genetic mutation of the target site enzyme or protein, or decrease in herbicide concentration at the target site.

In addition to modifications of the target site, resistance can occur through restricted transport of herbicide to target sites. Plants with a herbicide-sensitive target enzyme can survive if the herbicide only reaches its target at sub–lethal concentrations. Non-target site-resistance (NTSR) can be achieved by rapid metabolism of a herbicide to non-toxic products. Enhanced metabolism is most often catalyzed by cytochrome P450-dependent microsomal oxidases acting on herbicides as substrates.

Non–target site cross-resistance (NTSCR) is defined as cross resistance to dissimilar herbicide classes conferred by a mechanism(s) other than resistant enzyme target sites. It is often referred to as metabolic resistance. Certain weed biotypes of *L. rigidum* exhibit enhanced rates of herbicide metabolism, mediated by microsomal oxidases. In such cases, the degree of resistance at the whole plant level, while being sufficient to provide resistance at the recommended rates is much less than that conferred by the target-site cross-resistance mechanism.

Transgenic herbicide resistance

Humans are known to have altered the genomes of plant species for thousands of years, first through domestication followed by selection and relatively recently, by adopting cross hybridization techniques and mutagenesis to evolve more useful and productive cultivars. Every step involved a change in genetic composition and manipulation of genes, by choice or otherwise, to improve quantitative and qualitative traits. However, direct manipulation of DNA outside breeding and mutations has begun only since the 1970s.

In transgenic engineering, an exogenous gene, called transgene, is introduced into a living organism which will now exhibit a new property and transmit that property to its offspring. In this process, a segment of DNA containing a gene sequence is isolated from an organism or a plant and introduced into a different organism or plant. This non–native DNA segment may retain the ability to produce RNA or protein in the transgenic plant, or it may alter the normal function of the transgenic plant's genetic code.

Success in creating a transgenic mouse by introducing foreign DNA into its embryo in 1974 by Rudolf Jaenisch, a biologist at MIT, USA (Jaenisch and Mintz, 1974), production of a human protein, somatostatin (a human growth hormone-releasing inhibitory factor), in *E. coli* in 1977 by American biotech giant Genentech and production of genetically engineered human insulin in 1978 (Goeddel *et al.*, 1979) encouraged plant molecular biologists to isolate one or more specific genes from non–plant sources and introduce them into plants.

Engineering herbicide resistance

Herbicide resistance (“tolerance” being the apt word) is one of the first traits engineered into plants. This was made possible by rapid advancement in the knowledge of herbicide mechanisms, availability of genes for transfer, engineering methodologies, adopting herbicide genes as markers to select transformed tissues, and the commercial interest in such a trait for agro-biotech companies and farmers. With the development of transgenic herbicide-tolerant

(THT) crops, plant scientists have taken a giant step by moving away from linking chemistry of a herbicide to biology to adapting biology to chemistry.

Generally, there are two approaches in transgenic engineering for herbicide tolerance. One is the modification of a plant enzyme or other sensitive biochemical target of herbicide action to render it insensitive to the herbicide, or to induce the overproduction of the unmodified target protein permitting normal metabolism to occur. The other approach is the introduction of an enzyme or enzyme system that degrades or detoxifies the compound in the plant before herbicide reaches the site of action. Plants modified by both approaches may be obtained either by selection for resistance against a specific herbicide or by applying gene transfer techniques utilizing genes encoding herbicide resistance determinants.

The first THT crop variety to be released commercially was the bromoxynil-tolerant "BXN" cotton line developed in 1994 by Calgene and Rhône–Poulenc. Since then, scores of THT crop events continued to be released. Besides those in cotton, transgenic events were developed in crops like maize, soyabean, oilseed rape (canola), tobacco, rice, wheat, sugarbeet, potato, sweet potato, sunflower, linseed (flax) and lucerne (alfalfa). Genes used to transfer resistance traits belonged to glyphosate, glufosinate, bromoxynil, imidazolinones, sulfonylureas, sethoxydim, 2,4 D, dalapon, dicamba, atrazine, phenmedipham, paraquat, etc. Initially, transgenic engineering was used to generate plants that made greater than normal amounts of herbicide genes, with the expectation that they would withstand higher doses of herbicides than non–targeted plants. Later, some of these lines were modified to introduce higher tolerance level to the same herbicide or tolerance to a second and third herbicide, or to provide farmers more flexibility and options in weed management.

Initially, transgenic events or lines were developed to carry mono-traits in which a single trait is inserted into the plant as in the case of resistance to herbicides, insects, diseases, etc. Later, biotechnologists began pyramiding two or more traits in a single plant. In this, two or more genes that code for proteins having different modes of action are stacked in the plant. Compared to mono-trait crop varieties, multi-trait stacks offer broader agronomic enhancements that allow farmers to meet their needs under complex farming conditions. Biotech stacks are engineered to have better chances of overcoming the myriad of problems in the field such as weeds, insect pests, diseases, and environmental stresses so that farmers can increase crop productivity.

After two decades of producing THT crops, glyphosate-tolerant crops constitute 80 percent of all transgenic crops (Duke and Cerdeira, 2010). Before the commercialization of glyphosate tolerant maize in 1996, the bromoxynil-tolerant BXN cotton and a wide array of non-transgenic herbicide resistant crops were available only to find farmers not adopting them widely (Green and Castle, 2010). The key difference was the ability to use glyphosate, a relatively inexpensive and effective herbicide with an excellent environmental profile (Green, 2012) aside from the aggressive marketing efforts made by Monsanto. It goes to the credit of the glyphosate-tolerant Event NK603 (Roundup Ready) maize approved in the US in 2000 for ready acceptance of not only the subsequently developed transgenic herbicide tolerant varieties but all biotech crops that carried other desired traits.

The process of transgenic engineering requires the successful completion of a series of steps:

- Locating and identifying genes for agriculturally important traits, including herbicide resistance.
- Isolation of the gene of interest and cloning it for mass production.
- Development for interogression into plant by adding a promoter and selectable marker gene for the expression of transgene in plant.
- Transformation i.e. genetic alteration of a cell resulting from the uptake, incorporation, and expression of exogenous material (DNA) from its surroundings and taken up through the cell membrane(s).
- Testing if the inserted gene has been stably incorporated by evaluating first in greenhouse or screen-house, followed by field testing.
- If the transgenic crop plants passes all tests, back-crossing them with improved, elite varieties of the crop. The offspring are repeatedly crossed back to the elite line to obtain a high yielding transgenic line.
- Food and environmental safety assessment if the new transgenic crop variety is in the process of development. In this phase, the transgenic varieties are assessed for altered nutrient levels, allergenicity, known toxicants, new substances, antibiotic resistance markers, non-pathogenicity to animals and humans, toxicity to non-target organisms, etc.

Adoption

Since the commercialization of THT crops on 1.73 M ha in 1996 in the U.S., farmers around the world have readily accepted and rapidly adopted transgenic crops of soyabean, maize, cotton, oilseed rape (mustard/canola), lucerne (alfalfa), and sugarbeet. This area grew to 170.3 M ha in 2012 (ISAAA, 2012), a near 100–fold increase in 17 years. Thus, biotech crops are considered as the fastest adopted crop technology in the history of modern agriculture. The herbicide–tolerant transgenic (including the stacked herbicide–cum–insect–resistant ones) lines accounted for 80 percent of the global acreage. In 2012, 17.3 million farmers with 90% of them being resource–limited in 28 countries planted transgenic crops. Twenty of these were developing nations which have overtaken the eight developed nations by contributing more than 52% to the area under biotech crops. The global adoption of transgenic crops is expected to grow at about 6% annually. The six major countries adopting transgenics include USA (69.5 M ha), Brazil (36.6 M ha), Argentina (23.9 M ha), Canada (11.6 M ha), India (10.6 M ha), and China (4.0 M ha) (ISAAA 2012). Athough the European nations largely shunned transgenic crops so far, Spain, Portugal, Czechia, Slovakia, and Romania planted 1,29,000 ha with *Bt* maize in 2012.

Two transgenic traits dominate the global biotech crops: mono-trait herbicide tolerance accounting for 65%, mono–trait insect resistance 15%, and a combination of the two (stacked) accounting for the removing 15%. Among the four major transgenic crops, soybean accounted for the largest share (49%) in 2011 followed by maize (32%), cotton (14%), and oilseed rape (canola: 5%) (Mannion and Morse, 2012; Brookes and Barfoot, 2013). In terms of the share of biotech crops as compared to gross global plantings in 2011, transgenic traits accounted for 72% of soyabean, 28% for maize, 56% for cotton, and 23% for oilseed rape (Brookes and Barfoot, 2012). Across all four crops, transgenics had a share of 44% of the global acreage under them.

Regulation

In order for a transgenic crop variety to be commercially adopted, it needs to go through a strict regulatory approval mechanism. Each country has a different regulatory framework to assess and manage the risks and issues associated with the use of genetic engineering technology, and development and certification of genetically modified organisms, including transgenic crops and foods derived from them. For example, a crop intended for food use is generally reviewed and assessed by regulating authorities from a perspective different from non-food or feed use. Many a time, assessment, approval, and regulation are based not entirely related to technology.

In USA, biotechnology products are regulated under the same laws that govern health, safety, efficacy and environmental impacts of similar products derived by traditional methods. This may also mean that foods or products developed through biotechnology crops are treated on par with those derived through conventional technology, regardless of the fact that transgenic crops may have been recipients of genes from non–plant sources.

However, the key issue concerning global regulators is whether a particular transgenic product should be labeled as next. Labelling can be mandatory up to a threshold level of which varies between countries, or voluntary. In USA and Canada, labelling of genetically engineered food is voluntary, while in Europe all food (including processed food) or feed which contains greater than 0.9% of approved genetically modified organisms must be labelled (Davison, 2010). Although there is a broad consensus that transgenic crops on the market as food are safe to eat, many consumer–leaning advocacy groups and scientists have called for greater vigorous testing of transgenic foods over a much longer time period.

In India which only grows *Bt* cotton regulation policy on transgenic crops and foods has undergone various shifts. This is due involvement of various governmental and non–governmental organizations in the fierce debate on benefits and risks of transgenic crops and foods. The existing regulations of the Genetic Engineering Approval Committee have been heavily criticized for incompetence and non–transparency in the decision–making process for GM organisms.

Benefits

Increase in area under transgenic crops does not necessarily guarantee their success at the farm level. Good indicators of their success are pecuniary and non–pecuniary benefits derived by farmers over a long run.

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

Non–pecuniary or indirect benefits include intangible impacts influencing adoption of transgenic crops. They include greater management flexibility, reduced crop toxicity, increased savings in time and equipment usage, improved quality of crop produce, lesser impact on environment (lower greenhouse gas emissions), lower potential damage of soil-incorporated residual herbicides to rotation crops, etc. (Brookes and Barfoot, 2013).

Another benefit that can be derived from transgenic crops is its use in phytoremediation.

Phytoremediation

Phytoremediation is the process by which green plants detoxify soils, sediments, and aquatic sites contaminated with organic and inorganic pollutants. Most of the organic pollutants are xenobiotic and manmade. These include herbicides and insecticides, oil spills, explosives and military weapons (such as RDX, TNT, etc.), industrial chemicals, etc. Inorganic pollutants include natural elements (cadmium, cobalt, iron, lead, mercury, selenium, tungsten, etc.) released into the environment by human activities in areas such as mining, industry, traffic, agriculture (plant nutrients by way of fertilizers), military, etc. (Pilon–Smits, 1999). The contaminants vary in toxicity, but after long-term exposure they can be detrimental to human and animal health. Some of them cause damage to DNA and their carcinogenic effects in humans and animals are probably caused by mutagenic ability (Knasmuller *et al.*, 1998; Baudouin *et. al.*, 2002; Hooda, 2007).

Certain transgenic crops have ability to remediate soil of organic contaminants by producing a variety of enzymes (cytochrome P450s, glutathione s-transferases, and nitroreductases) that break down some of the essential elements and complex contaminants to carbon dioxide, water, inert gases and other non-toxic molecules. Crops such as tobacco, potato, rice, poplar, etc. besides the plant species *Arabidopsis thaliana* have been successfully inserted with genes that encode for these enzymes. The field of phytoremediation using transgenic crops is still in its infancy, but holds a great promise.

Risks

Commercial production of transgenic crops with desired beneficial traits has aroused concerns about their biosafety, a crucial factor in further development, and its utility and wider application of transgenic products in global agriculture. Genetically engineered crops, however, are a heterogeneous group. As such, it is not reasonable to lump all of them together. Therefore, it would be prudent to assess the biosafety of each of the transgenic crops separately.

Development of transgenic crops by the agricultural biotechnology industry is more of a profit–driven rather than need–driven process. Therefore, the thrust of the genetic engineering industry is not really to solve agricultural problems, but to create profitability (Altieri, 1998) as evident by last 30 years scores of multinational corporations that have initiated transgenic research in a variety of crops around the world. Although several universities and research institutions are also simultaneously involved in this field, their research agenda is being increasingly influenced by private sector in ways never seen in the past. The challenge these organizations now face is to ensure that ecologically sound aspects of biotechnology are researched and developed while at the same time carefully monitoring and controlling the provision of applied non–proprietary knowledge to the private sector, farmers, and consumers and making such knowledge available in the public domain for the benefit of society.

Currently, there is a great deal of confusion, as also controversy, on the risks, both real and perceived, attributed to transgenic crops now being used in global agriculture. This confusion is fueled, in part, by a lack of understanding, or rather misunderstanding, and misrepresentation of facts to reflect one's pre–conceived notions. Protagonists of transgenic crops highlight their virtues while ignoring risks, issues and perils, while antagonists sometimes find it hard to separate facts from fiction and half–truths. It thus, becomes incumbent upon scientists to examine the key issues scientifically, systematically, dispassionately and evaluate the merits at various positions/steps before arriving at meaningful decisions.

The risks are broadly grouped into agro-ecological concerns and food safety concerns. These include the following:

Agro-ecological concerns

- Transgene flow from transgenic crops to landraces, wild/weedy relatives, non-transgenic crops, and unrelated organisms
- Evolution of transgenic crop-volunteer weeds
- Effect on soil ecosystem which accounts for 80% of soil-borne communities dominated by microbes (one of the least understood areas in risk assessment of transgenic crops); soil microbe dynamics; uptake and availability of soil nutrients

Food safety concerns

- Alteration of nutrient levels of foods and feeds derived from transgenic crops
- Allergenicity in a result of consumption of foods derived from transgenic crops
- Horizontal gene transfer and antibiotic gene resistance leading to humans' loss of ability to treat illnesses with antibiotic drugs

Issues

There are several issues related to transgenic crops. These include the following:

- Production of terminator seeds by using genetic use restriction technology (GURT) and trait-specific gene use restriction technology (T–GURT)
- Intellectual property rights (IPR) of inventors granting exclusive ownership rights to their inventions and discoveries in a technical field
- Asynchronous approval of transgenic crops largely due to disparate regulatory procedures and standards in the countries that adopted biotech crops
- Biopiracy which, in fact, is the misappropriation and commercialization of genetic resources and traditional knowledge of rural and indigenous people of another country and making profit illegally from freely available natural biological materials that belong to it
- Coexistence of transgenic crops in the vicinity of non-transgenic, conventional, and organic crops leading to a socio–economic issue, but not necessarily a safety issue unless the foods derived from transgenic crops pose health risks
- Coexistence of transgenic and non-transgenic food products in food markets without proper segregation and traceability standards, thus curtailing the consumers' freedom of choice in buying the food they want.

Future perspectives of herbicide resistant transgenic crops in India

The introduction of transgenic crops has certainly changed global agriculture forever unlike probably any other invention in the history of mankind. Genetic engineering technology is here to stay, and it is likely to spread to other important crops.

The American biotech giant Monsanto's entry in India with its transgenic insect resistant *Bt* technology has changed cotton cultivation in the country forever. In 2012–13, 10.8 M ha have been brought under insect-resistant *Bt* varieties, accounting for 89% of the gross cotton acreage of 12.1 M ha. With a harvest of 36.5 million bales in 2012–13 (Afonso, 2013), India was able to displace China as the top cotton producer in the world. Despite this impressive record, *Bt* technology has apparently brought unending woes to marginal and poor cotton farmers, some of whom have ended up in deep financial crisis, leading to committing suicides. Although all farmer suicides are not entirely related to growing *Bt* cotton, the spate of suicides certainly has been on the rise since its commercialization in 2002.

The initial success of *Bt* cotton encouraged other international biotech companies such as Syngenta, Dow, DuPont, Novartis, etc. to set up shop in India, either directly or indirectly, through partnerships with domestic biotech companies. Currently, there are around 140 of them conducting research to develop transgenic crop hybrids/varieties carrying traits such as insect resistance, herbicide tolerance, disease resistance (fungal, bacterial and viral), yield increase, drought tolerance, nutrition enhancement, etc. The crops include, *inter alia*, cotton, rice, maize, sorghum, groundnut (peanut), potato, sugarcane, chickpea, brinjal (eggplant), tomato, watermelon, papaya, cabbage, cauliflower, ladyfinger, chillies, capsicum, pomegranate, banana, papaya, etc. Over 50 universities and 45 research institutions funded by Central and State governments are also engaged in transgenic research.

At the global level, further expansion of biotech crops in US, the world leader of transgenic crops with 69.5 M ha (accounting for 41% of the global biotech acreage), is very limited. This is because over 90% of the gross cultivated area under its major crops (soybean, maize, cotton, oilseed rape, and sugar beet) has already been brought under transgenic varieties. The growth of transgenic crops in Canada, the top global exporter of oilseed rape (canola) oil, has also reached a saturation point. Furthermore, biotech crops are under indefinite ban in most of the European Union countries. Hence, it is imperative for the global biotech companies, driven largely by business interests and profit motive, to work feverishly to bring in as much of the cultivated areas under major crops in large countries such as India and China.

In India, there is little scope for further expansion of *Bt* cotton unless stacked herbicide–cum–insect resistant varieties and transgenic stacks carrying herbicide resistant transgenes along with other genes that induce resistance to other biotic and abiotic stresses are developed locally and adopted. In addition, there is tremendous scope for business for the biotech companies if rice and wheat, the two major crops, are brought under transgenic crops over the next 10–15 years.

Against this possible scenario, the nation and her plant biotech scientists, including weed scientists, need to consider the following aspects.

Technical aspects

Major crops that biotech companies are likely to turn their attention towards commercialization including maize, soybean, and sugarcane. There are several glyphosate–tolerant transgenic lines in maize and soybean already being adopted in many countries and if the existing lax regulatory procedures are continued, Indian farmers may be tempted to adopt them much sooner than expected.

In sugarcane, a glufosinate–tolerant transgenic line was developed in 1996 by transforming the embryonic calli derived from immature inflorescences by biolistic method (Gallo–Meagher and Irvine). Later, Enriquez–Obregon (1998) and Manickavasagam *et.al.*, (2004) used *Agrobacterium*–mediated transformation and found lines with high–level resistance to bialaphos in most of the transformed lines. Despite this, the economic utility of transgenic lines in sugarcane is questionable because this technology is dependent on the premium price for transgenic seed material and costs associated with multiple conventional glufosinate applications needed during crop growth. Besides, there is little active research underway.

Biotech companies are also engaged in developing herbicide tolerant lines in rice and wheat, the most important staple food crops and biotech companies will find ways to develop herbicide–tolerant lines. Monsanto had tried to develop a glyphosate–resistant event (Roundup Ready) in in rice 2000–2001, but abandoned its efforts after a year. As such, there is little focus on development of glyphosate–tolerant transgenic rice. The alternative is to bring in glufosinate–resistant lines.

Bayer CropScience did develop two glufosinate-resistant rice events LLRice06 and LLRice62 containing the *bar* gene using biolistic method of transformation in 2000. These "LibertyLink" rice events were followed by another glufosinate–resistant rice event LLCRice601 using *Agrobacterium*-mediated transformation. However, large-scale commercialization of LLRice601 in the U.S. became hampered when trace amounts of this variety were found in August, 2006 in commercial rice samples imported by the European Union from USA. This resulted in the disruption of bi–lateral rice trade.

Better alternative to transgenic varieties are the non–transgenic ones tolerant to imidazolinone (IMI) herbicides. BASF developed three non-transgenic IMI herbicide-resistant rice lines (CL121, CL141 and CFX51) through chemically-induced accelerated mutagenesis of a rice cultivar. The IMI-resistant mutant with an altered binding site for the ALS encoding gene was crossed with elite commercial varieties. These imazethapyr-tolerant "Clearfield" rice varieties, which have no non-plant foreign DNA to derive herbicide resistance, were approved by USA and Canada in 2002.

Subsequently, BASF developed two more non-transgenic rice lines tolerant to the postemergence nonselective imazapyr and imazapic (Tan *et al.*, 2005) as well as selective imazethapyr through chemically–induced point mutations within the ALS encoding gene. These IMI-tolerant rice varieties, CL161 and XL8 were marketed in 2003 (Gealy *et al.*, 2003) and were followed by two more IMI-tolerant rice lines, IMINTA 1 and IMINTA 4, in 2006.

Currently there is no transgenic herbicide-tolerant line available for commercialization I wheat. However, several non–transgenic IMI-tolerant lines were developed by mutagenizing seeds of cultivars by sodium azide, ethyl methanesulfonate and diethylsulfate. Using this technique, Cynamid developed imazamox–tolerant wheat line SWP965001 for commercial availability in 2000. In 2003, BASF developed another imidazolinone-tolerant non-transgenic wheat line AP205CL in which the chemical mutagens,ethyl methanesulfonate and diethylsulfate, induced a point mutation of a single nucleotide in one (*als2*) of the three AHAS (ALS) genes (CERA 2005). This imazamox-tolerant "Clearfield Wheat" variety was approved by Canada in 2003.

BASF also developed another imidizolinone-tolerant wheat (bread wheat) line, BW7, which has a single base substitution in the *Als1* gene coding region. The mutation in *Als1b* of the *Als1* gene was stably inherited in BW7 (Health Canada 2007). Canada approved this imazamox-tolerant variety for commercial purpose in 2007.

The other major crops that biotech companies could possibly turn their attention to include groundnut, potato, sorghum, and tobacco. Currently, there is no transgenic or non-transgenic event available in groundnut for commercialization. In the case of potato, an effort had been made in 1998 (Eberlein *et al*,. 1998) to insert *bxn* gene which encodes the bromoxynil-specific nitrilase and produce bromoxynil–resistant transgenic potato by using *Agrobacterium*-mediated transformation, but remains to be taken further. Transgenic research in regard to sorghum has not yet reached advanced stages, and there is no THT sorghum line in the commercialization pipeline.

In context to tobacco, modest attempts have been made to develop transgenic events tolerant to 2,4-D, phenmedipham and paraquat by inserting *tfd*A, *pcd* and *pqr*A genes respectively. It may take many years before biotech companies attempt to commercialize these or different transgenic events. Besides, the decelerating importance to further expand tobacco crop in India may hamper any attempt to bring in a transgenic event to commercialization stage.

Non–transgenic imidazolinone-tolerant lines have also been developed in sunflower and linseed (flax), two of the major oilseed crops in India. However, these are unlikely to reach farmers' field in a large way because of limited economic utility to biotech companies.

Regulation aspects

One of the most contentious issues roiling the country is whether the country should permit commercial planting of genetically modified (GM) food crops (News & Analysis, 3rd May 2013) are next. The existing regulation rules have been heavily criticized for incompetence and non–transparency in the decision-making process relating to GM organisms.

Current regulation procedures apparently tilt more towards biotech companies rather than farmers. Besides, there is inadequate scope for, and consideration to, public debate. Many a time, decisions are taken arbitrarily regardless of farmer and consumer interests. One clear–cut example is the way *Bt* brinjal, developed by Monsanto–Monsanto Biotech (MMB), was approved by the Genetic Engineering Approval Committee (GEAC) in October 2009 for commercial cultivation despite the serious concerns expressed by some scientists, farmers, and anti-GM products. Added to this was Monsanto's attempt in collaboration with its Indian partner Maharashtra Hybrid Seed Company (Mahyco), to resort to 'biopiracy' of using native brinjal varieties for the purpose of genetic modification in violation of the country's Biological Diversity Act, 2002 (Mercola, 2012). It required the Minister of Environment to declare indefinite moratorium on cultivation of *Bt* brinjal that contained the *Cry 1Ac* gene and interference of Supreme Court to decide on the issue of biopiracy.

In response to a public interest petition filed in 2005 for banning GM crops in India because of approval of field trials by GEAC without proper scientific evaluation of biosafety issues, the Supreme Court appointed on 10 May 2012 a five–member Technical Expert Committee (TEC). In its report submitted to the court on 7 October 2012, TEC recommended a 10-year moratorium on commercial release of all GM crops till all systems are in place for independent research and regulation. It also recommended a moratorium on field trials of herbicide–tolerant crops until an independent assessment evaluated its impact and suitability.

In response to demands from biotech and pharmaceutical industry for a simpler regulation procedure, the Indian government proposed to replace the current regulatory regime with a bill known as the Biotechnology Regulatory Authority of India Bill, 2013. Under the BRAI Bill, awaiting final approval, the proposed National Biotechnology Regulatory Authority (NBRA) will act as a single window fast track clearance body. This autonomous and statutory agency regulates the research, transport, import, manufacture, and use of genetically engineered organisms and products derived thereof. The BRAI Bill provides, *inter alia*, unlike in the past, for a Regulatory Authority Appellate Tribunal to hear appeals against NBRA's decisions, orders and directions.

However, opponents of NBRA contend that the Bill lowers the bar for approval of genetically modified/engineered crops because it bypasses the Right to Information Act, provides opportunity for conflict of interest, curtails participation of public in decision making,

deviates from task force report, overrides state governments' role, lacks socio-economic assessments and kills consumer choice (CLRA, 2013). This Bill is in conflict with the provisions of Cartagena Protocol, the binding international agreement on biosafety, which India ratified on 17 January, 2003. The Protocol stipulates that governments shall consult the public in decision–making processes regarding GMOs and make all relevant decisions available to the public. It also stipulates that information about a summary of the risk assessment cannot be made confidential (CLRA, 2013). India is required to put in place a safety protocol and ensure that mandates openness, transparency, and public participation.

Labelling of a food product gives consumer the choice of buying it and currently, there are no mandatory labelling requirements. In order to placate consumer concerns, central government has made it mandatory, effective 01 January 2013, for packaged foods derived from transgenic crops to carry GM labels marked with letters “GM”. The decision was made because many products in India are either derived from, or processed in, countries such as USA, Canada, Brazil, and Argentina where a majority of crops cultivated are genetically modified.

While this decision is a step in right direction, critics contend that in a country where 90% of the food consumed is unpackaged and unprocessed, there is no way for people to know whether a product is genetically modified or not. Critics also raise a valid question about its successful implementation by Government regulators at the market level and compliance by suppliers.

Risks and issues

As mentioned earlier, development of transgenic crops by biotech industry is more of a profit–driven than need–driven process. Despite the fact that many public institutions are also involved in this field, it is the private industry that has a pervading influence over them.

With business expansion and profit motive being the primary consideration of private industry, it is incumbent upon scientists of public and independent research establishments to study the various risks and issues concerned with transgenic crops and foods, both over a short-term and long-term period. Consumer groups contend that independent research in these areas is systematically blocked by biotech companies which develop transgenic crops and own modified seeds and reference materials. Diels (2011) found a significant correlation between author affiliation to industry and study outcome in scientific work published on health risks or nutritional assessment studies of genetically modified products.

The timeline from development of a transgenic crop to the point at which products derived from it are approved for human consumption may take anywhere between 7 and 10 years and even longer in some instances.

It requires participation of scientists of various disciplines (weed science, agronomy, biochemistry, food science, etc.) to investigate the risks and issues listed earlier. More important of these include the following:

- Flow of transgenes to conventional varieties, landraces, weedy/wild relatives, unrelated organisms, etc.
- Transgenic crops as volunteer weeds, possible evolution of herbicide resistant weeds following long-term use of herbicides in THT crops, etc.
- Food safety (nutrient levels and composition, allergenicity, antibiotic gene transfer, etc.). Consumer advocates suggest that the supposed ill effects of transgenes on human and animal health are more subtle and take longer time to show up
- Soil ecosystem (rhizosphere microbes)
- Technologies alternative to varietal genetic use restriction technology (V–GURT) and trait-specific genetic use restriction technology (T–GURT) to produce fertile second generation seeds and help farmers avoid using terminator, also called suicide seeds
- Coexistence of transgenic and conventional crops without their becoming comingled and thereby possibly compromising the economic value of both
- Coexistence of transgenic and conventional food products in food supply

In the interest of farmers and consumers, thorough and dispassionate investigations on these and other related aspects of transgenic engineering in relation to herbicide tolerance by weed scientists in association with scientists of other disciplines are extremely crucial.

References

Afonso, S. 2013**.** *Cotton Production in India seen at Record as Rain Boosts Yields*. Bloomberg 1 November.

Altieri, M.A. 1998. The environment risks of transgenic crops: An agroecological assessment: Is the failed pesticide paradigm being genetically engineered fi*Pesticides and You*. Spring/Summer.

Baudouin, C., Charveron, M., Tarrouse, R. and Gall, Y. 2002. Environmental pollutants and skin cancer. *Cell Biology and Toxicology* **18**: 341–348.

Blackman, G.E. 1950. Selective toxicity and development of selective weed killers. *Journal of Royal Society Arts* **98**: 500–517.

Brookes, G. and Barfoot, P. 2012. *GM Crops: Global Socio–Economic and Environmental Impacts 1996–2010*, 187 p. PG Economics Ltd. Dorchester, U.K.

Brookes, G. and Barfoot, P. 2013. *GM Crops: Global Socio–Economic and Environmental Impacts 1996–2011*, 191 p. PG Economics Ltd. Dorchester, U.K.

Center for Legislative Research and Advocacy. 2013. *The Biotechnology Regulatory Authority of India Bill*. A threat to our Food and Farming. Policy Brief Series: 19: June–August.

Davison, J. 2010. GM plants: science, politics and EC regulations. *Plant Science* **178**(2): 94–98.

Diels, J., Cunha, M., Manaia, C., Sabugosa–Madeira, B. and Silva, M. 2011. Association of financial or professional conflict of interest to research outcomes on health risks or nutritional assessment studies of genetically modified products. *Food Policy* **36**: 197–203.

Duke, S.O. and Cerdeira, A.L. 2010. Transgenic crops for herbicide resistance, pp. 133–166. *In*: C. Kole, C.H. Michler, A.G. Abbott, and T.C. Hall (*Eds*.). *Transgenic Crop Plants*, Vol. 2: Utilization and Biosafety, Springer–Verlag, Berlin/Heidelburg, Germany.

Eberlein, C.V., Guttieri, M.J. and Steffen–Campbell, J. 1998. Bromoxynil resistance in transgenic potato clones expressing the *bxn* gene. *Weed Science* **46**(2): 150–157.

Enriquez–Obregon, G.A. 1998. Herbicide–resistant sugarcane plants by *Agrobacterium*– mediated transformation. *Planta* **206**: 20–27.

Gallo–Meagher, M. and Irvine, J.E. 1996. Herbicide resistant transgenic sugarcane plants containing the *bar* gene. *Crop Science* **36**(5): 1367–1374.

Gealy, D.R., Mitten, D.H. and Rutger, J.N. 2003. Gene flow between red rice (*Oryza sativa*) and herbicide–resistant rice (*O. sativa*): implications for weed management. *Weed Technology* **17**: 627–645.

Goeddel, D., Kleid, D.G., Bolivar, F., Heyneker, H.L., Yansura, D.G., Crea, R., Hirose, T., Kraszewski, A., Itakura, K. and Riggs, A.D. 1979. Expression in Escherichia coli of chemically synthesized genes for human insulin. *Proceedings of National Academy of Sciences USA* **76(**1): 106–110.

Green, J.M. 2012. The benefits of herbicide–resistant crops. *Pest Management Science* **68**(10): 1323–1331.

Green, J.M. and Castle, L.A. 2010. Transitioning from single to multiple herbicide resistant crops, pp. 67–91. *In*: V.K. Nandula (*Ed*.). *Glyphosate Resistance in Crops and Weeds: History, Development and Management*. Wiley, Hoboken, NJ.

Gressel, J. 2009. Evolving understanding of the evolution of herbicide resistance. *Pest Management Science* **65**: 1164–1173.

Health Canada. 2007. *Clearfield Bread Wheat Variety BW7*. 28 September. www.hcsc.gc.ca.

Heap, I. 2013. *The International Survey of Herbicide Resistant Weeds*. 1 July, 2013.

Heap, I. and LeBaron, H. 2001. Introduction and overview of resistance. *In*: S.B. Powles and D.L. Shaner (*eds*.). *Herbicide Resistance and World Grains*. CRC Press, Boca Raton, FL.

Hirschberg, J. and McIntosh, L. 1983. Molecular basis for herbicide resistance in *Amaranthus hybridus*. *Science* **22**: 1346–1349.

Hooda, V. 2007. Phytoremediation of toxic metals from soil and waste water. *Journal of Environmental Biology* **28**(2): 367–376.

ISAAA. 2012. *Global Status of Commercialized Biotech / GM Crops: 2012***.** ISAAA Brief 44–2012: Executive Summary.

Jaenisch, R. and Mintz, B. 1974. Simian virus 40 DNA sequences in DNA of healthy adult mice derived from preimplantation blastocysts injected with viral DNA. *Proceedings of National Academy of Sciences USA* **71**(4): 1250–1254.

Jasieniuk, M., Brule–Babel, A.L. and Morrison, I.N. 1996. The evolution and genetics of herbicide resistance in weeds. *Weed Science* **44**: 176–193.

Jasieniuk, M., Morrison, I.N. and Brule–Babe, A.L. 1995. Inheritance of dicamba resistance in wild mustard (*Brassica kaber*). *Weed Science* **43**: 192–195.

Knasmuller, S., Gottmann, E. Steinkellner, H., Fomin, A., Pickl, C., Paschke, A., God, R. and Kundi, M. 1998. Detection of genotoxic effects of heavy metal contaminated soils with plant bioassays. *Mutation Research* **420**: 37–48.

Manickavasagam, M., Ganapathi, A., Anbazhagan, V.R., Sudhakar, B., Selvaraj, N. and Vasudevan, A. 2004. *Agrobacterium*–mediated genetic transformation and development of herbicide–resistant sugarcane (*Saccharum* species hybrids) using axillary buds. *Plant Cell Reporter* **23**: 134–143.

Mannion, A.M. and Morse, S. 2012. GM Crops 1996–2012: *A Review of Agronomic, Environmental and Socio–Economic Impacts*. University of Surrey Center for Environmental Strategy Working Paper 04/13. 39 pp.

Maxwell, B.D., Roush, M.L. and Radosevich, S.R. 1990. Predicting the evolution and dynamics of herbicide resistance in weed populations. *Weed Technology* **4**: 2–13.

Menne, H. and Köcher, H. 2012. HRAC classification of herbicides and resistance development, pp. 5–28. *In*: W. Kramer, U. Schirmer, P. Jeschke, and M. Witschel (*Eds*.). *Modern Crop Protection Compounds*, (2/ed).Wiley–VCH Verlag GmbH & Co. KGaA.

Mercola. 2012. Monsanto to face biopiracy charges in India. *Organic Consumers Assoc*. 31 January.

Neve, P. and Powles, S.B. 2005. Recurrent selection with reduced herbicide rates results in the rapid evolution of herbicide resistance in *Lolium rigidum*. *Theoretical and Applied Genetics* **110**: 1154–1166.

News & Analysis. 2013. Scientists clash swords over future of GM food crops in India. *Science* **340**: 3 May.

Pilon–Smits, E.A.H., Hwang, S.B. , Lytle, C.M., Zhu, Y.L, Tai, J.C. *et al*. 1999. Over–expression of ATP sulfurylase in *Brassica juncea* leads to increased selenate uptake, reduction and tolerance. *Plant Physiology* **119**: 123–132.

Rao, V.S. 2000. *Principles of Weed Science* (2nd ed), 555 p. Science Publishers, Enfield, NH, USA.

Ryan, G.F. 1970. Resistance of common groundsel to simazine and atrazine. *Weed Science* **18**: 614–616.

Tan, S., Evans, R.R., Dahmer, M.L., Singh, B.K. and Shaner, D.L. 2005. Imidazolinone–tolerant crops: history, current status and future. *Pest Management Science* **61**: 246–257.

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Weedy rice and possible management approaches for its control in India

Bhagirath S. Chauhan and Gulshan Mahajan

Rice is the most important staple food in India, where it is grown on approximately 45 million ha with a production of 104 million tons. Rice is traditionally grown in India and most of the other Asian countries by manual transplanting of seedlings into puddled soil. In the past few years, however, there has been a concern of labour shortage, especially in northwest India. This is mainly because of migration of labour from rural areas to cities and implementation of government schemes, such as providing 100 days of paid work in people's home village. In addition of labour shortage, there are also concerns of water scarcity. In Punjab, for example, the increasing use of groundwater for rice cultivation has led to a decline in the water table by up to 1 m per year. Because of concerns over labour and water shortages, growers in many parts of India are moving toward direct-seeded rice systems. There are two kinds of direct seeding practices in India: dry and wet. In dry direct seeding, rice is sown under zero-till conditions or after cultivation in dry soil conditions. In wet direct seeding, pre-germinated rice seeds are sown (broadcast) on the soil surface after puddling or cultivation in ponded conditions.

There are several advantages of direct-seeded systems, such as rapid planting operations, less labour and water requirements, early maturity, and fewer methane emissions . Weeds, however, are the main biological constraint to the production of direct-seeded rice systems. Weedy rice (*Oryza sativa*) has been found to be one of the main threats that farmers face in direct-seeded systems. Such examples exist in Malaysia, Sri Lanka, Thailand, and Vietnam, in which direct seeding (mainly, wet seeding) is the dominant rice establishment method. Absence of the suppressive effect of standing water on weedy rice, simultaneous emergence of weedy rice and cultivated rice, and the physiological and morphological similarities of weedy rice to cultivated rice are some of the main factors responsible for association of weedy rice with direct-seeded rice systems.

Weedy rice are unwanted plants of *Oryza sativa* that compete with rice and other crops. Several suggestions were proposed about the evolution of weedy rice. The evolution may be through natural hybridization, through de-domestication of cultivated rice to weedy rice, and/or through adaptation of wild rice. In India, weedy rice is prevalent in Uttar Pradesh, Bihar, Odisha, and West Bengal. The major traits of weedy rice are early shattering of the grain and variable seed dormancy. It has spread in different regions through crop seed contamination and use of machines infested with weedy rice. In Malaysia and Vietnam, weedy rice infestation caused rice grain yield losses from 16-74%. Information on effect of weedy rice on growth and grain yield of rice is limited in India.

Because weedy rice and cultivated rice have similar physiological and morphological traits, selective herbicides are not available to control weedy rice in conventional rice cultivars. This presents a challenge for growers to manage weedy rice in India. Therefore, there is a need to integrate different preventive, cultural, mechanical and chemical approaches to manage weedy rice. Recent reviews compiled detailed information on different weed management strategies to manage weedy rice in Asia and in particular, India. This article aims to provide brief information on possible management approaches to manage weedy rice in India.

Preventive approaches

As mentioned earlier, weedy rice has spread in several regions through the use of contaminated rice seeds and contaminated machinery. Therefore, the use of clean rice seeds and machines can greatly reduce the spread of weedy rice to new areas. Sometimes, growers uproot weedy rice plants after flowering and throw in water channels, unknowingly spreading weedy rice to other fields. Therefore, there is a need to increase awareness of weedy rice among growers.

Stale seedbed

Stale seedbed practice has been found very effective in reducing weedy rice seedlings in the crop. In this practice, weedy rice seedlings are allowed to germinate after a light irrigation or rainfall. The emerged seedlings are killed using a non-selective herbicide or tillage operations. The best approach would be to prepare field ready for sowing and then allow weedy rice seedlings to emerge. After emergence, these seedlings can be sprayed with a non-selective herbicide and the crop can be sown without any further tillage. This practice will avoid bringing back the buried seeds again on or near the soil surface. Although the stale seedbed practice helps reducing seed banks of weedy rice and other weeds, the extent of efficacy depends on the degree of dormancy, especially for dormant biotypes of weedy rice.

Rotation of establishment methods

The problem of weedy rice in direct-seeded rice systems can be greatly reducing by shifting to transplanted rice culture. In transplanted rice, there are advantages of standing water and seedling size in suppressing weedy rice emergence and growth. Flooding is well known to suppress emergence of weedy rice. In a recent study at growers' fields in Sri Lanka, seedling broadcast (or "parachute planting") (3-15 panicles/m^2) and transplanted rice (1.3-3.0 panicles/m^2) had a lower number of weedy rice panicles than the growers' practice (60-80 panicles/m^2). In Malaysia and Vietnam too, growers reduce weedy rice in their field by introducing transplanted rice. Different studies conducted in other parts of the world suggest that the increasing problem of weedy rice in direct-seeded rice systems can be reduced by rotating to transplanted rice systems. As mentioned earlier, due to shortage of labour, growers cannot hire labour at the critical time of transplanting. In such situations, there is a scope for mechanized transplanting using transplanters, which are now being highly promoted and commercialized in different parts of India.

Line sowing

In some parts of India, direct-seeded rice, especially wet-seeded, is still sown by broadcasting method. In this method, however, it is difficult to distinguish weedy rice plants

from cultivated rice plants at early stages. Sowing of rice in lines or rows can help in identifying and removing weedy rice seedlings between the rows. Recently, a study at growers' fields in Sri Lanka reported that row seeding of rice reduced the number of weedy rice panicles and seed production compared with the growers' practice of random broadcast. In this study, row seeding increased rice grain yield by 14-31% compared with the growers' practice (5.1-6.7 t/ha). In a row-seeded crop, mechanical weeding is also easier.

Dry-seeded rice crop can be sown in rows using a seed drill fitted with 2- or 4-wheel tractors. These seed drills are easily available nowadays in India. The challenge is for wet-seeded rice systems. Drum-seeders are available, which can plant rice crop in rows; however, their adoption on growers' fields is negligible in India. There is a need to increase awareness among growers regarding the importance of line sowing. There is also a need to develop seeders fitted with 2- or 4-wheel tractors, which can easily plant rice in wet conditions.

Cultivars

Rice cultivars having early vigour are always more competitive against weeds, including weedy rice. However, such advantages are lost in direct-seeded culture and when other effective weed management approaches have not been used. Therefore, there is a need to integrate other weed management strategies when evaluating the competitive advantage of rice cultivars.

Rice cultivars with coloured (e.g., purple) leaves and stems may help in reducing weedy rice. Weedy rice emerging in fields planted with such rice cultivars can be easily distinguished and pulled out. Growers in Himachal Pradesh managed weedy rice by growing a purple-leaf rice cultivar. Such rice cultivars may have low yield potential and lower market values. However, this is better than abandoning the field due to severe problem of weedy rice.

As mentioned earlier, flooding can be used to suppress weedy rice emergence and growth. In direct-seeded rice systems, however, flooding is introduced only after the crop has emerged. By that time, weedy rice has also emerged and it is difficult to suppress its growth . In such conditions, there is a need to introduce rice cultivars capable of emerging under anaerobic or flooded conditions. International Rice Research Institute has recently developed such rice lines and now they are being tested in different parts of India, especially in eastern part. The use of these rice cultivars with appropriate flooding time and depth can greatly help to reduce weedy rice, especially in regions where water is plentiful. Such rice cultivars may also help to reduce herbicide use.

Chemical approaches

Selective herbicides are not available to manage weedy rice in conventional rice cultivars. However, some earlier studies reported that pre-plant herbicides (e.g., oxadiazon and metolachlor) may provide effective control of weedy rice. But, to avoid damage to cultivated rice, these herbicides should be applied well before rice planting. In general, there is a risk of rice toxicity, which is not acceptable at growers' fields.

Herbicide-resistant rice (HRR) is a very effective tool to manage weedy rice in rice crop. There are two kinds of HRR: transgenic and non-transgenic. In our view, we do not see the role of transgenic HRR in near future in India. However, there is a great possibility of introduction of non-transgenic HRR in Indian market. The use of HRR may improve weedy rice control and reduce weed control costs. However, there is a risk of gene flow from HRR to weedy rice, making weedy rice control even more difficult. A study in the USA reported the maximum field outcrossing rate of 0.03 to 0.25% between weedy rice and a rice cultivar. Such studies indicate that it is important to assess the potential risks and risk management strategies before HRR is introduced in India.

Crop rotation

Crop rotation is well known in breaking the growth cycle of weeds, including weedy rice. Growing a non-rice crop will allow to use different cultural practices and effective herbicides. In rice monoculture systems (for e.g., in eastern and south India), one rice crop (preferably dry season crop) can be rotated with an upland crop, such as corn and soybean. In a study in Italy, the rotation of soybean for a year led to greater than 90% reduction in weedy rice seed bank . Inclusion of a short-duration crop (e.g., mungbean) between two rice crops can also help in decreasing the population of weedy rice. Adoption of rotation crops, however, will depend on their market prices.

Conclusion

Weedy rice is likely to become a major problem in direct-seeded rice systems because of simultaneous emergence of weedy rice with cultivated rice, absence of standing water at the time of crop and weedy rice emergence, and absence of selective herbicides to control weedy rice in conventional rice cultivars. However, integration of different preventive, cultural, and chemical approaches may provide effective control of weedy rice.

Future research issues

In our view, there are several research issues, which need to be addressed on weedy rice in India.

- The most important need is to survey the extent of weedy rice infestation in different regions. There is also not clear understanding of identifying weedy rice.
- There is a need to characterize morphological and physiological traits of weedy rice occurring in different parts of India. Better understanding of biology and ecology of weedy rice biotypes may help identify weak points in its life cycle.
- There is a need to increase awareness about weedy rice and evaluate the extent of contamination of weedy rice in rice seeds on growers' fields.
- There is need to understand the mechanisms responsible for the genesis of weedy rice, and its possible transfer to other economically important crops and weeds.

- Climate change is the reality in India and the problem of weedy rice infestation is expected to increase with the changing climate in the near future. Clear understanding is needed why gene flows form weedy plants to domesticated rice increases with higher levels of carbon dioxide.
- There is a need to develop and evaluate guidelines for the risk management of herbicide-resistant rice.
- The most important strategy to manage weedy rice is the integration of different management strategies. However, such information is not available in Indian conditions.

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Utilization of weeds – how successful it has been in their management ?

O.P. Gupta

The utilization of weeds has been an attractive subject of reason with several weed scientists in the country for long, with the hope that it may form an effective component of weed control. Many a times, this idea is further supported by certain administrators in agriculture. It is now time to examine how successful we have been in respect of the practical utility of various methods of utilization of weeds advocated so far.

Utilization of weeds from farm fields

For considerable time, the utilization of weeds uprooted from farm crops has been largely confined to their consumption as (i) green (leafy vegetables), (ii) animal forage, (iii) medicinal plants, and (iv) compost material. Their utilization as greens is a specific species–based activity with weeds like *Chenopodium album, Amaranthus viridis, Commelina benghalensis, Rumex spp*. and *Portulaca spp*., which are consumed, sometimes, in urban areas as a delicacy. But, there is no denying fact that it is an extra micro–dimension utilization of weeds vis-a-vis tons of weeds that invade each hectare of crop land (when neglected).

The utilization of weeds as forage for milch animals involves consumption of mixed growth of varied weed species collected from neglected crop fields. Strange enough, this recommendation has been made by some scientists without reporting any critical analysis of individual weed species, particularly in respect of their alkaloid contents. It is a common observation that animals fed on either weeds or weedy forages, often yield tainted and foul smelling milk and meat. That is why utilization of weeds for animal feed has not been accepted extensively.

Regarding the medicinal uses of certain weed species, it may be uselful to note that no doubt several weed species occurring on crop lands (and other places) possess certain very useful medicinal constituents, but manufacturers of plant medicines do not use these weeds for the purpose. They, in fact, cultivate the very same plant species separately, under best cultivation care on their medicinal farms as medicinal crops.

Sometimes, the mixed growth of weeds uprooted from neglected farm crop fields is attempted to be utilized for composting on farms. However, the idea is beset with survival of many live weed seeds, thus compost dessiminates many weed seeds throughout the crop fields. That is why the crop fields treated with FYM/arid compost are found to be weedier than the urea and like synthetic fertilizer treated plots.

Over and above the analysis of various modes of utilization of weeds presented so far, the fundamental issue is whether we want to grow crops or weeds on our farmlands.

Obviously, the nation is spending huge sums of money and scientific manpower every year to ensure timely suppression of weeds in our crop fields and harvest bumper crops of high quality. There is no going back on this issue. Undue weed growth in crop fields is disastrous to crop production. As such, when all our efforts are to grow crops without competition from weeds, there is no room for wasting efforts on research on utilization of weeds from farm fields.

Utilization of weeds from non-crop lands and water bodies

Tons of weeds infest our grazing lands, plantations, National Parks and large waterbodies. And these grow by leaps and bounds each day, covering more and more area. On an average, it is observed that such weeds add 1–2 t/ha of biomass everyday. Water hyacinth (*Eichhorrnia crassipes*) is the oldest example of such a weed in water bodies throughout India. Among the terrestrial weeds, *Lantana camara* in northern India and *Mimosa*, *Mikania*, *Chromolaena* and *Solanum spps*. in southern India are of immediate concern. Unfortunately, no control measure (chemical, biological or physical) of the above weeds has been found feasible so far and these weeds continue to grow and expand fast. Their control by utilization is a good proposition, provided we are talking of their bulk or mass utilization which should be able to outsmart their average per day growth rates started earlier. Insignificant utilization methods of such gigantic weeds often reported in literature, like thatching and furniture material, cannot be helpful in recovering our wasted lands and water bodies. A rapid, extensive and economical method of composting of terrestrial and aquatic weeds is an attractive proposition for their management in near future. Intensive research is, however, required in this respect, jointly by the agronomists, microbiologists and biotechnologists. Hopefully, some day we shall achieve our objective when we can implement the weed composting programme in each district of the country.

To conclude, our present day methods of utilization of aquatic and terrestrial weeds are of no help. In future, probably, we shall be able to perfect some methods for their mass utilization in a feasible and economical way. On crop lands, an effective, early season suppression of weeds should continue to be our sole objective instead of wasting our efforts on the utilization of weeds which should not be there in the first instance.

About the Author

Dr. O.P. Gupta holds research specialization in weed science and strongly emphasizes importance of ecological approach to weed management and need to use herbicides as complements and not as substitutes to good crop practices in agriculture. He superannuated as Professor and Director of Research from the Rajasthan Agriculture University, Bikaner in 1993. He has been on several ICAR committees like the Research Advisory Committees and Quinquennial Review Teams. He has also been on the selection committees of ASRB, and continues to be active in promoting weed science through articles and books.

Zero tillage and management of herbicide resistance in wheat

R.K. Malik and Virender Kumar

India is not only large, but also very diverse with many cropping systems in place. For sustainable intensification of rice-wheat cropping system and incorporation of best management practices such as timely crop establishment, zero–tillage (ZT) was introduced and accepted by farmers at scale. This required a mind–set shift which did not come through research trials but through farmer participatory on–farm trials. During 1992–93, the crisis of herbicide resistance in *Phalaris minor* - a serious weed in wheat, brought down wheat productivity in northwest India. New alternative herbicides used for the management of resistant biotype of *Phalaris minor* were very expensive compared to currently used herbicide (isoproturon) against which *P. minor* had evolved resistance. Zero–tillage was introduced as a strategy to reduce tillage cost so that farmers could invest in purchasing new herbicides and for reducing turnaround time between rice harvest and wheat planting. Adoption of this technology has offered new opportunities in the field of cropping system intensification especially in eastern Indo–Gangetic Plains of India. In this paper we attempt to demonstrate the effectiveness of on–farm farmer participatory research approach in changing the mind set of research organization, scientists and farmers and also how zero tillage helped in managing the problem of herbicide resistance *Phalaris* in wheat in India.

Approach

The introduction of ZT in wheat in rice–wheat cropping system (RWCS) during last 17 years marked the evolution of the concept of conservation agriculture (CA) in South Asia. The first four years starting from 1993–94 to 1997–98 were the most uncomfortable years for sustaining wheat productivity in RWCS in north-west India because of huge losses in wheat yields as a result of evolution of herbicide resistance in *P. minor* (Malik and Singh 1995). Farmers were asking for remedies and expected answers with in one or two years. What could we do at that time? The first thing was to change the perception from a purely herbicide–based solution to an integrated solution. The long term solution needed a paradigm shift in the way we cultivate our crops. Zero tillage research which was at a dead end in 1996 was taken up using farmer's participatory approach. Farmers have had historical sensitivities from their perception that intensive tillage is must for high yields. The consensus on zero tillage was always harder than usual to reach. The farmer's participatory approach proved to be an accurate guide to its subsequent adoption by farmers throughout the Indo-Gangetic Plains. The technology has now evolved into something with a far broader appeal including cost effectiveness, convenience, profitability and security. First phase of reforms in Haryana was possible through collaboration of organizations such as Rice–Wheat Consortium (RWC), International Maize and Wheat Improvement Center (CIMMYT), International Rice Research Institute (IRRI), Australian Centre for International Agricultural Research (ACIAR), CCS

Haryana Agricultural University and NATP-ICAR. The surge in this innovation is now happening through Cereal Systems Initiative for South Asia (CSISA) project funded by USAID and Bill and Melinda Gates foundation and implemented by four CG centers (CIMMYT, IRRI, ILRI and IFPRI) in collaboration with national public and private sector partners including very stronger participation of the Departments of Agriculture (DOA). Since its inception in 2009, CSISA project has explored options for sustainable intensification across the IGP, including CA-based crop management.

Zero tillage is now the best-targeted technology for the eastern Indo-Gangetic Plains (EIGP) where cropping system optimization demands advancement in wheat establishment to beat terminal heat stress and for greater system productivity. CSISA in the Eastern Indo–Gangetic Plain is focusing on creating a critical mass of service providers so that small and medium farmers, who face cash-flow risks and who cannot buy machines, can also have access to ZT technology through custom– hiring services provided by service providers (SPs) who own such machines. Moreover, farmers in area have also started facing the problem of *Phalaris minor* due to late wheat sowing when temperature favours *P. minor* emergence compared to early planting. Zero tillage will be guard against such eventuality as early wheat sowing mediated through zero tillage will discourage this weed from dominating the wheat crop.

Evolution of herbicide resistance

The history of detection of herbicide resistance in weeds began in Washington in 1964 with the report of triazine resistance in common groundsel (*Senecio vulgaris* L.). Since then hundreds of such cases have emerged. In spite of this dramatic development, no herbicides have been lost to agriculture; they are here today, and will remain an integral part of food production through their effective use in combination with other weed control practices. From 1960 to 1980, the herbicide resistant weeds were reported more in case of triazines application followed by synthetic auxins and ACCase inhibitors. Triazines followed by ALS inhibitors and bypyridiliums were still at the top in next the decade. During 1990–2000, herbicide resitant against triazines followed by ALS inhibitors, ACCase inhibitors, bypyridiliums, ureas and amides, synthetic auxins, dinitroanilines and glycines were reported in a descending order (Heap, 2000). Annual rye grass (*Lolium rigidum*) from Australia and black grass (*Alopecurus myosuroides*) from England are two most discussed cases of herbicide resistance. Several biotypes of *Phalaris paradoxa* are resistant to triazines in Israel. Australia, USA, Canada, England, France and Israel are facing serious problem of herbicide resistant weeds. Problem of herbicide resistance in India and Mexico became more evident than Europe due to limited choice of herbicides, poor quarantine rules and inadequate weed management and technical expertise. The scientists of CCS Haryana Agricultural University, Hisar reported the first case of herbicide resistance in India and for the first time in the world in *Phalaris minor* against isoproturon during 1992–1993 (Malik and Singh, 1993, 1995). This was the most serious case of herbicide resistance in the world (Malik and Singh, 1995), resulting in total crop failure under heavy infestation (2000–3000 plants/m^2). Continuous use of isoproturon as single herbicide for

10–15 years under monocropping of rice–wheat cropping system led to the evolution of resistance in *P. minor* against isoproturon. Isoproturon resistance in *P. minor* was also reported in other states of India (Yadav *et al.*, 1996).

Zero-tillage – an integral part of integrated weed management strategy for the management of herbicide resistannt *Phalaris Minor*

Herbicide resistance in *P. minor* against isoproturon was the most serious problem in wheat in rice–wheat cultivation system during early 1990s. Efforts on herbicide resistance management before 1996-97 were concentrated around alternate crops (Malik *et al.*, 2002). The problem of resistance was so serious that farmers in Haryana started diversifying wheat with sunflower to exhaust the seed bank of *P. minor*. Crop rotation was possible only in small areas where farmers needed a viable technology for herbicide resistance management. ZT made it possible to achieve three major objectives that lead to create competition in favour of crop. These were optimum plant population, wheat sowing in advance when it is not conducive to *P. minor* emergence and accurate fertilizer placement. ZT in wheat reduces the emergence rate of *P. minor* compared to conventional tillage (CT) (Franke *et al.*, 2007). The lower emergence of *P. minor* under ZT may be attributed to (1) higher soil strength in ZT because of crust development in the absence of tillage after rice harvest, which can mechanically impede seedling emergence (Chhokar *et al.*, 2007) and (2) higher weed seed predation under ZT (Kumar *et al.*, 2013). Other possible factors could be (1) less soil temperature fluctuation because ZT helps in moderating soil temperature (Gathala *et al.*, 2011) or (2) lower levels of light stimuli, N mineralization, or gas exchange, all of which are known to stimulate germination of many weed species following tillage (Franke *et al.*, 2007).

In a study conducted by Franke *et al.* (2007) at farmer's field in Haryana correlation between the number of germinable *P. minor* seeds in soil with the number of *P. minor* seedling emerged under ZT was studied. It was found that ZT reduced the emergence rate of first flush of *P. minor* by 50% (Figure 1 A). Rate of emergence of second and third flush was also lower in ZT plots compared to CT plots (Figure 1 B & C). The first flush of *P. minor* is more damaging to the crops compared to later flushes and ZT is found relatively more effective in reducing first flush than other flushes. Laxmi *et al.* (2003) reported that 51% of farmers in Haryana and 85% of farmers in Bihar perceived that weed infestation had decreased due to the adoption of ZT in wheat.

A reduced population of *P. minor* in ZT doesn't mean that the problem is solved. It also does not mean that farmers can or will stop using herbicides. Long-term on-farm sites indicate that farmers can skip herbicide application once in 3-4 years. Emergence of very heavy population during early phases of crop cycles can be prevented with ZT.

Zero tillage when combined with residue mulch improve weed control in wheat under ZT-based systems (Kumar *et al.*, 2013). When rice residues are kept on soil surface as mulch, emergence of key weeds of wheat was reduced in the range of 45–99%, depending on species and mulch amount. Emergence of *P. minor*, *Chenopodium album* and *Rumex dentatus* was inhibited by 45, 83 and 88%, respectively at 6 t/ha rice residue load compared to without

residue mulch (Kumar *et al.*, 2013). With 8–10 t/ha of rice residue mulch, *P. minor* emergence was inhibited by 65% and that of *C. album* and *R. dentatus* by greater than 90%.

ZT also facilitates timely wheat planting which further creates ecological conditions in favor of wheat than *P. minor*. When ZT is combined with residue mulch (6-8 t/ha) and early planting (25th October), the emergence of *P. minor* is reduced by 83–98% compared with normal (mid–November) or delayed (25th November) planting without residue. In a long-term experiment since 2009 at CSSRI Karnal, Haryana where wheat is planted early (30th October) under ZT with full rice residue as mulch, weed density including of *P. minor* was reduced to almost zero. After an initial 2–3 years of effective weed control herbicide application was skipped in last 2 years (2012–13 and 2013–14) for weed control.

Majority of farmers in RWCS, especially in north-western IGP, burn residues of previous rice crop for its rapid disposal before wheat sowing because it can interfere with drilling. However, recent advances in planting technology have made it possible to sow wheat successfully into heavy residues and facilitate the use of residue as mulch for weed suppression. In particular, turbo happy seeder can seed wheat in heavy residue mulch of up to 8–10 t/ha without any adverse effect on crop establishment.

In addition to the suppressive effects on emergence of weeds, residues can contribute to weed seed bank depletion through seed predation. Preliminary studies conducted in India indicate that post dispersal seed predation of *P. minor* during a 1-wk period between wheat harvest and rice planting was 50–60% under ZT with residue compared to 10% under CT (Kumar *et al.*, 2013). This could be one of the many reasons for lower population of *P. minor* under ZT.

There is a constant danger that this weed will constantly evolve resistance to new herbicides. Using herbicides alone is not a long term solution for managing resistance. Details of resistance development and its management using integrated approach with focused attention on ZT have been published (Malik *et al.*, 2002; Franke *et al.*, 2007; Kumar *et al.*, 2013).

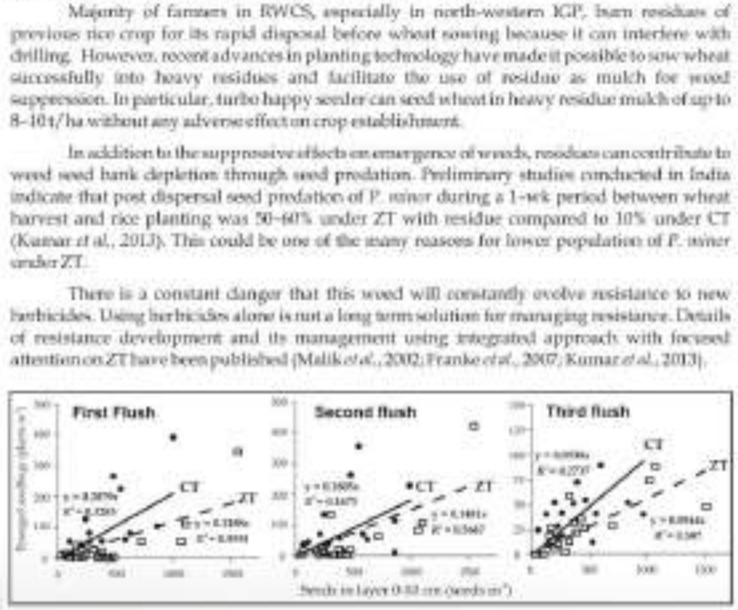

Figure 1. Emergence rate of the first, second, and third flush of *Phalaris minor* under conventional (•, solid line) and zero-tillage (□, dashed line) in wheat
Source: Franke *et al.* (2007)

Perennial weeds and zero tillage

In the Eastern IGP, problems with perennials such as *Cyperus rotundus* and *Cynodon dactylon* are serious under ZT. It is because of (i) inadequate/poor crop canopy of both rice and wheat crop mainly due to late planting and lower N fertilizer use which allows weeds to outcompete the crop, (ii) tillage option is eliminated to disrupt perennation, and (iii) poor management of perennial weeds before seeding crops under ZT. All these factors lead to a continuous build-up of stored food in the underground parts of perennial weeds.

In the eastern sector where sugarcane is cultivated in the cropping system cycles, heavy infestation of *C. rotundus* and *Cynodon dactylon* may require the treatment of pre-seeding non-selective herbicide application in fields where ZT has been planned. Similarly, a shift in cropping system from rice-wheat cropping system to sugarcane based cropping system encourages a weed flora shift from annuals to perennials. The use of pre-seeding non-selective herbicides like glyphosate will weaken the influence of such weeds under ZT in crops like sorghum, pearlmillet and rice. Use of herbicide in rainy season crops will help in the new phase of tillage reforms in favour of ZT or reduced tillage.

At research farm of CCS Haryana Agricultural University, ZT has been practiced for 15 years in pearlmillet-wheat rotation and for 12 years in sorghum-wheat rotation. Perennial weeds in the rainy season have been managed by using glyphosate applied few days before seeding pearlmillet or sorghum. Such plots continue to fare better during all years and the perennial weed pressure continued to be more under CT. The decline in overall perennial weed pressure is even more impressive because both glyphosate in rainy season and excellent wheat canopy cover in the month of March and beginning of April does not allow accumulation of food into the underground parts of perennials. Another way to look at this is that net flow of food material into the underground parts of perennials is less. On the whole, once the pre-seeding herbicides are used on case by case basis, ZT, in both rice and wheat, is set to reduce the stress of perennials. For those obsessed with CT, cultivation itself encourages weeds if the space is not occupied by crop. Remember, weeds will definitely occupy the space available between two crops or when the crop canopies are thin.

Impact of zero-tillage in India

According to the impact assessment study done by ACIAR, the Indian economy would gain about Australian $1800 million over the next 30 years by adoption of ZT in rice-wheat systems of Northwestern India due to savings in tillage and herbicide costs and higher wheat yields (Vincent and Quirke, 2002; see Table 1 for details). In a recent study conducted in Haryana, it is estimated that shifting from CT to ZT, farmer's net income has increased by US$ 97.5 per ha (Aryal *et al.*, 2014). They also estimated that with the shifting from CT to ZT, greenhouse gas emission is reduced by 1.5 mg CO_2 equivalent per ha. If we extrapolate these benefits on the total current area adopted under ZT in Haryana state (0.21 M ha), the economic benefit to Haryana state with the adoption of ZT is US$ 20.5 million more net revenue per year.

Similarly, at state level, current greenhouse gas benefit due to adoption of ZT is about 0.3 million Mg CO_2 equivalent.

In an impact assessment study conducted recently in the eastern IGP in Bihar under CSISA project, the benefits of ZT include 9.3% higher yield (0.24 t/ha) and US$ 74 more net revenue per ha compared to CT (Alwin *et al.*, unpublished). Other benefits of ZT compared to CT include irrigation water saving (15–33%) and improvement in soil health.

Table 1. Summary of benefits and costs of zero tillage in wheat

Producer Benefits	Net present value	
	A $m	(%)
Prevention of future decline in yield through re-emergence of herbicides resistance	103	5.7
Reduction in herbicide outlays	175	9.7
Reduction in tillage costs	950	52.5
Avoidance of long-term yield decline through degradation	24	1.3
Yield premium due to early sowing and closer spacing	557	30.8
Total producer benefit (world prices)	1809	100.0
Net gain to India	1809	

A : Australian

References

Aryal, J.P., Sapkota, T.B., Jat, M.L. and Bishnoi, D. 2014. On-farm economic and environmental impact of zero-tillage wheat - A case from Northwest India. *Experimental Agriculture* (in press) CJO2014. doi:10.1017/S001447971400012X.

Chhokar, R.S., Sharma, R.K., Jat, G.R., Pundir, A.K. and Gathala, M.K. 2007. Effect of tillage and herbicides on weeds and productivity of wheat under rice-wheat growing system. *Crop Protection* **26**: 1689–1696.

Malik, R.K., Yadav, A., Singh, S., Malik, R.S., Balyan, R.S., Banga, R.S., Sardana, P.K., Jaipal, S., Hobbs, P.R., Gill, G., Singh, S., Gupta, R.K. and Bellinder, R., 2002. *Herbicide Resistance Management and Evolution of Zero Tillage – A Success Story*. Research Bulletin, CCS Haryana Agricultural University, Hisar, India, 43 p.

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

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

Heap, I. 2000. International survey of herbicide resistant weeds online. Internet May 2, 2000. Available www.weedscience.com

Malik, R.K. and Singh, S. 1993. Evolving strategies for herbicides use in wheat : Resistance and integrated weed management, pp. 225–238, In: *Proceedings International Symposium Indian Society Weed Science*, Hisar, India, 18–20 Nov. 1993. Vol. I

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

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

Laxmi, V., Gupta, R.K., Swarnalatha, A. and Perwaz, S. 2003. Environmental impact of improved technology – farm level survey and farmers' perception on zero tillage (Case Study). Presented at Roles of Agriculture Workshop 20 - 22 October, 2003 - Rome, Italy. Indira Gandhi Institute of Development Research, Mumbai.

Vincent, D. and Quirke, D. 2002. Controlling *Phalaris minor* – in the Indian rice–wheat belt. 35 p. In: *ACIAR Impact Assessment Series No. 18*. ACIAR, Canberra, Australia.

Yadav, A., Balyan, R.S., Garg, V.K. and Malik, R.K. 1996. Resistance against isoproturon in different biotypes of littleseed canary grass. Test of Agrochemicals and Cultivars No. 17. *Annals of Applied Biology* **128** (Supplement): 34–35.

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Management of invasive alien weeds under changing climate

R.M. Kathiresan

Climatic change due to global warming in the last century has been greater than at any other time during the last millennium. The concentration of carbon dioxide is 33% higher than it was before the industrial revolution. The sea level has been rising at the rate of 2 mm a year since the beginning of 20th century. Droughts and floods have become more common (The Hindu, 2005). The year 1990 was the hottest in last century with all other five of the warmest years in the century falling within the last 22 years. Scientists agree that the planet's temperature has risen by 0.5^{o} C since 1900 and will continue to increase at a faster rate. Because of change in land use pattern, the terrestrial biosphere of 21st century would probably be further impoverished in species richness. The biosphere will be generally more weedy (Walker and Steffen, 1997).

Options for integration in a weed management programme are wide, as several elements such as pattern of cropping, land management practices, agricultural inputs and component enterprises offer ancillary benefits of managing weeds and these could well be integrated with weed control options such as mechanical, biological and chemical measures. Swaminathan (1987) reported an integrated farming system approach to address not only a reliable way of obtaining fairly high productivity with substantial fertilizer economy, but also a concept of ecological soundness leading to sustainable agriculture. Aquatic systems are more delicate considering weed management options as their impact is reflected on multiple resources like water, soil, crops and associated flora and fauna. Further, the invasive spread of weeds in the system is much faster. However, the absence of soil interface, unlike in terrestrial systems, could either hasten or impede the efficacy of management strategies depending upon the nature of such options. Research undertaken in these areas of alternative solutions or weed problems at Annamalai University, India are reviewed here.

Altered rainfall pattern and weed invasivity

Global warming directly reflects on rising sea levels due to melting of ice caps and natural expansion of sea water as it becomes warmer. Consequently, areas adjoining the coast and wetlands could be frequently flooded and the distribution pattern of monsoon rains may alter, through more intense downpours, storms and hurricanes. The meteorological data available at Annamalai University, for the tail end of the Cauveri river delta region of Tamil Nadu State, India, shows that the average annual rainfall during the last 20 years has increased by 233 mm compared to the average of the previous 10 years (1588 and 1355 mm, respectively). In contrast, annual evaporation has reduced by 453 mm (2153 and 1700 mm, respectively) (Table 1).

A phytosociological survey of floristic composition of weeds in this region reveals recent invasion of the wetland rice fields by alien invasive weeds *Leptochloa chinensis* and *Marsilea quadrifolia* (Table 2). These two weed species dominated the native weeds such as *Echinochloa* sp. by virtue of their amphibious adaptation to alternating flooded and residual soil moisture conditions prevalent during recent years in this region (Yaduraju and Kathiresan, 2003).

Table 1. Rainfall and evaporation pattern in the Cauvery river delta region

Period	Annual rainfall (mm)	Annual evaporation (mm)
1980 – 1990	1355	2153
1990 – 2000	1483	1898
2000 – 2010	1588	1700

Leptochloa chinensis owes its invasive behaviour to a longer life span that extends in to the relay crop of mung bean after transplanted rice. These two crops differ widely in soil conditions that they prefer, with transplanted rice surviving in inundated water, where as mung bean thrives in residual soil moisture below 30%. *Leptochloa chinensis* shows adaptation to both the extremes of climate, within the same generation. *M. quadrifolia* is tolerant to most of the grass killer herbicides used like butachlor. Further, frequent floods favour its perpetuation.

Table 2. Floristic composition of weeds in rice fields irrigated by channels in Cauvery river delta (Importance Value Index %)

Weed species	Channel I		Channel II		Channel III	
	1990	2010	1990	2010	1990	2010
Echinochloa sp.	25.56	7.93	28.48	8.01	27.52	4.02
L eptochloa chinensis	22.74	30.41	24.81	29.85	23.64	32.17
Cyperus rotundus	17.23	12.50	22.28	17.25	17.01	4.80
Sphenoclea zeylanica	2.02	6.28	0.68	2.17	1.68	7.24
M. quadrifolia	1.46	39.61	0.63	41.84	0.46	40.32

Surveys in the distributary channels of lake Veeranum during 1990 and 2010 (Table 3) indicate that the invasive alien species *E. crassipes* has invaded the watersheds in north Tamil Nadu. This is because the distribution from lake Veeranum during the period before 1990 was mainly from the river Cauvery, which received water from the adjoining state of Karnataka through Mettur Dam. Accordingly, water was flowing with higher velocity during monsoon periods commencing from June extending upto December. However, after 1990, following a dispute between the two states of Karnataka and Tamilnadu, these channels primarily served the purpose of drainage outlets following flash floods. Such events were frequent during this last 20 year segment. A comparatively lesser quantity of river water received during August

and September was also distributed through the channels. The flood waters from inland wetlands have served as infestation sources of invasive species such as *E. crassipes*.

Table 3. Survey of aquatic weeds in five of the distributary channels of Lake Veeranum in Tamil Nadu (Importance Value Index, %)

Weed species	Channel I		Channel II		Channel III		Channel IV		Channel V	
	1990	2010	1990	2010	1990	2010	1990	2010	1990	2010
Ipom oea reptans	10.3	6.4	21.3	4.8	14.6	3.1	19.6	6.0	27.2	2.9
Typha angustata	1.3	.3	–	–	2.7	–	7.2	2.0	–	–
Leptochloa chinensis	24.30	–	31.0	4.2	19.8	4.9	12.6	–	7.4	1.7
Eichhornia crassipes	–	39.42	–	46.4	–	42.6	7.8	58.6	–	63.4

Increasing temperature regimes and invasive behaviour of weeds

Introduced from Central America as a drought tolerant species suitable for afforestation in arid and semi arid zones of India in 1877, *P. juliflora* has invaded many parts of India. Remote sensing data has predicted expansion of the species in Gujarat at the rate of 25 km^2 per year. Reports predict that by the year 2020, more than 56% of the area in Banni, with rich bio–diversity and grassland ecosystem, would be under *Prosopis*. The most potential invasive feature of this species is typical greater assimilate partioning towards root, leading to extraordinary enlargement in the root mass with rich food reserves, aiding rapid and robust regeneration after mechanical lopping or after revival of ecological stress conditions such as drought or inundation. Studies at Annamalai University have shown that root enlargement in Prosopis species is greatly influenced by the temperature regime of the locality. The annual increase in root biomass is greater in areas where the mean annual temperature is higher in comparison to areas of lesser mean annual temperature (Table 4).

Table 4. Temperature regimes and root biomass enlargement in *Prosopis*

Mean annual temperature (^{0}C)	Mean annual increase in root biomass (kg)	Mean annual increase in shoot biomass (kg)
28	1.9	42
30	4.4	47
32	6.2	56

Increase in shoot biomass due to increasing temperature, though observed, is not as significant as the increase in root biomass. Increase in root biomass largely contributes to the weed's ability to tolerate climatic extremes such as peak summer associated with high temperature and water scarcity and peak monsoon winter with water inundation and flooding. This adaptation favors the weed to predominate over other native flora that are susceptible to any one of the two extremes.

Another similar alien weed of wide occurrence in Asia is *Parthenium hysterophorus*. This weed, originated in Gulf of Mexico and Central South America, has invaded India, Pakistan and Srilanka through cereal and grass seed shipments from USA during 1950s. The weed has been predicted to increase it's invasivity due to ecological niches provided by frequent flooding and higher CO_2 resulting from global warming (Adkins *et al*., 2005). These weeds are observed to possess periodicity of germination and phenology to evade environmental stress conditions (Kathiresan *et al*., 2005). Prevailing maximum temperatures between 30 and 34^0 C linked to available soil moisture status of 40–60% favour germination and flowering, whereas temperatures above 35^{0}C (coinciding with summer) or excessive soil moisture (coinciding with monsoon winter) above 80% is detrimental. The weed has adapted to complete two generations within one year, programming its phenology between these climatic extremes (Table 5).

Table 5. Phyto-eco-sociology of *Parthenium* in Veeranum Ayacut region (Mean of 2000 and 2001)

Months	*Parthenium* important value (%)	Available soil moisture (%)	Mean monthly maximum temperature (°C)
January	–	–	28.6
February	76	55	32.0
March	81	42	32.4
April	84	32	34.3
May	11	29	37.5
June	–	25	36.2
July	–	29	36.0
August	–	40	34.6
September	48	42	33.7
October	51	58	31.6
November	32	81	29.8
December	–	86	28.0

Farming elements offering weed solutions

Fish culture and poultry rearing in rice

Annamalai University has evolved an innovative integrated rice farming system to manage weeds. Through 12 years of rigorous institutional field experimentation with statistically replicated experimental design, the best suited component elements of fish culture and poultry rearing were selected from among rabbit, duck, fish and poultry birds for integration. The optimum mode of integration was also determined, including stocking density of fish fingerlings and poultry birds, size of fish trenches, size of poultry cages and nature and quantity of agro inputs (Kathiresan, 2007a).

The herbivorus feeding habits of fish fingerlings contributes to weed suppression while the acidic pH and allelomediatry principles of poultry waste interferes with weed seed germination (Kathiresan, 2007b). These positive contributions from the two component farming elements are responsible for suppression of both the invasive alien species in rice ecosystems in three districts as shown in Table 6. Pest incidence in rice as shown in Table 7, is also reduced due to integration of the fish culture and poultry components, because of the feeding habits of fish that suppresses the egg masses, larvae and alternate weed hosts of pests.

Table 6. Weed suppression due to fish and poultry components in rice

Location	Weed count/m^2				Weed biomass (g/m^2)			
Districts	*L. chinensis*		*M. quadrifolia*		*L. chinensis*		*M. quadrifolia*	
	Rice alone	R+F+P	Rice alone	R+F+P	Rice alone	R+F+P	Rice alone	R+F+P
Cuddalore	16	11	38	22	56	38	42	26
Villupuram	9	7	26	19	42	31	46	32
Nagapattinam	21	13	42	27	62	34	32	21

Table 7. Rice + fish + poultry and pest incidence in rice

Districts	Leaf damage in after 40 days (%)		*Nilaparvata lugens* population after 7 days	
	Rice alone	Rice+fish+poultry	Rice alone	Rice+fish+poultry
Cuddalore	23.0	18.0	11.0	8.0
Villupuram	21.0	17.0	14.0	10.0
Nagapattinam	17.0	14.0	15.0	11.0

Goats in upland crops

This technology involves rearing goats and using them for manuring as well as plant protection in crops that are grown during the succeeding cropping season. Under existing goat rearing modes, farmers rear goats exclusively on herbs and vegetation available on social and ranching sites. In this intervention farmers are trained to rear the goats allowing them to graze on the weed vegetation (mostly perennial grasses like *Cynodon dactylon* and sedges (like *Cyperus rotundus*) that predominate the cropped lands during the off-season. Reduction in weed biomass in the farmers' fields because of grazing by goats in off–season (Figure 1) was higher in Cuddalore and Nagapattinam districts compared to Villupuram. This is attributed to closer grazing of goats for want of excessive or adequate flushes of weed vegetation in the off-season in these two districts compared to Villupuram.

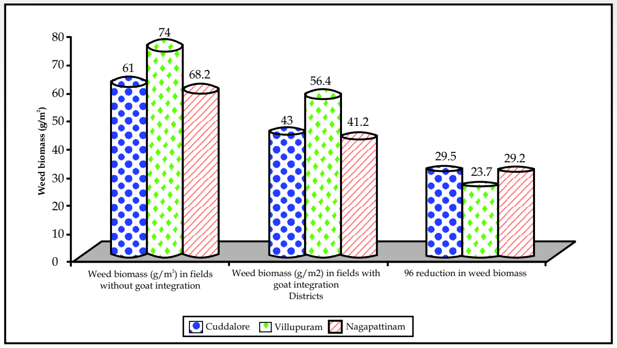


Figure 1. Weed suppression due to goat grazing in upland clusters

Use of pigs for weed control in rice

Experiments during consecutive rice seasons revealed that the use of pigs for burrowing the puddled fields before transplanting of rice was found better than other off-season land management techniques *viz*. summer ploughing and glyphosate spray @ 1.0 kg a.i./ha 45 days before transplanting in reducing nut sedge population (Figure 2). This treatment in combination with incorporation of tamarind husk @ 10 t/ha and hand weeding recorded the highest biomass and weed control indices (Table 8).

Table 8. Weed biomass (g/m^2) and weed control index (%) as influenced by ploughing and weed management

	Mean value	
Main treatments	**Kuruvai**	**Late samba**
Control	–	–
Use of pigs during land preparation	62.9 (47.8)	59.9(51.4)
Off-season ploughing	49.8 (35.0)	51.4 (40.8)
Glyphosate spraying	58.4 (41.2)	55.3 (47.3)
SEd±	1.04	1.09
CD (0.05)	2.08	2.18
Sub-treatments		
Unweeded control	–	–
Twice hand weeding	58.0 (58.1)	56.8 (53.9)
Tamarind husk @ 10 t/ha	52.5 (29.5)	50.3 (36.7)
Oxyfluorfen @ 0.25 kg ai/ha	51.7 (32.3)	49.4 (34.3)
Tamarind husk + hand weeding	59.3 (51.1)	57.3 (56.4)
Oxyfluorfen + hand weeding	55.6 (36.2)	53.5(42.1)
SEd±	1.12	1.13
CD (0.05)	2.24	2.25

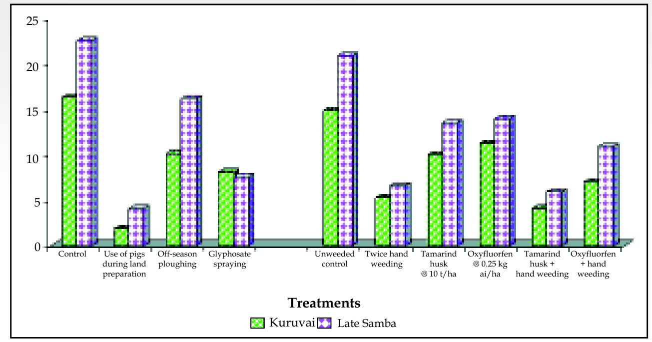


Figure 2. Population of *C. rotundus* on 60 DAT

Burrowing of puddled field by pigs before transplanting of rice, brought all the underground tubers of *C. rotundus* to the surface, many of which were eaten by the pigs, whilst others were skimmed away before final land preparation and levelling. Thus, the treatment was very effective in depleting the soil reserve of tubers of *C. rotundus* which were chiefly responsible for the perennation of the world's worst weed.

Integrated control of invasive *Eichhornia crassipes*

This strategy for managing the aquatic weed water hyacinth is through the integration of the insect biocontrol agent *N. eichhorniae* / *bruchii* with the use of dried plant material of the medicinal herb *C. amboinicus*. This herb is allelopathic on water hyacinth through the mechanism of membrane disruption and electrolyte leakage and the dried plant powder easily gets absorbed into the weed through the leaf scrapings made by the insects (Kathiresan, 2000; Kathiresan, 2007b). Observations made on the weed population at quarterly intervals after implementing this approach in selected water sheds of four districts are furnished in Table 9.

Table 9. Weed population of *Eichhornia crassipes*

Location	Weed population (no./m^2)				
	January 2010	April 2010	July 2010	October 2010	January 2011
Cuddalore	34	4	–	11	20
Villupuram	22	2	4	7	15
Nagapattinam	31	6	–	14	17
Thiruvannamalai	27	9	4	12	14

A mode of utility for the aquatic weed *E. crassipes* was shown to be successful with the extraction of nanofibers using three methods; chemical (alkali and peroxide) and mechanical treatments (TEMPO mediated oxidation treatment). The obtained nanofibers from the weeds using the above three treatments was estimated to be about 5–100 nm in diameter and lengths of several um. From the nanofibers transparent thin film, transparent sheet, paper and the transparent biodegradable nanocomposites were also prepared. The biodegradability test conducted following OECD Guidelines for the Testing of Chemicals OECD 30IB clearly indicates that the compound is readily biodegradable (Patent Application No–1877/ DEL/2010 filed on 11/08/2010 in Intellectual Property of Rights. New Delhi on TEMPO (2,2,6,6– Tetramethylpiperidinyl–1–oxyl radical) mediated catalytic oxidative synthesis of cellulose nanofibers 5–50 nm size from the aquatic weed water hyacinth).

Conclusion

A predominance of small holder farms in Asia offers scope for using component elements in a farming system for sustainable management of weeds that behave invasive in a changing climate. Altered precipitation, evaporation and temperature patterns due to climate change have resulted in weed flora shifts in northern coastal districts of Tamilnadu state, India. In particular, there has been a preponderance of invasive alien species such as *Leptochloa chinensis* and *Marsilea quadrifolia* in wetlands, *Trianthema portulacastrum* in uplands and *Eichhornia crassipes* in aquatic systems. Alteration in the precipitation and evaporation pattern coupled with frequent inundation and drought, increasing temperature regimes and sea-level rises that are regarded as consequences of global warming, would alter the nature of vegetation and agriculture in Asia. Increasing temperature regimes are observed to favor invasive potential of alien weeds in monsoon Asia. Under upland conditions, increasing temperature above 35°C favoured the germination and establishment of *T. portulacastrum*, an invasive weed originated in Tropical Africa. Germination of noxious carrot grass *Parthenium hysterophorus* L. is observed to be triggered by a combination of higher temperature and moderate available soil moisture. Similarly, the rate of increase in root biomass of invasive alien weed *Prosopis juliflora* under increasing temperatures is observed to be higher, increasing it's persistence potential and invasive behavior. Research undertaken at Annamalai University in India is providing some alternative solutions to manage these problematic weeds. Innovative use of fish culture and poultry rearing in rice fields was shown to compliment weed control through 400 on-farm experiments, with biomass reductions of invasive alien species ranging from 31–38%, in these districts. Similarly, using goats for off-season grazing reduced the biomass of weeds in upland crops. For example, biomass of the dominant *T. portulacastrum* declined by 23–29% in 500 on-farm participatory experiments. The invasive weed *E. crassipes* in aquatic systems was controlled in seasonal waterbodies within a season, by innovative and integrated use of insect agent (*Neochetina eichhorniae*) and plant product of *Coleus amboinicus* Utility modes for consuming the extensive biomass of *E. crassipes* have also been explored. Results indicate that tempo mediated extraction of nanofibers offers an innovative tag of utility for management of this weed.

The role of changing climate in triggering the invasive behaviour of certain weed species resulting in a shift in the floristic composition of weeds is becoming obvious. Such a scenario warrants the need for multiple options to address a particular weed problem rather than relying upon unified approach. Accordingly, exploring the feasibility of engaging a

systems approach of integrated farming, indigenous knowledge base and weed utility offers good weed solutions that reinforces sustainability.

References

Adkins, S.W., Navie, S.C. and Dhileepan, K. 2005. *Parthenium* weed in Australia – Research progress and prospects, pp. 11–27. In: *Proceedings of Second International Conference on Parthenium Management*, Bangalore, India.

Kathiresan, R.M. 2000. Allelopathy Potential of Native plants against water hyacinth. *Crop Protection* **19**: 705–708.

Kathiresan, R.M., Gnanavel, I., Anbhazhagan, R., Padmapriya, S.P., Vijayalakshmi, N.K. and Arulchezhian, M.P. 2005. Ecology and control of Parthenium invasion in command area, pp. 77–80. In: *Proceedings of Second International Conference on Parthenium Management, Bangalore*, India.

Kathiresan, R.M. 2007a. Linking Environment and weed management through integrated farm management, pp. 21–26. In: *Proceedings of the 21st Asian – Pacific Weed Science Society Conference.* Colombo, Sri Lanka.

Kathiresan, R.M. 2007b. Integration of elements of farming system for sustainable weed and pest management in the tropics. *Crop Protection* **26**: 424–429.

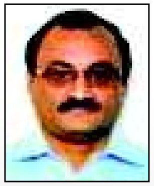
Swaminathan, M.S. 1987. Inaugural address at the International Symposium of sustainable agriculture. The rate of decomposition of green manure crops in rice farming system. International Rice Research Institute, Los Banos, Philippines.

The Hindu. 2005. Report from The Director and Meteorologist, Regional Meteorological Centre, Chennai, India. In: *The Hindu*, dated 26 March, 2005.

Walker, B. and Steffen, W. 1997. An overview of the implications of global change for natural and managed terrestrial ecosystems. *Conservation Ecology* (online) **1**(2): 2. URL: http/www.consecol.org/voll/iss2/art2.

Yaduraju, N.T. and Kathiresan, R.M. 2003. Invasive weeds in the tropics, pp. 59–68. In: *Proceedings of the 19th Asian–Pacific Weed Science Society Conference,* Manila, Philippines. Vol. I.

About the Author



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In march of weed science – What next in my opinion ?

Jay G. Varshney

It is very difficult to write an article on the subject which has been in the heart of a person for more than four decades and more particular to a person who had drafted the Vision document 2020 and provided leadership in the field of weed science at national level for a period of five years. When Dr. A.R. Sharma, my friend and present Director, desired from me to write an article for the Souvenir I was in a great fix. I could not refuse to write the article but at the same time could not think of an appropriate topic to write an article on as my views were known to all weed scientists as I had delivered talks on almost all issues not only once but at several times. To write an article on such known issues would have been repetition and boring to all those who had listened to me earlier. Later on, I thought that I may touch those issues which kept rolling my mind and I could not do much to address them.

After giving my nod to write an article I surfed the institute web site and went through the DWSR Vision 2050. Immediately it crept in my mind that whether it's justifiable to project the vision for any research institution 40 years in advance as the circumstances in next 40 years cannot remain same as on today. But, since these are policy issues decided at the top level in Delhi, it will not be appropriate for me to comment. After going through the document I could not find the differences as imperative in the challenges and strategies projected earlier and stipulated for next 40 years. I am sure that nobody could have predicted anything new in such advance stage. If I was to present it I would have also presented in the same way. The other issues which came to my mind I will discuss ahead.

We are fortunate enough that we have an institution which deals absolutely on the issues related to weeds in our eco system. As known to everybody, National Research Centre for Weed Science was conceptualized with the kind efforts of eminent weed science personalities like Dr. Raj Prasad from Canada and several others. Later on it was agreed to establish NRCWS by ICAR. Dr. Raj Prasad was kind enough to hand over all correspondence to us which were kept in the library at that time.

Accordingly a site selection committee was constituted by ICAR under the kind chairmanship of Dr. V.M. Bhan. The members included Dr. S.K. Mukhopadhyaya, Dr. O.P. Gupta, Dr. S. Sankaran and Member Secretary, Dr. V.N. Saraswat. After visiting several sites it was decided to establish the NRCWS at Jabalpur which started functioning with the joining of Dr. V.M. Bhan as 1st Director on 22nd April, 1989. Later on NRCWS was upgraded as Directorate

of Weed Science Research on 23rd January, 2009 when I was working as Director of the centre.

As the institution has completed 25 years of its existence, it's time that we analyze and introspect our success and failure regarding the issues for which this centre was established. It's a matter of satisfaction that since then many distinguished weed scientists have contributed to NRCWS/DWSR in various ways by shouldering the responsibilities as director/project coordinator, chairman/member, research advisory committees, institute management committees and QRT's etc.

DWSR Vision document 2050 has enumerated the following challenges;

- Weed dynamics in high input intensive production system
- Crop weed interactions under changing climate
- Weeds in conservation agricultural systems
- Development of herbicide resistant weeds
- Herbicide tolerant crops and evolution of super weeds
- Growing infestation of parasitic weeds
- Environment impact of herbicides
- Weeds in organic farming system
- Obnoxious weeds in terrestrial and aquatic environment
- Globalization and introduction of alien invasive weeds
- Continuous monitoring and development of data base
- Dissemination of weed management technology

The issues which have been raised are genuine and need to be addressed with great vigour. However, I would like to add some issues which also need to be addressed as below:

Development of weed management technologies for rainfed situations

We all are aware that most of the crops are grown under moisture stress conditions or under rain dependent agriculture (46–75%) (Table 1). Under moisture stress conditions, on one side, there is acute moisture deficiency and on the other side the existing moisture meant for crops is utilized by weeds in abundance. While working as Director, DWSR, I along with Director, CAZRI, Jodhpur planned a "National Consultation on Weed Management under Moisture Stress Conditions" at Jodhpur. The strategy was to bring the workers who have done some work on weed management under moisture stress conditions or even the senior persons who can give some serious input in to the matter. Unfortunately, we could not find even a single speaker who could deliver a talk on innovative ideas on weed management under moisture stress conditions and the programme had to be dropped.

Table 1. Current Scenario on rainfed situation in India

Category	Grown area (M ha)	Irrigated area (M ha)	Rainfed area (M ha)	Rainfed area (%)
Foodgrains	124.0	58.0	66.0	53.2
Cereals	100.8	54.2	46.5	46.1
Pulses	23.2	3.6	19.5	84.2
Oilseeds	26.5	8.2	18.2	68.8
Commercial crops	14.3	8.0	6.2	74.8

This must be remembered that availability of water for agriculture in future will be a limiting factor. Under moisture stress conditions there is always a risk of crop failure as crop is withered due to moisture shortage and lion's share of which is utilized by weeds, Moreover for effective control of weeds through application of pre emergence or pre planting herbicides minimum soil moisture content is essential. Therefore, intensive research on integrated weed management schedule / technology for rainfed situations is the prime need of the time.

Mitigating the emerging threat of weedy rice in rice growing areas

Weedy rice is the form of *Oryza* species that are variable in appearance and occur in all major rice growing areas. Seed shattering, seed dormancy and competitiveness with cultivated rice enable weedy rice to become a weed. The other characters in weedy rice are vigorous vegetative growth, comparative early maturity, easy shattering. Some variants have long awns while in some variants pericarp colour after milling is red and possess variable seed dormancy. Weedy rice develops in nature by cross and back crossing of cultivated rice (*Oryza sativa*) with wild rice (*Oryza rufipogon*/*Oryza nivara*) making intermediate forms (weedy rice) i.e. *sativa var. fatua* or *O. sativa f. spontanea.*

According to an estimate, global average yield losses due to weedy rice figures 12–22% (Norton, 2010, IRRI, Philippines). In India the infestation due to weedy rice ranges in 5–60% in different states (Varshney and Tiwari, 2008).The inactivation of the CTD phosphatase like gene OsCPL1 enhances the development of the abscission layer and seed shattering in rice (Ji *et al.*, 2010). *Oryza sativa* conserved carboxy terminal domain phosphatase–like gene OsCPL1. Weedy rice consumes more nutrients and water meant for the rice crop but is not harvestable due to high intensity of shattering. Biotechnological innovation can be helpful to activate and conserve the carboxy terminal domain phosphatase like gene OsCPL1 responsible for reduction in shattering in nature.

Management of alien invasive weed species

Majority of the important weed species in India have been introduced in the past either accidentally or as contaminants in food or grain imports or deliberately. A large portion of our country's agricultural and non agricultural area has been invaded by a number of unwanted plants which are aliens. We are aware that *Parthenium hysterophorus* and *Phalaris minor* got introduced with import of Mexican wheat in the country in sixties. *Parthenium hysterophorus*

has now covered almost 35 M ha in the country. There is practically no state in the country where this deadly weed is not available. *Phalaris minor* is prevalent in wheat and all other *Rabi* crops especially in the north and central India. *Lantana camara* is a serious menace particularly in Uttar Pradesh, Madhya Pradesh, Himachal Pradesh, Punjab, Haryana, North-eastern region and has also spread to Southern states. *Chromolaenea odorata, Ageratum houstonianum, Mikania mirantha* are creating havoc in plantation crops in Karnataka, Tamil Nadu, Maharashtra, West Bengal and NE states. Water hyacinth, Salvania and alligator weed are a great nuisance to fisheries, navigation, irrigation and in tourism. Severe infestation of *Mimosa* species in Kaziranga national park in Assam has become a very serious problem to the rhinos in the park. Recently with the import of 6.2 M tons of wheat from several countries, 5 weeds viz., *Cenchrus tribuloides, Solanum carolinese, Viola arvensis, Cynoglossum officianale, Ambrosia trifida* which are of quarantine nature have entered in the country. DWSR, Jabalpur in collaboration with DPPQS, Faridabad conceptualized, planned, implemented and monitored the project in all the 267 districts of 10 states for early detection of such weeds which appear to have established. Unfortunately, DAC did not proceed further for further detection, occurrence and removal of such weeds which may cause similar havoc as created by *Parthenium*, *Phalaris* or other weeds. There is an urgent need to analyze the risk factor associated with different exotic weeds to design safe guards and lower the risk of their entry and spread.

Considering the great risks involved with such weeds and other pests a national programme on Integrated National Biosecurity System (INBS) was conceptualized and finalized during 2008–09 by the DAC. I, as a core expert, gave my inputs and even drafted/developed the technical details to mitigate the challenges. Its proclamation as law is long awaited which needs to be hastened by DAC and Law Ministry.

Effects of climate change on crop–weed competition, distribution and productivity

Growth of crop and weeds is influenced under changing climate. Weeds in the ecosystem are inevitable and how crops interact with weeds under varied climate is a matter of concern. This includes change / increase in CO_2 temperature, ozone and so on. Studies so far carried out have revealed that increase in CO_2 encourages growth of crops as well as weeds. Detailed investigations are required to be carried out on the impact of elevated CO_2 on different crops and weeds alone and with prominent weeds associated in a particular crop. Such studies are further needed to be taken under different situations such as soil moisture content, environmental humidity, soil and atmospheric temperature. Further, the effect of different weed control techniques including herbicides application need to be evaluated under the impact of elevated CO_2 and other climatic conditions.

We are the pioneers in having a 3–ring FACE facility in our institute and also have qualified scientists. The detailed studies on effect of elevated CO_2 may be further strengthened. Other facilities for studying the impact of other climatic factors on crop weed interaction can be created if needed.

Development of herbicide resistance in weeds

It's an established fact that certain prominent weeds have got resistance to one or more herbicides. *Phalaris minor* has been found to have resistance to isoproturon. It is also reported that it is getting resistance to sulfosulfuron or even clodinafop in few cases in Haryana. If in the cropping season you happen to visit different wheat growing areas in UP, Haryana etc., you will find that almost all fields are infested with *Phalaris minor* vigorously though the crop has been treated with existing herbicides. One may say that this situation might be due to use of spurious herbicides but in research experiments the resistance has also been observed in Hissar and Jabalpur, etc. Glyphosate, a prominent herbicide, does not control many weeds as per records available. Genetically modified herbicide resistant crops may lead to development of super weeds which may create a challenge if the cultivation of such crops comes into existence. Therefore, it would be a great challenge to develop molecules which can break the resistance.

Table 2. Herbicide resistance in different weed species

Herbicide	Weed species	Crop	Country
Trifluralin	*Eleusine indica* *Setaria viridis*	Cotton Cotton	USA Canada
Chlorsulfuron	Five species	Wheat	USA
Paraquat	*Conyza sp.* *Epilobium ciliatum* *Poa annua* *Lolium perenne*	---	Australia USA
2,4-D	*Sinapsis sp.* *Ranunculus acris*	Wheat	New Zealand
MCPA	*Cardus nutans*		
Cholrotoluron	*Alopecurus myosuroides*	Wheat	England
Diclofop-methyl	*Lolium rigidum*	Wheat	Australia
Isoproturon	*Phalaris minor*	Wheat	India

Need of post–emergence herbicides and enhancing herbicide persistence

Weeds are serious constraints in realizing optimum yield potential in pulses and oilseeds. Though there are several effective herbicides for managing weeds in these crops but they are pre-emergence in nature, and take care for initial 15–20 days in *Kharif* and 25–30 days in *Rabi*. Moreover, the time available for applying the pre-emergence herbicide in *Kharif* is either not available or is very less. With seeding, rains occur and no time is left for herbicide application. Therefore, there is a great need of post emergence herbicides in pulses and oilseeds and also in several other crops. To take care of second flush which comes out normally in 30–45 days, or the pre-emergence herbicide must have the longer persistence capable to take care of the second flush of weed under normal grown situation. Research is required to be carried out on this aspect.

Environment impact of herbicides

High dose of several current herbicides in cereals, pulses and other food crops may carry risk of herbicide residue and affect export. Though enough research has been carried out in reducing the doses of herbicides, but still lot has to be done. Herbicides residues may also damage the succeeding crop if used in continuation. There are several reports that different herbicide contamination has been found in ground water in significant proportion in various parts of the country.

There are several reports that certain herbicides such as diazinon, pendimethalin, dicamba, metolachlor cause cancer and other diseases in human beings as observed by significant exposure–response associations with lung cancer. Alachlor has been found to be associated with lymph hematopoietic and methyl bromide associated with prostate cancer. As significantly higher prostate cancer incidences have been observed among farmers in both North Carolina and Iowa than general population of the same age and race. Due to the rampant use of herbicides (alachlor, diazinon, atrazine), men in rural areas have lower sperm counts than their urban peers and causing potential reproductive problems.

It has been observed that herbicides affect non target organisms too. Exposure to freshly dried roundup (glyphosate) killed over 50% of three species of beneficial insects: a parasitoid wasp, a lacewing and a ladybug. Triclopyr inhibits soil bacteria that transform ammonia into nitrite; glyphosate reduces growth and activity of both free-living nitrogen–fixing bacteria in soil and those that live in nodules on plant root. 2,4-D reduces nitrogen fixation by the bacteria that live on the roots of bean plants, reduces the growth and activity of N_2–fixing blue-green algae, and inhibits the transformation by soil bacteria of ammonia into nitrates.

Therefore enough research is needed to monitor the existing level of pesticide residues in food grains, vegetables and other crops including non-target organisms like fish etc which consume the herbicide slowly and gradually. The effect of such herbicides in runoff water and water bodies needs to be monitored regularly. As known, herbicides in grain/produce are not found in significant quantity to cause harm to human health significantly, but, it has been observed that secondary metabolites of such herbicides may cause significant adverse effect on human, animals, flora and fauna and aquatic creatures which needs to be monitored and their effect studied regularly. The institute has modern laboratory and also possess HPLC, LCMS–MS etc. capable of undertaking such analysis. In AICRP-WC also there are several residue scientists who can undertake such work in the institute laboratory.

Need of nano-herbicides, ecofriendly bioherbicides for organic weed management

Considering the damage to human, animals, flora and fauna due to herbicides is a great need to develop nano herbicides. The development of ecofriendly or bioherbicides may prove a very significant step in this direction. Practically not much research work has been carried out on weed management through herbicides in vegetables, medicinal and aromatic plants, horticultural and plantations crops. In organic agriculture the manual weeding or weeding through tools is the only alternative left which has its own limitations in several ways. Research need to be undertaken on priority as organic agriculture is popularizing now days not only because of health hazards due to pesticides, but for earning a huge foreign exchange too.

Weed management under conservation agriculture

This is an important issue. While recommending zero tillage to farmers we should be a little cautious. Research results reveal that zero or minimum tillage is not suitable for all soil types and climatic conditions. Minimum tillage criteria has to be ascertained for different situations. I personally observed profuse growth of *Cyperus rotundus* in second year of a zero tillage experiment. It is, therefore, suggested that more research is needed in conservation agriculture under different agro-climatic conditions for its better adoption.

Constraints

The basic constraint in DWSR has been the limited resources, particularly the trained manpower. The existing sanctioned strength of the scientists is 27 at the headquarters. Some of the scientists who are initially posted don't have basic knowledge of weed science and need enough time to understand it. In fact, it has never been realized that weed science is a different discipline which also necessitates the knowledge of agronomy, taxonomy, physiology and organic chemistry in addition to weed science as a core subject.

There are very few scientists in the country who have acquired such knowledge to become a successful weed scientist. In DWSR, most of the existing scientists have acquired excellent knowledge of weed science. In AICRP–WC, barring few centres, any one is posted as a weed scientist without realizing that whether the new incumbent has sufficient knowledge of weed science or not but is expected to work as a weed scientist. During my working as Director at DWSR, I raised the issue many times with the concerning VCs but they also had many technical and administrative limitations.

During my entire stay of 5 years the existing strength of scientists remained almost 15–16 at a time . In some of the disciplines there are hardly 1 or 2 scientists. The challenging issues are huge. The expectations are large, but scientists are only few. Under such a situation we have to prioritize the issues. During my working as Director, I had decided to create centres of excellences in AICRP to shoulder the specific responsibilities such as parasitic weeds, aquatic weeds and herbicide residue and toxicity etc.

When I was working as Director, I used to repeatedly say that the policy planners must know the importance of weed science as weeds alone cause heavy loss to yield in the range of an average 37% to total failure of the crop. The weeds rob nutrients and water meant for crop. If we are able to manage weeds in a system, then in addition of increasing the yield very significantly, we are also saving the nutrients and moisture. Weeds also harbour insect pests and diseases and managing the weeds may reduce the expenditure on pesticides use. If the policy planners don't know the importance of weed science, then how they can support the efforts of weeds scientists? Considering this, I invited Dr. K. Kasturirangan, the then Member, Planning Commission, for giving foundation lecture on 23rd January, 2010. He planned to stay

full two days at DWSR but due to hostile weather at that time he could reach a day late. He accompanied a team of 7 advisors to study the importance of weed science.

I am happy that Dr. S. Ayyappan, the present DG, realized the importance of weed science and asked me to convene a meeting of all Directors and Project Coordinators of crops, Horticulture and NRM divisions under ICAR and accordingly a meeting was held in May, 2010 at DWSR, Jabalpur under his chairmanship. DDGs of crops, horticulture and extension participated in the said meeting. Prior to 2006, it was even thought to shut the NRCWS or merge it with any other institute due to this reason.

I am of the opinion that the Director of an institute can do wonders provided he is fully supported not only in terms of infrastructure and manpower but also by boosting his enthusiasm or morale in discharging duties without fear.

About the Author

Dr. Jay G. Varshney is known for his research on sustainability in pulse-based cropping sytems, weed dynamics and management, and role of adjuvants in enhancing herbicide-use efficiency. He was National Coordinator, AICRP on prominent grain legume crops; Head, Crop Production Division, IIPR, Kanpur; and Founder Head, Regional Centre, Directorate of Pulses Research. He was Director, Directorate of Weed Science Research, Jabalpur from 2006-2011.

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My journey to DWR and a mid-term self-appraisal

A.R. Sharma

Weed science has been my favourite area of study and research over the years. However, I did not get the exclusive opportunity to concentrate on this subject before my joining at this Directorate. In fact, I consider it a matter of great privilege to be the Director during the Silver Jubilee Year of the Directorate and responsible for organizing the activities including the various celebrations befitting the occasion. Although I am here for a little more than 2 years, I have learnt a lot about weeds and the functioning of this Directorate. I wish to share my personal experiences on the subject and impressions about this unique institute which is considered to be the only one of its kind devoted to the cause of weed management.

Being the son of a farming family in Himachal Pradesh, I have been actively involved in the cultivation of crops and performing other household activities since my childhood. In fact, after school, I often used to spend most of my time helping my parents in ploughing, sowing, fertilizer application, weeding, interculturing, harvesting, threshing, cleaning and processing of crops like maize, wheat, greengram, blackgram, sesame, cowpea, mustard, toria, sugarcane, turmeric, colocasia and other vegetables grown in our fields. Manual weeding was an important activity in all these crops but one of the most tedious, difficult and time–consuming. We did not allow weeds to grow along with crops in early stages through repeated manual weedings using hand hoes, while the weeds emerging later in the season in crops like maize and wheat were often used as fodder for domestic animals. Mulching with brought–in vegetative materials from trees and shrubs growing in waste lands / pasture lands was also a common practice in rainy season crops which helped to control weeds and soil erosion, improve soil moisture conservation and provide nutrients to the current as well as subsequent crops. This practice is now rarely followed due to operational constraints and high cost. Some weeds like *Ageratum* and *Lantana* gradually became very serious in both cropped and non–cropped lands which also posed serious health hazards.

Initial studies and research in weed science

I was one of the best students in my school and always secured the top rank as well as scholarship in all the board examinations. Despite that I was not sure of continuing my studies at higher level because of family circumstances. It was my sheer hard work and continuous good performance that got me admitted to B.Sc. Agriculture programme at the College of Agriculture, Palampur, after my father was assured of adequate financial support in the form of scholarship. I did not look back since then and crossed all hurdles by virtue of academic excellence in different examinations. In fact, I always top scored in most of my college and university level examinations and availed scholarship throughout.

* *The views expressed in this article are entirely personal based on author's own experiences and assessment, and no motives of any kind should be attached.*

As a graduate student of agricultural science with elective subject of Agronomy, I was fascinated by the two courses on weed science. In fact, it was due to the teaching of Prof. N.N. Angiras at Palampur that I developed interest in weed science and thought of pursuing this subject in higher studies. I conducted research work on weed management in blackgram and field peas as part of my M.Sc. programme at PAU, Ludhiana and published two research articles in scientific journals at that time. Somehow I could not continue research on weeds in the Ph.D. programme at IIT, Kharagpur because Prof. B.N. Mittra had something else in his mind for me which also paid rich dividends later. During my professional career at different institutes including CRRI, PAU, CSWCRTI and IARI, I could make some definite contributions to the subject of weed control besides nutrient and tillage management in diversified crops and cropping systems.

Conservation tillage has been talked about as an important area of research in resource management since early 1990s. This involved growing of crops with zero or minimum tillage but posed a serious problem of weeds. I was sanctioned a project on this subject under NATP–CGP at CSWCRTI, Dehradun and conducted extensive studies in maize–wheat cropping system. It was demonstrated that weeds can be effectively controlled through *in situ* or brought–in mulching and herbicide use under zero / minimum tillage conditions. This led me to further intensify research after my joining at IARI, New Delhi in 2001. Systematic investigations were made on tillage, stale seed–bed, mulching, residue, nutrient and weed management in different cropping systems involving maize, cotton, pigeonpea, soybean and greengram in rainy season, followed by wheat, mustard, linseed and chickpea in the *rabi* season. Following the success of these trials, a Challenge Programme on conservation agriculture was undertaken from 2008 under my leadership which showed promising results. These programmes are continuing even now and have become a major attraction for the visiting dignitaries to show the long–term effects of conservation agriculture–based practices.

Joining at DWSR

There was a desire in me to do research work exclusively on weeds. I had even thought of getting transfer to this institute in the early stage of my professional career, which somehow did not materialize. Therefore, it was a sort of ambition fulfilled when I was selected to work at this Directorate in March 2012. I had visited this Directorate earlier once in 2005, and was impressed with the infrastructure and facilities here. However, I never thought that I shall come here as Director and perform the bigger responsibility of managing weed science research in the country. Before joining here, I was aware of my weaknesses and the environment prevailing at the Directorate. Despite some apprehensions, I had no second thought to come to this place and contribute my bit to the growth and development of this institute. During my first interaction with the staff, I mentioned that I have come here with an open mind to make a new beginning, ignoring all that may have happened in the past. I also mentioned that we need to work hard to achieve excellence and take this Directorate to a higher level. For achieving this, the necessary support and encouragement will be provided to the good workers while the non–workers will be made to realize their responsibility and asked to mend their ways accordingly.

Initial impressions

Directorate is housed in an impressive building designed architecturally in 'W' shape (meaning weed), with beautiful landscape in the front, which to any outside visitor gives the initial impression of a 5–star hotel. The view from the entrance gate becomes more fascinating during night when the lights are put on special occasions. I was informed that the credit should be given to Dr. V.M. Bhan, the first Director who worked very hard and surveyed several institutes to give a final shape to this plan. Many visitors appreciate the vision of Dr. Bhan in developing this Directorate.

When I joined here, I was highly impressed with the landscape, neat and clean surroundings, offices / laboratories, Director's chamber, residence and other infrastructure. This was a unique experience because I had not seen such facilities at other institutes including CRRI, CSWCRTI and even IARI where I worked or other ICAR institutes which I visited over the years. Gradually I realized that this was the best institute in terms of infrastructure and had all the facilities required for a modern institute. Although it is a small Directorate in terms of manpower with less than a score of scientists in position and total staff strength of around 70, we could claim all India presence due to inclusion of 72 scientists and 100 non–scientific staff in the AICRP on Weed Control centres at 19 agricultural universities of the country. I considered myself fortunate to be a part of this family and sometimes wondered about the negative impression this Directorate had developed in the ICAR.

Infrastructure facilities

Over the 25 years of the establishment of the Directorate, excellent infrastructure has been developed which is comparable to any world class institute. Main building of the Directorate consists of a 3–storey front side and 2–storey middle arm of the alphabet 'W' (the two side wings are yet to be constructed). The ground floor or the basement was originally planned to be used as parking but it was subsequently remodeled and utilized as sitting space for scientists and laboratories. All the scientists irrespective of status have individual chambers on one side of the building with latest models of computers and internet connectivity, and most of the rooms are also provided with air conditioners. Well–equipped laboratories with all the required equipments are located on the other side, just opposite to the concerned scientist's sitting room. Similarly, all the administrative and technical staff are provided with excellent sitting/working places with the required facilities. There is a library with the latest books, journals and other e–resources. Further, two conference halls, one committee room, VIP room, visitors' room, DKMA Cell, PME Cell, Rajbhasha Cell, ITMU, AICRP–WC unit, ISWS office and others are also located in the building.

Besides the main building, there are other small buildings, where the environment chambers, soil processing laboratory, documentation and reprographic unit, field laboratories, farm offices, workshop, godowns, stores, implements/threshing yard, net house/polyhouses,

Director's residence, agro–waste compost unit and 33 KV electric station are located within the premises of the Directorate. Containment facility with controlled temperature, humidity and light, OTCs and FACE are excellent facilities for conducting research on crop–weed competition under changing climate. A working model of phytoremediation has also been developed. A guest house with 9 rooms and 2 staff quarters are available outside the main campus about 100 m away from main gate. Unfortunately, there is no campus life for the families here, because almost all the staff members have their own houses in the city.

The Directorate covers a total land area of 150 acres, of which about 120 acres are available for field experiments. The entire research farm is well protected with a cemented wall all around and the fields are suitably divided into different blocks, with underground irrigation pipelines and provision for drainage as well. There are 4 tube wells, 3 water harvesting tanks, and orchards of mango, citrus, guava, bel, pomegranate, and a temple as well within the campus. Ground water used for irrigation as well as drinking purposes is of very good quality and available in plenty. The Directorate enjoys a special privilege of near 24 hour electricity without any scheduled cut or breakdown through a dedicated power transmission line. Overall, it is a model farm, ideal for weed science research with all kinds of weed flora present in diversified cropping systems.

Salient achievements

The Directorate has played a meaningful role in developing weed management technologies in diversified cropping systems and also for non–crop lands including aquatic situations. We can righty claim that solutions are now available for managing weeds through the adoption of cultural, mechanical, chemical and biological measures. Herbicide residues have been monitored in soil, water and food chain, and their degradation and mitigation measures developed. The Directorate has earned recognition for creating awareness and successful management of *Parthenium* through Mexican beetle throughout the country. Besides, various kinds of literature in the form of research articles, bulletins, leaflets, folders, weed atlas, e–modules for identification of weeds, seedlings and seeds have been prepared.

We have also imparted trainings on improved weed management technologies to a large number of stakeholders including teachers and scientists of SAUs and ICAR Institutes, extension officers of state department of agriculture, NGOs, Cooperatives, students and farmers. The Directorate has fulfilled the mandated objectives to a reasonable extent and served the cause of farming community.

New initiatives

Despite the significant achievements made over the years, the contributions of the Directorate and general administration have been a subject of discussion at the ICAR. Immediately after my joining, a meeting of the top research management officials concerned with weed science was called by the Director General, ICAR on 22 April, 2012. The meeting was attended by all the DDGs, most ADGs, Chairman of RAC and QRT of the Directorate, Directors of some institutes and invited experts to chalk out a strategy for strengthening research, revamping administration and improving the visibility of the Directorate. Thereafter, I attended all the meetings with different Directors of ICAR Institutes which were organized to discuss the XII Plan proposals during May–June, 2012. I also attended the meetings of the regional committee of different zones held during July to November, 2012. The purpose was to gather inputs and consolidate the ideas to reorganize the activities on weed management. Following this marathon exercise, we took several initiatives from June 2012 as follows:

1. More than 30 research projects running at this Directorate were reorganized into five major research programmes. Focussed programmes on conservation agriculture, climate change, problematic weeds, herbicide residues and on–farm research were launched from 2012–13 in a truly multi–disciplinary mode.

2. Six Nodal Officers were identified from HQ for effective collaboration with ICAR Institutes of Crop Science, Horticulture Science and NRM Division in different regions of the country. These officers are interacting with the concerned identified scientist and also visiting these institutes for the refinement of their weed management programme.

3. Network research programmes of AICRP on Weed Control were strengthened in the Annual Review Meeting held at KAU, Thrissur during April, 2012 and further at CSKHPKVV, Palampur during April, 2013. An effective system of monitoring research and extension work at 22 centres of AICRP on Weed Control was developed. The identified Nodal Officers from the HQ are effectively monitoring and evaluating the progress of these centres.

4. A major initiative was taken to show visibility of our research efforts on the farmers' fields. Six teams, each with three scientists, were constituted, and assigned a cluster of 2–3 villages, located about 50–100 km from Jabalpur, for validating, refining and disseminating weed management technologies. Each member of the team is visiting the locality on a specific day every week; thus spending about 15–20% of his time for 'On–Farm Research' in a farmer participatory mode.

5. A major research programme on weed management in conservation agriculture systems was undertaken at the HQ as well as AICRP–WC centres. The entire research farm of the Directorate was covered under zero–till sown crops from 2012–13, and burning of any kind of residue including weeds was completely stopped. A large composting unit was established for turning available biomass into nutrient–rich manure / vermicompost.

6. Initiatives for modernization and reducing file / paper work in the office were undertaken. Wi-Fi internet connectivity, biometric system for marking attendance and Online Leave Management System were introduced.

7. Website of the Directorate was improved, both in content and quality. All the information of weed database including weed seed / seedling identification was uploaded on the website.

8. Research farm was developed as a 'Model' based on the principles of conservation agriculture involving laser land leveling, mechanization of field operations, zero–till sowing, residue management *in situ*, biomass composting, crop diversification, beautification with ornamental plantations, boundary plantations, renovation of internal roads, ponds for water harvesting and facilitating drainage, layout and reorganization of blocks etc.

9. New generation farm machinery, *viz.* laser leveler, happy seeder, roto–till drill, multi–crop zero–till drill, multi–crop seed–cum–fertilizer drill, multi–boom tractor operated sprayer, power weeder, reaper, trailed type disc harrow, disc plough, mould board plough, rotavator, disc bund former, dozer blade, tractor–mounted front loader etc. were procured. This ensured prefect leveling of fields and near full mechanization of the field operations.

10. Technology park displaying the weed management technologies in different crops was developed.

11. Joint visits with all scientists were organized to examine the field / net house experiments on a regular basis.

12. An Agreement of Understanding was signed in 2012 with JNKVV and National Seeds Corporation for quality seed production on non–experimental area of the research farm. More than 100 t seed of rice, soybean, wheat, maize and chickpea is being produced annually.

13. Training programmes on "Advances in Weed Management" were initiated for the scientists and teachers of ICAR institutes, SAUs, KVKs, and also extension officers of state department of agriculture, NGOs, progressive farmers and students. More than one dozen such programmes were organized since 2012

14. '*Parthenium* Awareness Week' was organized on a much larger scale during 2012 and 2013 involving all ICAR institutes, SAUs, KVKs, state department of agriculture, NGOs, various schools and colleges and other stakeholders. The various events were widely covered by the national and local print and electronic media. The Directorate received the ICAR award for the first time for this outstanding work.

15. Research farm of the Directorate was made *Parthenium*–free, and efforts are on to make it free from weedy rice, para grass, *Saccharum* and other problem weeds as well. Isolated sick plots of *Orobanche* and weedy rice for undertaking precise research work have been developed. An appeal is also being made to all ICAR Institutes, SAUs, KVKs etc. to make their campuses free from *Parthenium*.

16. Monthly meetings with scientists including technical seminars by the scientists of the Directorate as well as outside experts were started.

17. Meeting of Institute Management Committee (IMC) was held after a gap of 3 years, and the report of QRT was submitted on time. The IRC meetings were held under the guidance of external experts.

18. PME cell was reorganized and strengthened. All records of RPFs were updated and computerized, and contract research / consultancy projects were implemented through the PME Cell following the prescribed ICAR guidelines. Applications for awards, assessment of scientists, articles for publication etc. were duly examined as per norms and routed through the PME Cell.

19. Most equipments lying idle for several years were repaired and made functional, such as ovens, refrigerators, balances, autoclaves, incubators, shakers, microscopes, water bath, heating mantle, mixer / grinder, vacuum compressor, pH meter, conductivity meters etc. FACE facility which was non–functional for nearly two years was repaired and further improved. Two laboratories on Plant Physiology and Environmental Chambers were renovated.

20. Two projects on weed utilization approved under NFBSFARA were initiated. Many proposals for external funding were submitted to different agencies. Collaboration with JNKVV, IGKVV, RDVV and other universities / colleges for PG students' research was started.

21. Thematic bulletins on 'DWSR technologies', 'Herbicide use in Indian agriculture', 'Input–use efficiency through weed management', 'Weed utilization', 'Herbicide tolerant crops', 'Parasitic weeds', 'Major weeds of India', 'Weed management in conservation agriculture systems', Weed management in organic farming systems', 'Weed management in agroforestry systems', 'Weed management in agri–horticulture systems', 'Allelochemicals and weed management', 'Phytoremediation through aquatic weeds', 'Invasive weeds and their management', 'Crop–weed interactions under changing climate', 'Weedy rice and its management', 'Aquatic weed management', 'Herbicide residues and their mitigation', 'Adjuvants for enhancing herbicide efficacy', 'Bioherbicides', 'Yield loss assessment due to weeds', 'Impact assessment of weed management technologies' and 'Statistical treatment of weed control data' were planned and are in various stages of publication.

22. Silver Jubilee Publications based on the contributions made in different areas, viz. 'Marching ahead', 'Souvenir', 'Success stories', '25 years in the service of nation', 'Glorious 25 years', 'Publications' and others were planned and are under printing.

23. The load of non–scientific activities on the scientists has been considerably reduced, and passed on to the technical staff. This has ensured greater time availability and peace of mind to the scientists to concentrate on their research work.

24. All the days as per instructions of the Council were organized, *viz.* Agricultural Education Day, Foundation day, Innovative Farmers Day, Industry Day and National Science Day.

25. Rule of law was established at the Directorate, and violation of norms in administrative and financial management was checked. Many cases pending in the legal/vigilance section, ICAR were resolved. Irrational distribution of honorarium was stopped.

26. Issues between the two factions of Indian Society of Weed Science were resolved. Elections for constituting a new representative Executive Council were conducted in a fair and transparent manner during December, 2012. The Society is now back on track and the Indian Journal of Weed Science received a reasonably good NAAS rating of 3.94.

27. Director's residence in the campus, which was constructed in 2006 and remained virtually unoccupied since then, was occupied by me immediately after joining; thus settling a major audit para every year.

28. Other initiatives including mass plantation programme by the staff, establishment of bee farming and fisheries units, orchard rejuvenation, cleanliness drive within and outside the campus have been undertaken recently for further impressing our visibility.

My intention is not to applaud the initiatives and achievements listed above, which are in fact only a small fraction of the total work that needs to be done at the Directorate. We often claim that we are the only institute in the whole world dealing exclusively with weed science but this needs to be proved through our actions and high quality research output. It has been my feeling that our research is not of sufficiently high standard. In fact we do not stand anywhere in terms of quality research in weed science when compared with other research institutions elsewhere. The research publications of our scientists are not in good journals, which have affected our visibility to the outside world. We need to take more initiatives to further improve the quality of our research, training and extension through which only we can raise our head high in the coming years.

Some concerns

In my opinion, a great deal of change has occurred at this Directorate since March 2012. We have been able to make a definite improvement in many areas which is visible all around. We have been able to resolve some of the old pending issues, and fortunately no new problems related to administration and financial management have cropped up so far. The Directorate is definitely in a better condition now than what it was earlier. Many visiting dignitaries have also appreciated the efforts made. An atmosphere of fear and ill–will has been replaced with a congenial environment where everyone can express his grievances without any hesitation or other limitations.

Notwithstanding the achievements made, there are some areas where no definite progress has been made. A few of these are mentioned below :

1. We do reasonably good quality research, which of course requires further improvement. There is required to be a greater involvement of scientists in the planning and execution of experiments, data recording, compilation, analysis and interpretation to generate better quality research output.

2. Research publications both in terms of number and quality have been abysmally poor. Despite repeated requests and persuasions, research publications record has not shown any improvement, which is a mere 0.5–0.6 per scientist per annum. Some scientists have not a single research article to their credit, not only in the last 2-3 years but also in the last 5–10 years.

3. No publications / bulletins have been brought out based on the work done over the last 25 years during the Silver Jubilee Year. This is despite the fact that we took initiative in this regard in May–June 2013 to complete these publications by the 26th Foundation Day on 22 April, 2014.

4. Scientific on–farm research is still lacking despite initiation of a major programme in 2012. All scientists irrespective of the discipline need to devote an adequate share of their time for testing, verifying and validating the techniques and technologies developed by them in a farmer participatory mode.

5. Despite having sufficient funds for tribal area research and development, we have not been able to undertake any activity in the identified Mandla and Dindori districts of Madhya Pradesh.

6. Monitoring and evaluation of AICRP on Weed Control centres has not shown sufficient improvement despite identification of Nodal Officers for different zones/ themes. The 22 centres of AICRP–WC are our strength and we must generate quality information through them.

7. There has not been sufficient number of externally–funded research projects submitted by the scientists despite persistent efforts.

8. The recommendations made by different review committees like QRT, RAC, IRC and IMC have not been adequately acted upon, which often invited adverse comments from the members and also from the Council.

9. There is a lack of initiative on the part of different individuals to do new things and differently.

10. Most of our scientists have not been able to get their assessment from the due date because of poor record of scientific contributions including research publications. This is a matter of concern and requires serious introspection.

11. Several lectures by outstanding senior level scientists and young achievers from other institutes were organized to motivate our staff members to bring out the best from them. However, the desired results have not been forthcoming.

12. We have not been able to stick to the very reasonable deadlines fixed for a particular assignment on several occasions. In fact some persons assigned a given job often failed to deliver any output even after two years. Some of them have become very complacent and easy–going type, take things very casually and often do not bother even after repeated instructions.

13. It has been a matter of concern that some of the very good scientists did not continue at this Directorate and left to other institutes out of sheer frustration. It is equally unfortunate that we are not able to attract good people to this Directorate because of our not so good track record.

14. There were several institutes established by the ICAR in the late 1980s including the DWSR. It has been my feeling that most other institutes have progressed better and made a mark in terms of scientific contributions such as quality research publications, awards, fellowships, externally–funded projects, acquiring high positions elsewhere, etc. Our record in this regard requires considerable improvement.

15. ICAR has designed some guidelines for evaluating the performance of scientists and also of the institute as a whole, such as HYPM, RFD, performance indicators, publications, etc. Unfortunately, our Directorate does not figure among the best ones.

Some suggestions

It is often mentioned that not much has changed in weed science over the years, and we are doing routine and monotonous type of research with a conventional mindset. We must change with time to address the present day requirement and future challenges. It is now time to reorient our strategies towards more problem-solving research in a multidisciplinary mode to develop technologies for adoption on the farmers' fields. A few of suggestions for better quality and visibility of research are given below:

- Disciplinary to multi-disciplinary approach
- Crop-based to cropping system–based management
- Small plot to large plot field experimentation
- Manual operations to machine-based agriculture
- Productivity to profitability and value addition-based technologies
- On-station adoption of the technologies developed
- On-farm testing and verification of technologies generated
- Intensive data collection – below ground, soil and plant analysis
- Sound statistical analysis and interpretation of data
- Input-use efficiency – economics, water, nutrient, energy, weed control
- Research publications in highly rated journals

There is also required to change the mindset of the people connected with research work. Most of us have become used to a very easy-going and comfortable lifestyle despite having excellent opportunities in terms of funding, information sharing and facilities. It is my view that the quality of research has not improved much over the years, rather it has come down, when we compare our standards with the stalwarts of 1970s and 1980s. A combination of factors is responsible for this downslide including the present personal policies for assessment. We need to do serious introspection and analyze our contributions vis-a-vis the resources invested on us. We, the elite class, owe much greater responsibility towards nation building, which we should do by fully justifying our existence and contributions for alleviating the sufferings of the farming community. As often said, there is no point in doing research which is of no use, and wasting resources of the country.

I wish to offer the following pieces of unsolicited advice to all the staff members of the Directorate based on my personal experiences as a research scientist for nearly 3 decades while working in different parts of the country. In fact, I have been following these principles in my career, and was reasonably successful:

- Make best use of the available opportunities
- Accept challenges, and consider them as opportunities
- Always give your 100% while doing research - casual approach will not yield anything
- Give your best under the given circumstances – bother not of the consequences / results
- Never say 'NO' to any work assigned – even if you are not conversant with it
- No complaint about the lack of facilities / resources
- Show concern for the organization / country – equally as your family, if not more
- Accept mistakes / failures – donot justify delays or wrong deeds
- Set targets and must try to achieve them
- Respect instructions / orders of the authorities – avoid questioning
- Leave behind some marks for others to follow – good impression counts
- Always try to return more that what you receive from others
- Do not expect / seek favours from others – be your ownself
- Do it yourself with your hands – do not depend on others
- Take initiatives – show your presence that you can do what others cannot
- Do not bother much about money – bother more about your work
- Do not grumble when questioned by authorities – do introspection and try your best to do better
- Impress authorities with your work, sincerity, dedication and commitment
- Never leave any work / assignment incomplete / unfinished when you leave the institute
- Analyze your progress on daily basis – what you got and paid back to the system
- Start planning for the day when you get up in the morning
- Do not bother much about the credit – the hard work and sincerity will always be rewarded
- A scientist's job is not merely a duty – it is not a 10 to 5 job, it requires complete devotion.

What next?

Weed problems are likely to increase in future, despite adoption of control measures. This is due to increased use of fertilizers and other inputs, growing of dwarf crop varieties with poor competitive ability against weeds, altered agronomy of crops like discontinuance of mulching, intercropping or mixed cropping systems with legumes, wider spacings and zero–till sowing, development of herbicide resistance in weeds, invasion of alien weeds due to globalization, and impact of climate change favouring more intense weed competition with crops. In view of these emerging challenges, the importance of weed science research will grow in the coming years. There is also the possibility of introduction of herbicide tolerant crops after the anticipated concerns are suitably addressed. This will change the complexion of weed management scenario in the country. Therefore, it is essential to reorient our strategies and refine the technologies on weed management on a continuing basis.

Directorate needs committed scientists and qualified technical manpower. Unfortunately a lot of time and energy was wasted in the past on unproductive and negative activities which not only affected the quality of research output but also spoiled the work culture and brought a bad name to the Directorate. Now the situation have stabilized and we are poised to take a quantum jump to excel in weed science research. For achieving this, the scientists have to shoulder a greater share of responsibility, come forward to take new initiatives, do good quality research, bring out publications in highly rated journals, and win externally–funded projects, awards and recognitions not only to raise their own standing but also of the Directorate at the national and international level. Weed science is a practical subject and the farmers are in dire need of cost–effective management options under the fast changing environment of labour scarcity, rising costs and reduced incomes. Therefore, the scientists must spend a good amount of their time in the field, particularly with the farmers and address the real problems through participatory approach. It is only through such problem–oriented research and development of technologies that we can remain relevant and raise our head high among the agricultural scientists of the country and the world.

It has been a very eventful first half of my tenure during which mixed feelings have emerged. When I look back at some of the achievements made, I feel happy and satisfied but there is an equal amount of frustration over the failures. The expectations from our higher authorities including the Director General and Deputy Director General (NRM), ICAR are very high and they have often expressed their concerns about this Directorate. In fact there have been some inherent problems at this Directorate, due to which, some people have developed a very different mindset which unfortunately is percolating down to the younger staff as well. There is required to be a serious introspection and self-realization about the role and responsibility bestowed upon us, and we must justify our existence individually and collectively.

The research and infrastructure development at the Directorate is poised to take a quantum leap forward in the XII Plan. As per the approval accorded by the ICAR recently, our long–awaited demand of the construction of the side wing of the Directorate building has been approved. Besides, a training–cum–farmers' hostel will also be constructed. The farm infrastructure including threshing and implements shed, internal roads, irrigation and drainage will be further renovated. Active participation of our Directorate in the two consortia research platforms dealing with 'conservation agriculture' and 'seeds' will strengthen our research programmes considerably. Laboratories will be further modernized with the most sophisticated equipments and facilities. Similarly, the network research programmes under the AICRP on Weed Control will be made more focused and result–oriented. All this was possible due to allocation of handsome increase in the budget, which is beyond our expectation.

I like to conclude by saying that my sole purpose is to bring about a qualitative improvement in the functioning of this Directorate in all spheres. To achieve this objective, I have been devoting my full time and energy but the improvements made during the first half of my tenure cannot be termed as outstanding as per my own assessment. We could have done better together if all of us had put in that extra effort. There should be a burning desire among all the staff to do something notable, and we have everything in us to make DWR a truly great institute of its own kind in the country and the world at large.

About the Author

Dr. A.R. Sharma has made outstanding research contributions in the field of tillage and weed management, conservation agriculture and nutrient management. He has developed technologies for improving productivity, profitability and input-use efficiency in different cropping systems. He is recipient of several awards and prestigious fellowshops. He is presently the Director, ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh.

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Establishment and growth of Directorate of Weed Research (1989-2014)

R.P. Dubey, Meenal Rathore, Bhumesh Kumar and A.R. Sharma

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 were 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 beetles (*Zygogramma bicolorata)* were 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 was organized. • Extension work on weed management was initiated.
	• First Kisan Mela was organized. • Weed science museum/information centre 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 database 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. • 25th Foundation Day was celebrated on 22 April, 201 3.
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'. • 26th Foundation Day was graced by the presence of Dr. A.K. Sikka, DDG (NRM). Agro-biomass and composting unit was inaugurated.

Staff position

The Directorate is a relatively small institute of the ICAR, with a total of 85 sanctioned positions as follows: scientists – 27, technical – 23, administrative – 13, and support skilled staff – 22. While the positions of other staff have remained largely filled, the number of scientists has fluctuated between 15 and 20 over the last many years (Figure 1).

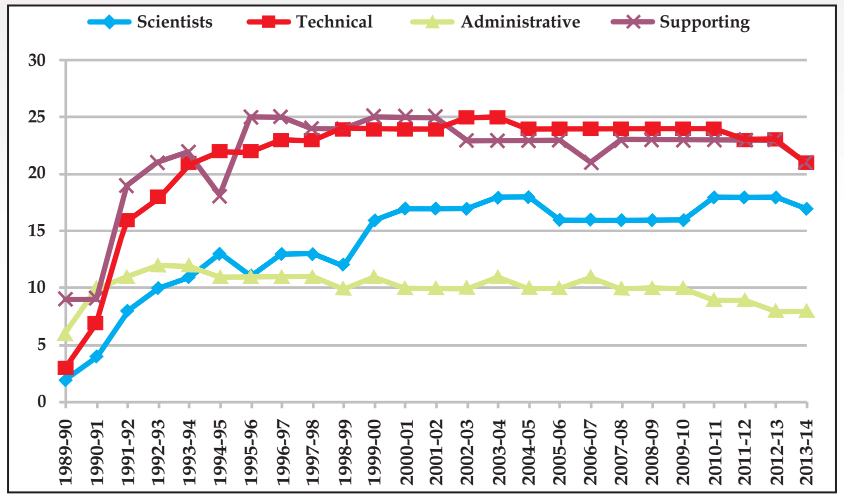

Figure 1. Staff position over the years

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 1995, 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. (from 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 was found effective in defoliation of *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)

The 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. Similatrly, 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 *Lathyrus sativus* and *Amaranthus viridis,* respectively under ambient conditions, and 0 and 8% under elevated CO_2 condition.
- 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).
- Non-availability of herbicides and labour, and lack of technical knowledge were found to be major constraints for adoption of weed management technology.

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 w.e.f. January 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. glabrescens*, *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 bicolorata* 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 glabrascens*, *Echinochloa 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: 'JN 638742' through 'JN 638750', and 'JN 944746' through 'JN 944751'.
- *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, 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 ORT, 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 into the AICRP network.

Facilities

The Directorate is one of the best equipped institute 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, (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, (xii) Thermal cycler (PCR), (xiii) Multi-probe soil moisture meter, (xiv) Gel documentation unit,

(xv) Root scanner, (xvi) Atomic absorption spectrometer (AAS), (xvii) Ultra water purification unit, (xviii) Soil CO_2 flux analyser, (xix) High speed centrifuge, (xx) Spectro-radiometer, and (xxi) 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 3057 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.

Awards and recognitions

During the past 25 years, the scientists working at the Directorate have received many awards and recognitions, such as the following:

- Dr. V.M. Bhan: ISWS Fellow (1994); IWSS Outstanding International Achievement Award for Developing Countries (1995); PPAI Hexamar Foundation Award (1995); ISWS Gold Medal (1997)
- Dr. N.T. Yaduraju: ISWS Fellow (2001); ISWS Gold Medal (2005)
- Dr. Jay G. Varshney: CWSS **Gold Medal** (2008); ISWS Best Book Award (in English) (2008); ISWS Best Book Award (in Hindi) (2008); SPSS P.P. Singhal Memorial Award (2009-2010); ISWS Best Book Award (in Hindi) (2010); ISWS Gold medal (2010); ISWS Best Book Award (2010)
- Dr. J. S. Mishra: ISA P.S. Deshmukh Young Agronomist Award (1999)
- Dr. V.S.G.R. Naidu: ISPP Sirohi Award (2004); NIWS Recognition Award (2011).

- Dr. P.K. Singh: SEE Best Appreciation Award (2007); SEE Best Extension Professional Award (2009)
- Dr. V.P. Singh: ISWS Fellow (2010)
- Dr. Shobha Sondhia: ISWS Fellow (2010)
- Dr. R.P. Dubey: ISWS Fellow (2011)
- Dr. Sushilkumar: ICAR Swami Sahajanand Saraswati Outstanding Extension Scientist Award (2011); SPSS Late Shri P.P. Singhal Award (2012-2013); AZRA Dr. Anand Prakash Award (2014); Crystal National Agri Award (2014)
- Dr. Anil Dixit: CWSS Fellow (2011); ISWS Fellow (2013)
- Dr. Chandra Bhanu: ICAR Dr. Rajendra Prasad Puraskar (2013)
- Dr. A.R. Sharma: ISA Fellow (2009); IASWC Fellow (2010)

Review Committees

Quinquennial Review Teams (QRT) and Research Advisory Committee (RAC) were constituted by the ICAR to review the work of the Directorate during different periods.

Period	Members
QRT	
1989-1994	Chairman: Dr. R.P. Singh; Members: Dr. Vikram Singh, Dr. S.K. Mukhopadhyay, Dr. H.K. Pande, Dr. R.K. Malik and Dr. V.M. Bhan (Member Secretary)
1995-2000	Chairman: Dr. S. Sankaran; Members: Dr. O.P. Gupta, Dr. N.K. Jain, Dr. (Mrs.) Gita Kulshrestha, Dr. R.C. Rajak and Dr. L.P. Kauraw (Member Secretary)
2001-2005	Chairman: Dr. G.B. Singh; Members: Dr. R.J. Rabindra, Dr. David N. Sen, Dr. D.C. Upreti, Dr. Jamaluddin, Dr. P. Balakrishnamurty and Dr. D. Subramanyam (Member Secretary)
2006-2012	Chairman: Dr. S.C. Modgal; Members: Dr. M.K. Porwal, Dr. B.C. Barah, Dr. P. Ananda Kumar, Dr. R.J. Rabindra, Dr. B.S. Parmar and Dr. R.P. Dubey (Member Secretary)
RAC	
2000-2002	Chairman: Dr. S. Sankaran ; Members: Dr. O.P. Gupta, Dr. R.K. Malik, Dr. C.M. Singh and Dr. L.S. Brar
2003-2005	Chairman: Dr. J.S. Kolar ; Members: Dr. V.M. Bhan , Dr. G. Kulshrestha , Dr. David N. Sen and Dr. R.E. Dhanraj
2006-2008	Chairman: Dr. Ambika Singh ; Members: Dr. U.C. Sharma , Dr. R.S. Singh , Dr. K.C. Joshi, Dr. G.L. Bansal and Dr. L.S. Brar
2009-2012	Chairman: Dr. D.P. Singh; Members: Dr. R.K. Malik, Dr. D.V. Singh, Dr. Madhuban Gopal, Dr. D.N. Singh and Dr. O.P. Singh
2012-2015	Chairman: Dr. R.K. Malik; Members: Dr. B.S. Parmar, Dr. R.S. Malik, Dr. B.L. Jalali and Dr. O.P. Singh

Inhouse research projects

A large number of inhouse research projects were undertaken at the Directorate, as given below:

Sl. No.	Name of the Project	Principal Investigator	Period
1.	Study on the non-chemical methods of weed management	Dr. Sahadeva Singh	1990–1995
2.	Survey, collection and identification of weeds of NRCWS farm and preparation of weed herbarium	Dr. D. Swain	1991–1992
3.	Identification and classification of C_3, C_4 and CAM weeds basing on CO_2 compensation points and anatomical structures	Dr. D. Swain	1991–1993
4.	Studies on the phytotoxic and stimulatory effect of plants on germination, growth and development of weeds and crop plants	Dr. D. Swain	1991–1994
5.	Microbial control of weeds	Dr. L.P. Kauraw	1991–1994
6.	Study on the non -chemical methods of weed management in pulses and oilseed crops	Dr. A.N. Singh	1991–1997
7.	Integrated weed management in rice	Dr. A.N. Singh	1991–1997
8.	Biological control of weeds by plants	Dr. L.P. Kauraw	1991–1997
9.	Weed management technology in rice	Dr. A.N. Singh	–
10.	Effect of cropping system and herbicides sequence on floristic distribution of weeds	Dr. D. Swain	1992–1995
11.	Weed management in pulse crops	Dr. J.S. Mishra	1992–1906
12.	Weed management in soybean	Dr. V.P. Singh	1992–1997
13.	Farming system and emergence pattern of weed flora	Dr. V.P. Singh	1992–1997
14.	Effect of intensity of cropping on distribution of weed	Dr. V.P. Singh	1992–1997
15.	Physiological investigations on the effect of seed quality on crop and weed germination and stand establishment in relation to weed management	Dr. D.K. Pandey	1992–1997
16.	On the possibilities of the use of various growth retardants on different crop-weed ecosystems to reduce crop weed vegetative growth for better crop protection (against lodging) and higher yield	Dr. D. Swain	1993–1995
17.	Biology and control of *Parthenium hysterophorus*	Dr. J.S. Mishra	1993–1995

18.	To investigate the influence of weed and crop debris (decomposition products) on germination and growth of weed and crop plants in crop-weed ecosystem	Dr. D. Swain	1993–1996
19.	Survey of insect and non-insect fauna of weeds in Jabalpur and adjoining area	Dr. Sushil Kumar	1994–2002
20.	Weed management in direct-seeded rice	Dr. A.N. Singh	–
21.	Influence of cultural and chemical methods of weed management in cereals	Dr. Anil Dixit	1995–1997
22.	Genetic manipulation and screening of herbicide resistance/ tolerance of economically important crops through tissue, cell and protoplast culture	Dr. D. Swain	1996–2001
23.	To study the physiology of the allelopathic effect of *Sphaernthus indicus* on maize and those of *Ricinus communis* and *Parthenium hysterophorus*	Dr. D. Swain	1997–1999
24.	Non-chemical approaches for weed management	Dr. V.P. Singh	1997–2004
25.	Studies on the herbicide residues and their manageme nt in soil and plants	Dr. Subhendu Datta	1998–2002
26.	Weed management in vegetable crops in vertisol	Dr. V.P. Singh	1998–2002
27.	Biology and ecology of problem weeds	Dr. J.S. Mishra	1998–2003
28.	Studies on the herbicide residue in the soybean-wheat cropping System	Dr. Shobha Sondhia	1999–2000
29.	Studies on the herbicide residue in the maize and potato cropping system	Dr. Shobha Sondhia	1999–2002
30.	Design improvements and prototype development of different designs of improved weeding tools and implements	Er. H.S. Bisen	1999–2002
31.	Design, development and performance evaluation of a self-propelled power weeder for line sown crops	Er. H.S. Bisen	1999–2002
32.	Studies on herbicide-soil microorganism interactions	Dr. M.B.B. Prasad Babu	1999–2002
33.	Design, development and evaluation of powered aquatic weed cutter/harvester for ponds	Er. H.S Bisen	1999–2004
34.	Field demonstration on proven weed control technologies and training on weed management	Dr. P.K. Singh	2000–2011
35.	Weed flora shift in cropping system	Dr. V.P. Singh	2001–2008
36.	Design, development and evaluation of mechanical weeding tools and machinery as a component of integrated weed	Er. H.S. Bisen	2002–2004

37.	Tillage and weed control methods cropping systems	Dr. J.S. Mishra	2002–2006
38.	Survey, surveillance and impact evaluation of bioagents and herbicides with/ other methods for integrated management of some important weeds	Dr. Sushil Kumar	2002–2007
39.	Role of intercrops and cover crops in weed management	Dr. R. P. Dubey	2002–2007
40	Influence of herbicides on soil micro-flora, soil fertility and productivity	Dr. K.K. Barman	2002–2007
41.	Role of weed competitive cultivars in IWM	Dr. B.T.S. Moorthy	2002–2007
42	Nutrient and plant residue management on weed dynamics in cropping system	Dr. P.J. Khankhane	2002–2007
43	Screening and testing of new molecules	Dr. Anil Dixit	2002–2010
44	Studies of different spray application techniques for herbicide in field conditions	Er. H.S. Bisen	2003–2006
45	Studies of herbicides residues in soil and foodgrain	Dr. Shobha Sondhia	2004–2010
46	Integrated management of *Cuscuta campestris* in berseem and *Lucerne*	Dr. J.S. Mishra	2005–2011
47	Development of aquatic weed collector from ponds and water bodies.	Er. H.S. Bisen	2006–2008
48	Evaluation of bioagents and herbicides alone or in combination on water quality and fish mortality for integrated management of some aquatic weeds	Dr. Sushil Kumar	2006–2009
49	Isolation and identification of root exudates of linseed and marigold and their growth inhibitory effect on few weeds	Dr. Shobha Sondhia	2006–2009
50	Physiological basis for genotypic differences in weed competitiveness in field crops	Dr. D. Subrahmanyam	2006–2009
51	Biology, host-specificity and damage potential of bioagents on *Trianthema portulacastrum*	Dr. Sushil Kumar	2006–2009
52	Influence of herbicides on soil micro-flora, soil fertility and productivity	Dr. K.K. Barman	2006–2010
53	Tillage and weed management in rice-based cropping systems	Dr. J.S. Maishra	2006–2010
54	Evaluation of methods of breaking weed seed dormancy	Dr. V.S.G.R. Naidu	2006–2011
55	Studies of herbicide residues in long-term herbicides trial in	Dr. Shobha Sondhia	2006–2011
56	Evaluation of manually-operated weeding tools suitable for uprooting of soil em bedded weeds	Er. H.S. Bisen	2007–2009
57	Detection of weeds through remote sensing technique	Dr. M.B.B. Prasad Babu	2007–2010
58	Herbicide as a tool for weed management	Dr. V.P. Singh	2007–2010

59	Impact of soil physical environment on the pre-emergence herbicides	Dr. K.K. Barman	2007–2011
60	Identification and evaluation of weedy plants for phytoremediation of heavy metal contaminated drain water	Dr. P.J. Khankhane	2007–2012
61	Development of organic weed management techniques in rice-wheat, soybean -wheat cropping systems, vegetable and medicinal crops	Dr. R.P. Dubey	2007–2012
62	Organic weed management techniques in vegetable cropping systems	Dr. R.P. Dubey	2007–2012
63	Weed management in horticulture	Dr. V.P. Singh	2007_2013
64	Herbicide- soil moisture interaction studies	Dr. V.P. Singh	2007–2013
65	Development of weed management techniques in mango and citrus orchards	Dr. V.P. Singh	2007–2013
66	Bio-herbicidal potential of plant constituents from lantana, neem, tropical soda apple and *Parthenium* against targeted weeds	Dr. D.K. Pandey	2007–2014
67	Biological management of *Eichornia crassipes* using potential aquatic fungal pathogens	Dr. C. Kannan	2008–2010
68	Effect of elevated CO_2 on weeds and competitive interaction between crops and weeds	Dr. V.S.G.R. Naidu	2008–2011
69	Collection, characterization and evaluation of plant pathogens for biological control of some important weeds	Dr. Chandra Bhanu	2008–2012
70	Evaluation of *Neochetina* sp for biological control of water hyacinth	Dr. Sushil Kumar	2009–2012
71	Establishment of techniques and protocol for the investigation role of leaf surface in the photo transformation of herbicide	Dr. P.P. Choudhury	2009–2012
72	Investigation on photo-transformation of sulfosulfuron and propaqiuzafop in aqueous phase and on soil surface	Dr. P.P. Choudhury	2009–2012
73	Induction of systemic of systemic resistance against *Cuscuta campestris* in chickpea	Dr. C. Kannan	2009–2012
74	Characterization of important weed seeds of central and southern India	Dr. V.S.G.R. Naidu	2009–2012
75	Photo-transformation of isoproturon 2, 4-D on leaf surface and sulfosulfuron and propaquizafop in environment	Dr. P.P. Choudhury	2010–2012
76	Survey, characterization and evaluation of plant pathogens for management of water hyacinth and *Cuscuta* sp.	Dr. C. Kannan	2010–2012
77	Design, development and evaluation of wick applicator and also spray techniques for weed management in crops	Er. H.S. Bisen	2010–2014
78	Effect of elevated CO_2 on physiological, biochemical and molecular aspects in mungbean, chickpea and their associated weeds	Dr. Bhumesh Kumar	2010–2012
79	Efficient weed management through herbicides in field crops and their impact on soil health	Dr. Anil Dixit	2010–2012

80	Long-term effect of herbicides on weed dynamics, soil microflora, non-targeted organisms and herbicide residues in direct seeded rice-wheat and direct seeded rice-chickpea cropping systems	Dr. V.P. Singh	2011–2014
81	Development and evaluation of diverse methods for herbicide slow delivery and weed control	Dr. K.K. Krishnani	2011–2012
82	Testing the viability of important weed seeds from soil seed bank	Dr. V.S.G.R. Naidu	2011–2012
83	Effect of crop establishment techniques and weed management practices on growth and yield of rice under rice-wheat cropping system*	Dr. Raghvendra Singh	2011–2012
84	Characterization of weedy rice biosimilars*	Dr. Meenal Rathore	2011–2012
85	Biological of control of *Chromolaena odorata* using gall fly by inoculative release in Chhattisgarh area*	Dr. Sushil Kumar	2011–2012
86	Monitoring of herbicide accumulation in soil and water under non-cropped conditions*	Dr. Shobha Sondhia	2011–2012
87	Demonstrations on weed management technology in crop and non-crop situations and their impact assessment*	Dr. P.K. Singh	2011–2012

*Combined with the newly-launched research projects from 2012-13

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

Externally-funded projects

Besides the inhouse projects, 28 externally-funded projects were also undertaken as follows:

S. No.	Project	Principal Investigator	Period	Funding agency	Budget (Rs. in lakhs)
1.	Biological control of weeds by plant pathogens	Dr. L.P. Kauraw	1994–1997	DBT	11.44
2.	Studies on pest potential the Mexican beetle (*Zygogramma bicolorata*) introduced for biocontrol of *Parthenium*	Dr. Sushil Kumar	1995–1999	ICAR	8.00
3.	Biological control of *Echinochloa* in rice and *Phalaris minor* in wheat crop	Dr. L.P. Kauraw	2000–2003	ICAR	5.00
4.	Developing strategies for the management of *Parthenium* weed in India using fungal pathogens	Dr. L.P. Kauraw	1997–2001	CABI-UK	1.40
5.	Fate and phytotoxicity of applied herbicides and their impact on nutrient cycle in relation to soil factors and management practices	Dr. K.K. Barman	2001–2004	ICAR	3.74
6.	Phytotoxicity of allelochemicals to aquatic weeds	Dr. D.K. Pandey	2000–2003	ICAR	17.50
7.	Evaluation and management of allelopathic infl uences of crops and weeds of rice-wheat cropping system	Dr. D. Swain	2001–2004	ICAR	3.74
8.	Role of insects in suppression of problematic alligator weed (*Alternanthera philoxeroides*) and testing of herbicides for integrated management	Dr. Sushil Kumar	2000–2003	ICAR	7.50
9.	Development of national database on weeds	Dr. A.K. Gogoi	2001–2004	NATP, ICAR	20.57
10	Molecular characterization and field trials of mustard transgenic for hybrid seed production and resistance to herbicides (in collaboration with Delhi University and IARI, New Delhi)	Dr. N.T. Yaduraju	2002–2005	DBT	19.06
11	Integrated management of *Cuscuta* sp. in field crops	Dr. J.S. Mishra	2002–2004	NATP, ICAR	3.78
12	Organization and management of PME (in collaboration with NCAP)	Dr. A.K. Gogoi	2002–2004	NATP	4.0
13	Systematic study on weed seeds of India (in collaboration with AAU, Jorhat)	Dr. V.S.G.R. Naidu	2002–2005	ICAR	8.75
14	Systematic studies on weed atlas in India	Dr. V.S.G.R. Naidu	2003–2006	ICAR	5.00
15	Large scale demonstration on management of *Parthenium* through integrated approach (network project with 7 other centers)	Dr. N.T. Yaduraju and Dr. Sushilkumar	2004–2007	DBT	11.35
16	Determination of the role of weeds in epidemic and perpetuation of economically important plant viruses (in collaboration with IARI)	Dr. Anupam Verma and Dr. Chandra Bhanu	2004–2007	ICAR	4.50
17	Effect of elevated atmospheric carbon dioxide on crop-weed interactions	Dr. V.S.G.R. Naidu	2004–2007	ICAR	19.57
18	Detection of weeds for precision crop management using remote sensing technique	Dr. M.B.B. Prasad Babu	2004–2007	ISRO	10.17
19	Socio-economic survey of maize growers of Bihar and Karnataka with reference to weed management	Dr. P.K. Singh	2005–2007	Monsanto-India	10.00
20	Feasibility of increasing persistence of some rice herbicide and its consequence in soil environment	Dr. K.K. Barman	2005–2008	ICAR	19.53
21	Augmentation and activity enhancement of Mexican beetle for biological control of *Parthenium*	Dr. Sushilkumar	2005–2008	ICAR	14.53
22	Herbicidal property of invasive and noxious weed *Lantana*	Dr. D.K. Pandey	2005–2008	DST	16.14
23	Structural behaviour of different sulfonylurea herbicides in sub-soil under the influence of cropping conditions-identification and quantification of potential metabolites responsible for the toxicity and their bio-accumulation in fish (in collaboration with IIBAT, Padappai and PAU, Ludhiana)	Dr. S. Sondhia	2005–2008	ICAR	9.26
24	National Invasive Weed Surveillance Programme	Dr. V.S.G.R. Naidu	2008–2011	DPPQS	716.0

25	Compost production from weed biomass for the socio-economic development of rural people	Dr. V. Parmar and Dr. S. Sondhia	2008–2011	DST	5.55
26	Precision farming technologies based on microprocessor and decision support systems for enhancing input application efficiency in production agriculture	Dr. V.P. Singh	2008–2011	NAIP	65.41
27	Development and formulation of microbial metabolites for the management of root parasite weed *Orobanche* in mustard*	Dr. C. Kannan	2012–2015	MPBT	15.05
28	Study on domestication traits of two weed species*	Dr. Bhumesh Kumar	2013–2016	NFBSF ARA	119.50
29	Bioremediation of contaminants in polluted sites – use of weedy plants*	Dr. P.J. Khankhane	2013–2017	NFBSF ARA	206.31

*Currently ongoing

Extension activities

Year	Field demonstrations	Kisan Melas/Goshtis organized/ participated	Radio /TV talks	Trainings organized	Extension bulletins/ folders/ articles in newspapers	Lectures on /off campus
1989-90	-	-	-	-		-
1990-91	-	-	-	-	-	-
1991-92	-	-	-	-	-	-
1992-93	-	-	-	-	-	-
1993-94	-	-	-	-	-	-
1994-95	-	2	-	1	10	-
1995-96	5	2	2	1	14	-
1996-97	-	1	2	1	12	-
1997-98	-	-	4	-	-	-
1998-99	-	1	3	-	-	-
1999-00	-	2	-	-	-	-
2000-01	18	2	-	1	1	3
2001-02	18	6	4	2	8	6
2002-03	65	8	12	3	24	10
2003-04	81	8	8	5	10	15
2004-05	86	9	10	6	9	13
2005-06	92	3	3	2	4	12
2006-07	64	4	2	1	-	15
2007-08	94	3	7	2	-	15
2008-09	79	4	3	2	2	20
2009-10	85	5	4	3	30	18
2010-11	83	5	3	2	2	21
2011-12	82	3	4	2	2	18
2012-13	65	2	4	4	2	22
2013-14	65	3	3	4	3	31

Trainings organized

As per the mandate, following training programmes were organized for different stakeholders:

S. No.	Title of training	Period	No. of participants	Sponsor
1	Weed management: a tool for improving crop production	16–23 January, 1995	15	NRCWS
2	Weed management: a tool for improving crop production	8–15 January, 1996	4	NRCWS
3	Weed management: a tool for improving crop production	28 January – 4 February, 1997	15	NRCWS
4	Role of allelopathy in weed management	26–27 April, 2002	70	NRCWS
5	Winter school on recent advances in weed management	21 October–10 November, 2002	31	ICAR
6	Training on management of *Parthenium*	9–11 August, 2005	50	NRCWS
7	National training on weed management in *kharif* crops	29 August–1 September, 2007	50	NRCWS
8	National training programme on advanced instrumental training for the analysis of pollutants in the food commodity and water	20–26 November, 2007	42	NRCWS
9	Consultation on herbicide tolerant GM crops	10–11 December, 2007	60	NRCWS & BCIL
10	Model training course on recent advances in weed management	29 December, 2008–5 January, 2009	23	DAC, GOI
11	Training programme on protocols and methodologies for weed survey and surveillance	2–6 March, 2009	-	DWSR
12	National consultation on weed utilization	20–21 October, 2009	-	DWSR
13	Advance instrumentation for the analysis of herbicide residues in soil, water and food chain	16–22 November, 2009	-	DWSR
14	National training on weed management in field crops	4–11 January, 2010	-	DWSR
15	National consultation on biological control of weeds	17–18 March, 2010	30	DWSR
16	Model training course on recent advances ion weed management	11–18 October, 2010	23	DAC, GOI
17	One day training programme on weed management for technical officer of IFFCO	26 May, 2011	-	DWSR & IFFCO
18	Advancement in weed management techniques	16–20 October, 2012	25	DOA, UP
19	1st National training on 'Advances in weed management'	31 October–9 November, 2012	22	ICAR
20	Model training course on weed management for sustainable oilseeds and pulses production	13–20 December, 2012	24	MOA, GOI
21	Weed management and chemical weed control	12–14 March, 2013	24	ATMA, Parbhani
22	Weed management techniques	13–15 June, 2013	30	ATMA, Parbhani
23	Microbes and their biotechnological interventions for sustainable agriculture with special reference to biological weed management	22 July – 5 August, 2013	30	MPBT, Bhopal
24	2nd National Training Course on 'Advances in Weed Management'	14–23 January, 2014	31	ICAR
25	Advances in weed management technology	11–15 March, 2014	25	SIMA, U.P.
26	Training-cum-workshop on weed management for KVKs scientists	19–21 May, 2014	30	ZPD, Zone-VII
27	Herbicide Residue: review of research-cum-training workshop	11–17 November, 2014	15	DWSR
28	Model training course on 'Weed management for sustainable oilseed and pulse production'	16–23 December, 2014	25	MOA, GOI

Publications

The Directorate has published a number of different publications over during the last 25 years. A consolidated list is given below:

Publication	Number	Publication	Number
Research articles	231	Practical manuals	10
Review articles	11	Success stories	4
Book chapters	46	Technical extension bulletins	43
Books	20	Information bulletins	16
Popular articles	228	Reports on awareness campaigns	9
Video films	9	Regular publications	5
Technical bulletins	8	Papers presented in conferences/symposia	476
Externally funded project reports	24		

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, (viii) Large packings of herbicides, (ix) Registration of new molecules, (x) Lack of awareness / extension efforts, (xi) 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 control 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 infrastructure 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, quarantine facilities for Weed Risk Analysis, and biocontrol related studies, and a referral laboratory for herbicide residue study.

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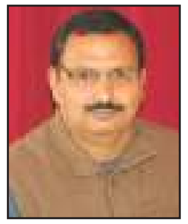

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Events Organized

During the Silver Jubilee year of the Directorate (2013-14), various programmes were organized befitting the occasion to highlight the achievements over the last 25 years, and to increase awareness and visibility of weed management technologies among the stakeholders. These events included 25th Foundation Day, trainings and awareness programmes, Agriculture Education Day, Industry Day, National Science day, Kisan Goshthi, Biennial Conference of ISWS and Annual Review Meeting of AICRP–Weed Control, Interface Meet with stakeholders and others. Brief details of these activities are given below:

Silver Jubilee Foundation Day

The Directorate celebrated its Silver Jubilee Foundation Day on 22 April, 2013 in presence of guests: Dr. D.P. Singh, Chairman, Kisan Kalyan Board, Haryana and former Vice Chancellor, JNKVV, former Director of DWSR, Dr. Jay G. Varshney; and Mrs. Rama Bhan, wife of Late Dr. V.M. Bhan, first Director, DWSR. Scientists, officials and employees of the Directorate were felicitated for their outstanding work on this occasion.

Training on Advanced Weed Management Technology

A 3-day training programme entitled "Advanced Weed Management Technology" was conducted for progressive farmers and ATMA officials from Parbhani, Maharashtra from 13–15 June, 2013. Training was imparted on mechanical, chemical and organic methods for weed management with introduction to conservation agriculture, climate change and its influence on agriculture production. Participants benefited by visits to field demonstrations on no-till mungbean cultivation at famers' fields in Panagar and Singaud villages, and by discussion with farmers and sharing their experiences.

Training on Weed Management for PG students

A training programme was organized on "Microbes and their biotechnological interventions for sustainable agriculture with special reference to biological weed management" sponsored by Madhya Pradesh Biotechnology Council during 22 July-5 August, 2013. A total of 30 students from different colleges of Jabalpur participated. The participants were exposed to different aspects of microbes with special reference to their role in biological weed management.

Farmers–Scientists Interface at Dindori

A Farmer–Scientist Interface Meeting was held on 31 July 2013 at Krishi Vigyan Kendra, Dindori, which was sponsored by ATMA Project and Farmers' Welfare Society. In this meeting, Deputy Director (Agriculture), Block Technology Manager (BTM), Assistant Directors, Sub–divisional Agricultural Officers, progressive farmers and farmers from tribal belt participated. Dr. A.R. Sharma, Dr. P.K. Singh, Dr. V.P. Singh, Dr. R.P. Dubey participated from the Directorate and imparted technical knowhow of weed management. The farmers desired to know herbicide application techniques in minor millets including kuttu, kodo millet and fingermillet, which are the major crops of the area. Parthenium was also a major problem in the area for which management techniques including release of Mexican beetle were suggested.

Nationwide organization of Parthenium Awareness Programme

In an effort to spread awareness about the ill effects of Parthenium amongst farmers, students, scientists and general public, Parthenium Awareness Week was organized from 16–22 August, 2013 throughout the country. Published material in form of charts, posters, leaflets, banners, display boards etc. were distributed to AICRP–Weed Control centres, ICAR institutes, SAUs, KVKs, State Department of Agriculture and NGOs. A training–cum–awareness programme was conducted at the Directorate on 19 August, in which about 56 stakeholders from the city and adjoining districts participated. Mexican beetles were distributed to the farmers for release in Parthenium infested areas farmers.

Agriculture Education Day

DWSR celebrated the Agriculture Education Day on 10 December, 2013 to promote the spirit of agricultural science among school children. Thirty-four students along with their teachers from six different schools, located in rural areas of Jabalpur, took part in day long

activities, viz. inspirational talks, visits to information centre, laboratories and research fields, and quiz competition organized to mark the day. Dr. K.K. Barman, Programme Convener highlighted the importance of agricultural education among the school children for country's socio–economic development. Dr. A.R. Sharma, Director, enlightened the participants about the historical perspectives and current status of agricultural research and education in India, and informed about the career opportunities for in higher agricultural education. The students enthusiastically interacted with the scientists while visiting laboratories, experimental fields and information centre. In the closing ceremony, the students were given certificates of participation, and prizes were distributed to successful participants by the Director.

Industry Day

An industry day was organized for the first time on 19 December, 2013 in order to furthe strengthen the linkages for effective collaboration with the herbicide industry for testing of new molecules/formulations as well as those dealing with farm machinery, spraying equipments and instrumentation. Er. H.S. Bisen, acting Director, DWSR and participants from JNKVV, Jabalpur; Pesticide India, Indore; Dhanuka Agritech Limited, Indore; Silver Agencies, Jabalpur; Sameer Science Lab and Supplements, Jabalpur; Supreeti, Jabalpur and others were present on this occasion. Discussions were held emphasizing on need to change scientific enterprising in the era of globalization, DWSR– herbicide industry linkages, spurious herbicides in the market, and biological control and utilization of weeds. In discussion, scientists from DWSR suggested industry persons to orient pesticide dealers to further disseminate knowledge to stakeholder's about safe use of herbicides and disposal of containers. It was suggested that some initiative should be taken by the Government to check spurious pesticides in the country.

ISO 9001: 2008 Certification

DWSR was awarded the certification by implementing the Quality Management

System in the organization as per the ISO 9001:2008 standards on 21 December, 2013. Acquiring this certification is one of the performance monitoring indicators to be complied with by all Government Departments in the country as per the Result Framework Document (RFD) requirement by Performance Management Division, Cabinet Secretariat. Implementation of ISO 9001 as per the approved action plan of RFD 2013–14 is the success indicator of mandatory objective under administrative reforms of all the Government Departments. It testifies the commitment towards assuring quality services to its customers with continual improvement of its delivery system. As per the quality policy, DWSR is committed to continual improvement for achieving excellence in agricultural research.

Second National Training Programme on Weed Management

Second National Training programme was organized during 14-23 January, 2014 on 'Advances in Weed Management". Thirty trainees from different ICAR institutes and agricultural universities participated in this programme. Dr. A.R. Sharma briefed about the importance and purpose of the training programme. He emphasized that this raining programme will help the participating scientists to improve their future research programmes and extension activities related to weed management. Dr. V.S. Tomar, Vice Chancellor, JNKVV, Jabalpur and the Chief Guest of the inaugural function mentioned that advanced knowledge of weed management is need to make intensive agriculture a profitable venture. Dr. C.B. Singh, Ex-Dean and Director Extension services, JNKVV chaired the closing ceremony on 23 January, 2014. Appreciating the programme, Dr. Singh asked the scientists to utilize the acquired knowledge of weed management in practical field.

Annual Review Meeting of AICRP–Weed Control

Annual review meeting of the AICRP–WC centers was organized at the Directorate from 12–14 February, 2014. Dr. L.S. Brar, former Professor & Head, Department of Agronomy, PAU, Ludhiana was Chief Guest of the occasion. Besides, Dr. R.K. Gupta, Borlaug Institute for South East Asia, Jabalpur and Dr. Jay G. Varshney, Former Director also graced the occasion along with participants from 22 agriculture universities and eight voluntary centres from across the country. Dr. R.P. Dubey, Incharge, AICRP–WC briefed the research achievements of different centres in the inaugural session. Dr. Brar emphasized on need of enhanced production from reducing arable lands and the increasing need to develop efficient weed management technologies in the regime of climate change and reduced manpower availability. Dr. Varshney recommended interdisciplinary research to manage weeds in future and suggested adoption of biotechnology, biochemistry and nanoscience techniques to develop advanced weed management technologies. Technical bulletins on medicinal use of weeds, weed management in *kharif* and *rabi* crops, problem and management of sargauja in mustard, weed management in wheat, etc. were released on the occasion. Detailed research achievements presented by individual centers were reviewed in the meeting and in depth discussions were held to frame the new technical programme for coming year.

Biennial Conference of ISWS

A 3-day Biennial Conference of Indian Society of Weed Science on 'Emerging Challenges in Weed Management' was held at the Directorate from 15–17 February, 2014. Prof. V.S. Tomar, Vice–Chancellor of Jawaharlal Nehru Krishi Vishwa Vidyalaya was chief guest of the occasion. Dr. T.V. Muniyappa, Dr. R.K. Malik, Chairman, RAC; Dr. N.T. Yaduraju, President, ISWS graced the inaugural ceremony. More than 250 participants from across the globe participated in the conference. Keynote lectures were delivered on 'Conservation Agriculture and weed management in South Asia region: perspectives and developments' by Dr. R.K. Malik, 'Herbicide use efficiency using adjuvants' by Dr. Megh Singh, USA and 'Living with weeds – a new paradigm' by Dr. Nimal Chandrasena, Australia. A total of 50 lectures were delivered under 10 themes in 12 concurrent sessions. Interaction among students, scientists and industry was organized. A visit to on–station farm trials and on-farm trials at Mahagwan and Panagar villages of Jabalpur district was also organized.

National Science Day

National Science Day was celebrated on 28 February, 2014 on the theme "Role of scientific research in agriculture development in India". Dr. C. Kannan convener welcomed the gathering and informed about the genesis and significance of celebrating the National Science Day. Er. H.S. Bisen, I/c Director gave inaugural remarks, followed by a presentation of Dr. V.P. Singh on weeds and their impact on

Indian agriculture. The students were taken for laboratory and field visit. They were explained about the various activities and equipments like OTCs, lysimeter, containment chambers, FACXE and farm machinery. Dr. U. Prakasham, Director, TFRI, Jabalpur was the Chief Guest of the post-lunch session. He delivered a special lecture on "Science as a way of learning". A competition was held wherein the students participated. Prizes and certificates were distributed to the best 3 students.

Training Programme on Weed management

A 5-day National Training Programme on "Advances in Weed Management Technology" was organized from 11–15 March, 2014 for agricultural officers of Uttar Pradesh with the financial support of SIMA, Rehmankhera, Lucknow, U.P. A total of 25 participants including two achiever farmers benefited from the training programme. In technical sessions, 20 lectures covering cultural, mechanical, biological, chemical and integrated weed management were delivered by the scientists / experts from DWSR. The trainees were exposed to the practical aspects of weed identification, spraying techniques, mechanical weeding tools, climate change, weed utilization, biocontrol agents, herbicide residue analysis, herbicide resistant crops and conservation agriculture through practical sessions. Field visits to farmers' fields, experimental fields of the Directorate and Borlaug Institute for South East Asia, Jabalpur were also organized.

Field Day–cum–Sangosthi

A Field Day–cum–*Sangosthi* was organised on 26 March, 2014 at Bharda (Padariya) village, which was attended by 125 farmers. The female farmers also participated in good numbers. Dr. A.R. Sharma, Director informed about the new technologies in weed management and emphasized adoption of conservation agriculture – based systems for improving productivity, profitability and sustainability. Dr. P.K. Singh highlighted the research activities being carried out at farmers' fields of Mahgava, Baihar, Bahmnoda and Bharda villages of Panagar locality in a participatory mode. The importance of conservation agriculture along with the use of happy seeder and improved weed management techniques were explained through the live examples of on-farm trials conducted in different farmers' field. The farmers who had used the happy seeder for

wheat sowing shared their experiences to the participating farming community. The scientists of DWSR replied questions raised by farmers related to their problems in weed management and crop production. All the farmers visited the nearby field of Shri Satish Dubey, Bharda, where good crop of wheat had been raised by adopting the conservation agriculture technology. The crop was healthy and distinctly superior to the wheat crop raised in adjoining field where conventional practices were followed.

26th Foundation Day

The Directorate celebrated its 26th Foundation day on 22nd April, 2014 in the presence of Dr. A.K. Sikka, Deputy Director General (Natural Resource Management, ICAR and Dr. V.S. Tomar, Vice Chancellor, JNKVV, Jabalpur. Dr. A.R. Sharma in his welcome address briefed the dignitaries about the research and development activities at the Directorate. Dr. V.N. Saraswat and Dr. Jay G. Varshney informed about the gradual establishment of the Directorate and its face lifting in terms of infrastructure development and prioritization of research programmes. Dr. V.S. Tomar emphasized the indispensable need of continuous research on weed science. Dr. A.K. Sikka emphasized the need of efficient weed management technologies for sustainable production. On this occasion, Best worker awards in the category of skilled support staff, administrative staff, technical officers and scientists were conferred upon Sh. S.K. Kostha, Sh. Sandeep Dhagat, Smt. Nidhi Sharma and Dr. Sushil Kumar respectively.

Interface Meeting with Progressive Farmers and Agricultural Officers

Interface meeting of progressive farmers with state department officers and scientists was organized on 29 April, 2014 to discuss various aspects of weed management and problems faced by the stakeholders. In this meeting, 120 achiever / progressive farmers, 40 officers of the state departments from 13 districts of Jabalpur, Rewa and Satna divisions of Madhya Pradesh, and 16 scientists of DWSR participated. Dr. A.R. Sharma, Director, DWSR presided over the function. Dr. P.K. Singh, Principal Scientist (Agricultural Extension) coordinated the programme. Visits to the experimental farm were organized to show the encouraging results under conservation agriculture with the use of improved farm machinery. Seed packets of *Sesbania* were distributed to the representatives of different districts to popularize the green manuring technology in their areas.

Training-cum-Workshop on Weed Management

DWSR and Zonal Project Directorate, Zone VII Jabalpur jointly organized training-cum workshop on weed management during 19-21 May, 2014 for the 40 scientists of KVKs of Madhya Pradesh, Chhattisgarh and Odisha. Dr. A.R. Sharma, Director, DWSR have an overview of the Directorate's activities for strengthening weed management through on-farm research and organizing trainings/ workshops. Dr. Anupam Mishra, Director, ZPD explained the strengths and opportunities of the KVKs to disseminate technologies on weed management among the farmers. Dr. P.K. Mishra, Director Extension services, JNKVV Jabalpur emphasized the importance of weed management in present situation of labour scarcity.

Mass Plantation on Independence Day

Directorate celebrated the 68th Independence Day on 15 August 2014 in a unique manner. Teak saplings were planted by all the staff of the Directorate in the DWSR campus. It was decided that the plants will be looked after the concerned staff members and also named after them.

Review Meeting with Dr. A.K. Sikka

Dr. A.K. Sikka, DDG (NRM) visited the Directorate on 3 September, 2014 to review the ongoing research programmes. He was accompanied by Dr. S.K. Patil, Vice Chancellor, IGKVV, Raipur. The dignitaries took a round of the research farm to see the progress of conservation agriculture experiments. The progress of research work and various assignments was reviewed.

Cleanliness Drive at DWSR

Under the Swatchh Bharat Mission of the Government of India, a special cleanliness drive was launched at the Directorate on 25 September, 2014. Dr. A.R. Sharma motivated the staff members for making the campus clean. All the staff members were given the responsibility to clean the identified places within the premises. The staff members participated in the cleanliness campaign with enthusiasm and cleaned the corridors, floors, basement, parking area, lawn and farm roads of the campus. On the occasion of Gandhi Jayanti (2 October, 2014) all staff members again cleaned the adjoining areas of the campus and also motivated the local people for their contribution in the Swatchh Bharat Mission.

Visit of Dr. S. Ayyappan, Secretary, DARE and DG, ICAR

Dr. S. Ayyappan, Secretary, DARE and Director General, ICAR visited the Directorate on 29 September, 2014. Dr. V.S. Tomar, Vice Chancellor, JNKVV, Jabalpur and Dr. Anupam Mishra, Director, ZPD Zone VII also accompanied him. Dr. A.R. Sharma, Director, DWSR welcomed the dignitaries. Dr. Ayyapan had a brief informal interaction with the scientists and staff of the Directorate. He also visited the field experiments and showed keen interest in conservation agriculture. A publication on 'DWSR: Marching Ahead" was released on the occasion.

Training-cum-Workshop on Herbicide Residues

A training-cum-workshop on herbicide residues was conducted from 11-17 November, 2014. Scientists working on residue analysis at different AICRP-WC centres participated in this workshop. Research work on residue analysis was reviewed. Training was imparted to the participants on advance analytical techniques related to herbicide residue analysis.

Model Training Course on "Weed Management for Sustainable Oilseed and Pulse Production"

Eight-days Model Training Course (MTC) on 'Weed management for sustainable oilseed and pulse production' was organized from 16–23 December, 2014. Thirty senior agriculture officers from ten states participated in the training course. The programme was inaugurated by Dr. V.S. Tomar, Vice Chancellor, JNKVV, Jabalpur. During the programme, 35 lectures covering cultural, mechanical, biological, chemical and integrated weed management were delivered by the scientists/experts from the DWR and other institutions. Seven practical sessions were also conducted covering important aspects of weed management.

Silver Jubilee Lectures

Renowned scientists were invited to deliver Silver Jubilee lectures at the Directorate during 2013-14. They shared their experiences on the outstanding research contributions made by them. Scientists of the Directorate were inspired and motivated to achieve higher laurels in their professional career.

Dr. R.K. Rattan, Head, Centre for Environmental Sciences and Climate Resilient Agriculture, IARI, New Delhi delivered a lecture on 'Pollutant Elements' on 10 July, 2013

Dr. Ranjan Bhattacharya, Senior Scientist, Division of Environmental Science, IARI, New Delhi delivered a lecture on 'C-Sequestration under rice-wheat systems' on 21 September, 2013

Dr. T.R. Sharma, Principal Scientist, NRC on Plant Biotechnology, New Delhi delivered a lecture on 'Plant genomics for gene discovery and genotype development' on 14 November, 2013

Dr. B. Gangwar, Project Director, PDFSR, Modipuram, Meerut delivered a lecture on 'Farming Systems Research' on 20 December, 2013.

Dr. R.C. Gautam, former Dean and Joint Director (Education), IARI, New Delhi delivered a lecture on 'Principles of Agronomy and 21st Century agriculture in India' on 4 January, 2014.

Dr. U.K. Behera, Principal Scientist, Division of Agronomy, IARI delivered a lecture on 'Farming Systems Research' on 6 January, 2014.

Dr. A.K. Singh, Principal Scientist, Division of Genetics, IARI, New Delhi delivered a lecture on 'Innovations in basmati rice breeding" on 25th January, 2014.

Dr. M.D. Reddy, Ex-Director, Water Technology Centre, ANGRAU, Hyderabad delivered a lecture on 'Agriculture Development in Telangana' on 1 August, 2014

Dr. D.K. Benbi, ICAR National Professor, Punjab Agriculture University, Ludhiana delivered a lecture on 'Carbon sequestration and soil health enrichment' on 4 September, 2014

Technical Seminars

Following lectures were delivered by the scientists of the Directorate on different emerging issues during the Silver Jubilee Year.

S. No.	Scientist	Designation	Date	Topic
1.	Dr. Anil Dixit	Principal scientist (Agronomy)	31 April, 2013	Herbicide tolerant crops: Opportunities and challenges
2.	Dr. Raghwendra Singh	Senior Scientist (Agronomy)	31 May, 2013	Greenhouse technology for future agriculture
3.	Dr. R.P. Dubey	Principal Scientist (Agronomy)	29 June, 2013	Indigenous technical knowledge in weed management
4.	Dr. A.R. Sharma	Director	30 July, 2013	Integrated weed and nutrient management
5.	Mr. Dibakar Ghosh	Scientist (Agronomy)	27 August, 2013	Herbicide resistant weeds
6.	Dr. Meenal Rathore	Senior Scientist (Plant Biotechnology)	30 October, 2013	Weedy rice: problem and prospects
7.	Dr. D.K. Pandey	Principal Scientist (Plant Physiology)	28 March 2013	Future weed problem scenario
8.	Dr. V.P. Singh	Principal Scientist (Agronomy)	28 June, 2014	Weed flora shift and crop rotation
9.	Dr. A.R. Sharma	Director	5 July, 2014	Presentation of data and thesis writing
10.	Dr. C. Sarathambal	Scientist (Microbiology)	4 August, 2014	Bioprospecting of weed rhizosphere