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Vision 2050

Directorate of Weed Research

Indian Council of Agricultural Research

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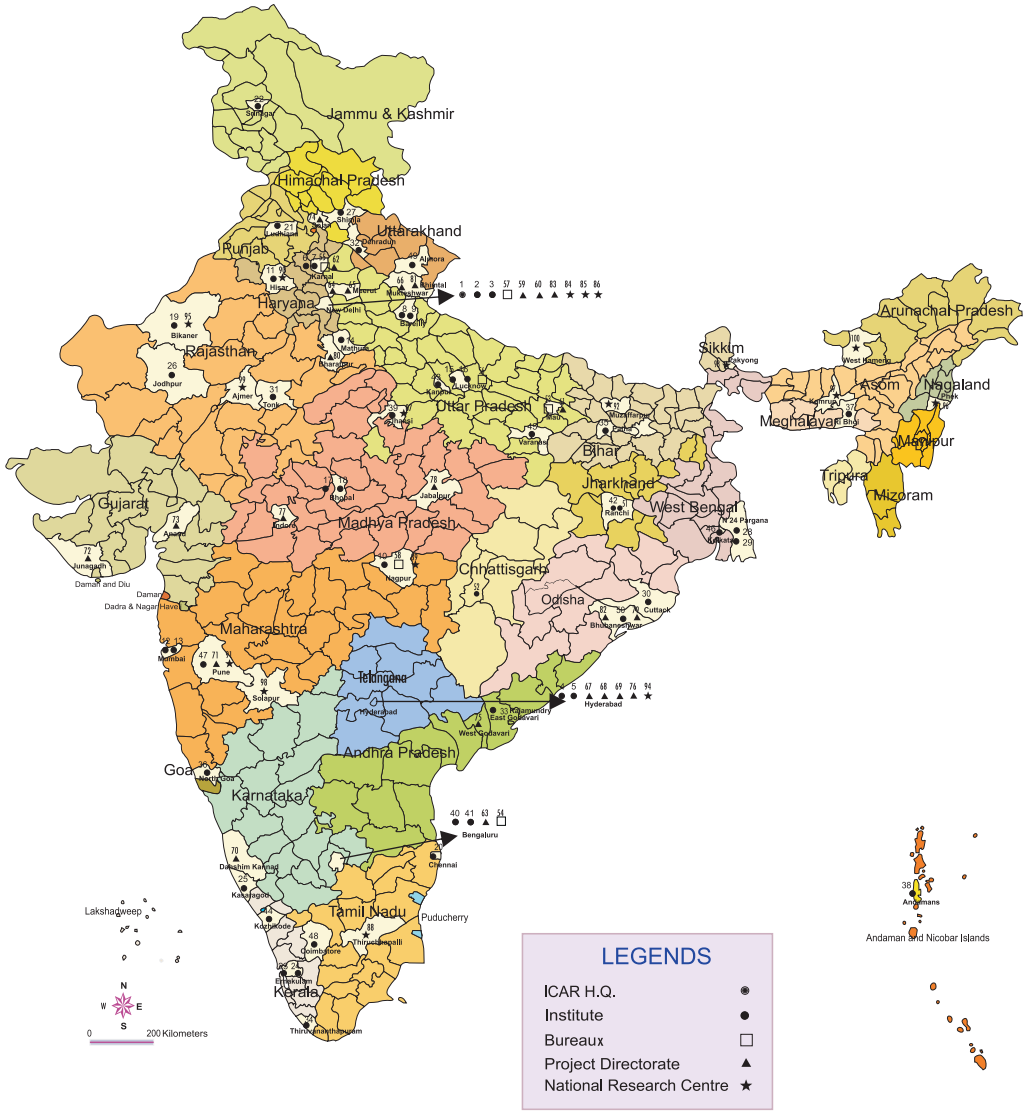

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- Bureaux
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Vision 2050

Directorate of Weed Research
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संदेश

भारतीय सभ्यता कृषि विकास की एक आधार रही है और आज भी हमारे देश में एक सुदृढ़ कृषि व्यवस्था मौजूद है जिसका राष्ट्रीय सकल घरेलू उत्पाद और रोजगार में प्रमुख योगदान है। ग्रामीण युवाओं का बड़े पैमाने पर, विशेष रूप से शहरी क्षेत्रों में प्रवास होने के बावजूद, देश की लगभग दो-तिहाई आबादी के लिए आजीविका के साधन के रूप में, प्रत्यक्ष या अप्रत्यक्ष, कृषि की भूमिका में कोई बदलाव होने की उम्मीद नहीं की जाती है। अतः खाद्य, पोषण, पर्यावरण, आजीविका सुरक्षा के लिए तथा समावेशी विकास हासिल करने के लिए कृषि क्षेत्र में स्थायी विकास बहुत जरूरी है।

पिछले 50 वर्षों के दौरान हमारे कृषि अनुसंधान द्वारा सृजित की गई प्रौद्योगिकियों से भारतीय कृषि में बदलाव आया है। तथापि, भौतिक रूप से (मृदा, जल, जलवायु), जैविक रूप से (जैव विविधता, हॉस्ट-परजीवी संबंध), अनुसंधान एवं शिक्षा में बदलाव के चलते तथा सूचना, ज्ञान और नीति एवं निवेश (जो कृषि उत्पादन को प्रभावित करने वाले कारक हैं) आज भी एक चुनौती बने हुए हैं। उत्पादन के परिवेश में बदलाव हमेशा ही होते आए हैं, परन्तु जिस गति से यह हो रहे हैं, वह एक चिंता का विषय है जो उपयुक्त प्रौद्योगिकी विकल्पों के आधार पर कृषि प्रणाली को और अधिक मजबूत करने की मांग करते हैं।

पिछली प्रवृत्तियों से सबक लेते हुए हम निश्चित रूप से भावी बेहतर कृषि परिदृश्य की कल्पना कर सकते हैं, जिसके लिए हमें विभिन्न तकनीकों और आकलनों के मॉडलों का उपयोग करना होगा तथा भविष्य के लिए एक खाका तैयार करना होगा। इसमें कोई संदेह नहीं है कि विज्ञान, प्रौद्योगिकी, सूचना, ज्ञान-जानकारी, सक्षम मानव संसाधन और निवेशों का बढ़ता प्रयोग भावी वृद्धि और विकास के प्रमुख निर्धारक होंगे।

इस संदर्भ में, भारतीय कृषि अनुसंधान परिषद के संस्थानों के लिए विज़न-2050 की रूपरेखा तैयार की गई है। यह आशा की जाती है कि वर्तमान और उभरते परिदृश्य का बेहतर रूप से किया गया मूल्यांकन, मौजूदा नए अवसर और कृषि क्षेत्र की स्थायी वृद्धि और विकास के लिए आगामी दशकों हेतु प्रासंगिक अनुसंधान संबंधी मुद्दे तथा कार्यनीतिक ढांचा काफी उपयोगी साबित होंगे।

(राधा मोहन सिंह)
केन्द्रीय कृषि मंत्री, भारत सरकार

Foreword

Indian Council of Agricultural Research, since inception in the year 1929, is spearheading national programmes on agricultural research, higher education and frontline extension through a network of Research Institutes, Agricultural Universities, All India Coordinated Research Projects and Krishi Vigyan Kendras to develop and demonstrate new technologies, as also to develop competent human resource for strengthening agriculture in all its dimensions, in the country. The science and technology-led development in agriculture has resulted in manifold enhancement in productivity and production of different crops and commodities to match the pace of growth in food demand.

Agricultural production environment, being a dynamic entity, has kept evolving continuously. The present phase of changes being encountered by the agricultural sector, such as reducing availability of quality water, nutrient deficiency in soils, climate change, farm energy availability, loss of biodiversity, emergence of new pests and diseases, fragmentation of farms, rural-urban migration, coupled with new IPRs and trade regulations, are some of the new challenges.

These changes impacting agriculture call for a paradigm shift in our research approach. We have to harness the potential of modern science, encourage innovations in technology generation, and provide an enabling policy and investment support. Some of the critical areas as genomics, molecular breeding, diagnostics and vaccines, nanotechnology, secondary agriculture, farm mechanization, energy, and technology dissemination need to be given priority. Multi-disciplinary and multi-institutional research will be of paramount importance, given the fact that technology generation is increasingly getting knowledge and capital intensive. Our institutions of agricultural research and education must attain highest levels of excellence in development of technologies and competent human resource to effectively deal with the changing scenario.

Vision-2050 document of ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh has been prepared, based on a comprehensive assessment of past and present trends in factors that impact agriculture, to visualise scenario 35 years hence, towards science-led sustainable development of agriculture.

We are hopeful that in the years ahead, Vision-2050 would prove to be a valuable document in guiding our efforts in agricultural R&D and also for the young scientists who would shoulder the responsibility to generate farm technologies in future for food, nutrition, livelihood and environmental security of the billion plus population of the country, for all times to come.

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Preface

Weeds are one of the major biotic constraints in agricultural production. As per the available estimates, weeds cause up to one-third of the total loss in crop yield, besides impairing produce quality and various kinds of health and environmental hazards. Despite the development and adoption of weed management technologies, the weed infestations are virtually increasing in cropped and non-cropped lands. This is due to adoption of high-input and intensive cropping systems; neglect and discontinuation of some of the traditional practices like intercropping, mulching and crop rotations involving legumes; shift in weed flora due to adoption of fixed cropping systems and management practices including herbicides; development of herbicide resistance in weeds e.g. *Phalaris minor* in the 1990s; growing menace of weedy rice in many states and *Orobanche* in mustard growing areas; invasion by alien weeds like *Parthenium, Lantana, Ageratum, Chromolaena, Mikania* and *Mimosa* in many parts of the country; impending climate change favouring more aggressive growth of weed species, and herbicide residue hazards. This suggests that weed problems are dynamic in nature, requiring continuous monitoring and refinement of management strategies for alleviating their adverse effects on agricultural productivity and environmental health.

Research work on weed management is going on in India for the past 6 decades since the initiation of a coordinated scheme in principal crops like rice, wheat and sugarcane in 1952. This work was strengthened with the launching of All India Coordinated Research Project on Weed Control in 1978, which is now being implemented all over the country. The establishment of National Research Centre for Weed Science in 1989 at Jabalpur and its upgradation as Directorate of Weed Science Research in 2009 (renamed as Directorate of Weed Research in 2014) was a major step forward to undertake systematic research and development programmes on weed management in a holistic and comprehensive manner by adopting multi-disciplinary approach. Over the last 26 years, the Directorate has played a meaningful role in developing and promoting sound weed management technologies in the country, which have helped in reducing costs and drudgery involved in weed control, and increasing crop productivity.

In view of the emerging concerns and challenges in agricultural production with respect to weed infestation, the Directorate needs to reorganize its research and development programmes in the coming decades. Focused multi-disciplinary research programmes need to be formulated to address the emerging challenges and develop location-specific weed management strategies aimed at increasing productivity and input-use efficiency while reducing costs and environmental hazards. Sustainable weed management practices in diversified cropping systems should address issues of weed management in conservation agriculture systems; adoption of systems approach with emphasis on horticultural crops, rainfed and organic farming systems; improving use-efficiency of water, nutrients and other resources through weed management; and efficient spraying techniques for low-volume high-potency herbicide molecules, and mechanical tools for weed management. Weed management research in the context of climate change and herbicide resistance need to focus on the effect of CO_2 and temperature on crop-weed associations, biochemical and physiological aspects of herbicide resistance development in weeds, weed risk analysis and development of weed seed standards. Some weed species are assuming serious proportions in different parts of the country, and are causing havoc to agricultural production, biodiversity and environment. Herbicides are becoming increasingly popular because of their high efficacy and increasing shortages of labour in almost all parts of the country. However, there are some concerns with respect to their residues and adverse effects on environment. A strong programme on transfer of technology needs to be launched with emphasis on on-farm evaluation of weed management technologies, their adoption and impact assessment.

The Directorate needs to expand its reach and show visibility and impact of weed management technologies through effective collaborations, networks and partnerships with various agencies including international organizations. Awareness programmes on the serious problem weeds such as *Parthenium* need to be organized in association with state department of agriculture and other agencies. The Directorate should also serve as a nodal centre for training on weed management and related aspects to different stakeholders.

Vision documents (2020, 2025 and 2030) of the Directorate have been prepared previously considering emerging problems in weed management. Vision 2050 document has focused on the emerging issues in Indian agriculture with respect to weed management, and developing sound weed management strategies for meeting these

challenges, effective collaboration and linkages with other institutions in order to increase the visibility and impact of technologies over the next three and a half decades. A thorough exercise was undertaken with various stakeholders and experts to focus the document on the following aspects: (*i*) Integrated weed management, (*ii*) Weed management in conservation agriculture systems, (*iii*) Developing techniques for managing weeds in precision agriculture, (*iv*) Evaluation of new low-dose high-potency herbicide molecules and their application technology, (*v*) Basic research in allelopathy and bioherbicides, (*vi*) Biocontrol of major alien invasive weeds in non-cropped areas, (*vii*) Simulation models and expert systems in weed management, (*viii*) Collaboration with other scientific organizations, (*ix*) On-farm research in participatory mode for technology, refinement and transfer, (*xi*) Training of scientists in new areas – Weed Risk Analysis (WRA), precision farming, herbicide residue estimation, C-sequestration, crop-weed modelling, biotechnology and climate change.

It is expected that the approaches and forward looking concepts outlined in this document will provide a roadmap for researchers, policy makers, and stakeholders to address the future challenges for growth and development of agricultural sector, and ensure food and income security.

I sincerely thank Dr. S. Ayyappan, Secretary (DARE) and Director General (ICAR), and Dr. A.K. Sikka, Deputy Director General (NRM, ICAR) for their unstinted guidance in preparing this document. Thanks are also due to Dr. B. Mohan Kumar, Assistant Director General (Agronomy, Agroforestry and Climate Change) and Dr. Rajbir Singh, former Principal Scientist (Agronomy), ICAR for their comments on this document. The valuable suggestions by the members of the Quinquennial Review Team (QRT) and Research Advisory Committee (RAC) are also gratefully acknowledged. I complement the efforts made by Dr. K.K. Barman, Dr. V.P. Singh, Dr. Anil Dixit, Dr. P.P. Choudhury and Dr. M.S. Raghuvanshi in preparing this document. I thank all other scientists of the Directorate for giving their valuable inputs.

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Context

Weeds are the most severe and widespread biological constraint to agricultural production and cause damage in cropped and non-cropped lands. They reduce crop yield and degrade quality of the produce besides raising cost of production. In non-cropped lands, the weeds also cause health hazards and loss of biodiversity. As per the available estimates, about one-third of the total losses caused by agricultural pests are due to weeds alone (Figure 1). Unlike other pests, weeds are ubiquitous and affect almost all situations. The biology and ecology of weeds is not the same for all regions. The composition and distribution of weeds, and consequently, the competition by weeds is dependent on soil, climate, crop and management factors. Hence, weed management strategies will have to be different for each agro-ecological condition. Many of the weed problems are location-specific. Further, many a times the farmers ignore weeds even during the critical period of crop-weed competition because of a variety of reasons. Hence, creating greater awareness about the losses caused by weeds and the need for improved weed management technologies are, therefore, vital for improving crop production. Proper training and reorientation of the stakeholders is essential for successful weed management.

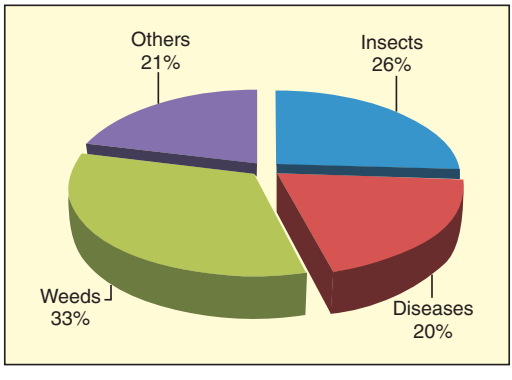

Fig. 1 Crop yield losses caused by weeds and other pests in India

National Research Centre for Weed Science (NRCWS) was established in April 1989 and upgraded as the Directorate of Weed Science Research (DWSR) in January 2009. It was renamed as Directorate of Weed Research (DWR) in November 2014, and mandated

to carry out basic, applied and strategic research for dealing with the challenges in respect to weed management in different agro-ecological regions. The Directorate has contributed significantly in identifying major weeds in different crops and non-crop situations, weed dynamics in crops and cropping systems, weed competitive crop cultivars, weed smothering intercrops, management of parasitic and perennial weeds, and developing effective, economic and eco-friendly weed management practices. The information generated has been very well documented in the form of weed identification kit, national database on weeds covering 435 districts of the country, several technical bulletins, manuals, books, extension pamphlets, posters and video films for the farmers and stakeholders. In addition to print media, the Directorate has also disseminated weed management packages through electronic means, *Kisan Mela* and *Sangoshthi*, exhibitions, trainings, and FLDs across the length and breadth of the country through its AICRP centres in different SAUs. The impact of these efforts can be gauged from the fact that there has been significant increase in acceptance of herbicides as a cheaper and effective tool in weed management. Commendable work has been done in evaluating and disseminating the biocontrol technologies for weeds like *Parthenium hysterophorus* through the use of Mexican beetle (*Zygogramma bicolorata*), water hyacinth (*Eichhornia crassipes*) using weevil (*Neochetina* spp.) and *Salvinia molesto* through *Cyrtobagus salviniae*. Several competitive plants such as *Cassia tora, Cassia serecia, Tagetes* spp. etc. have also been recommended to suppress *Parthenium* effectively.

Despite increased awareness and adoption of technologies, some of the weeds have assumed serious magnitude in different parts of the country. Major weed species in different situations are mentioned below:

Crop lands: *Phalaris minor, Echinochloa crussgalli*, weedy rice, *Ageratum conyzoides, Cyperus rotundus, Cynodon dactylon* and *Parthenium hysterophorus*.

Non-crop lands: *Parthenium hysterophorus, Lantana camara, Mikania micrantha, Mimosa invisa, Ageratum haustonianum, Saccharum spontaneum, Chromolaena odorata* and *Alternanthera sessilis*.

Water bodies: *Eichhornia crassipes, Salvinia molesta, Hydrilla verticillata, Typha angustata* and *Alternanthera philoxeroides*

Parasitic weeds: *Orobanche cernua, Striga asiatica, Cuscuta reflexa* and *Dendrophthoe falcata*

Weed science is a multi-disciplinary and dynamic area of research. The subject is very much advanced in developed countries where weed management is undertaken with minimal labour by harnessing the advances made in cutting edge disciplines such as biotechnology,

information and space technology. Keeping in view the current advances in science and technology, and changing dynamics of weeds in crops and cropping systems in the country, it is necessary to revise and prioritize the research programmes to ensure increased role of research-based technologies for ecofriendly weed management and sustainable crop production. The weed problems are likely to increase due to increased emphasis on high-input agriculture. With greater public awareness on environmental pollution, the focus is shifting towards the development of eco-friendly weed management technologies. Further, new and emerging issues like climate change, altered crop architecture, precision agriculture, conservation agriculture, and herbicide tolerant crops have necessitated a thorough revision of the perspective plan of the Directorate.

❑

Challenges

Human population is still increasing at a fast rate necessitating increased production of foodgrains in successive years. As per the available estimates, India's population will reach 1.7 billion requiring about 70% increase in foodgrains production, besides other food commodities by 2050. The food consumption patterns are also likely to change considerably. Although no major changes are foreseen in the consumption of cereals and pulses, per capita consumption of milk and vegetable oil will increase by about 2-fold and that of meat by 6-fold (Alexandratos and Bruinsma 2012). Economic development of a society also increases its consumption of fruits and vegetables. Thus, the future demand for increased production of fruits, vegetables, oilseeds and fodders will be much higher than of cereals over their existing production level. In India, so far major emphasis has been given on development of weed management technologies for cereals. It is time for weed scientists to change their focus, and lay increased emphasis towards development of improved weed management technologies for oilseeds, vegetables, fruits and fodder crops.

Weed problems are dynamic in nature and are likely to be more serious in the coming decades due to the following factors:

- Adoption of dwarf HYVs and hybrids
- High-input agriculture
- Altered agronomy – discontinuation of intercropping, mulching and adoption of zero-till, organic farming systems
- Monocropping/fixed cropping systems – shift in weed flora
- Development of herbicide resistance in weeds
- Herbicide residue hazards
- Growing infestation of weedy rice, parasitic and other obnoxious weeds
- Globalization and invasion of alien weeds
- Implications of climate change
- Lack of quality human resource in weed science

Future challenges in weed management to be encountered in Indian agriculture in the coming decades are described below:

Weed Dynamics in High-input Intensive Production Systems

The scope for increasing area under crops is limited, and therefore

enhanced food production will necessarily have to come from vertical growth, i.e. by increasing productivity per unit area per unit time. This will require more intensive cultivation of crops with high doses of fertilizers, irrigation and other inputs. While these interventions will put a greater constraint on the available natural resources, the weed problems are likely to shift in unpredictable ways. Increased use of inorganic fertilizers and irrigation also results in increased weed infestation. It is evident that with the discontinuation of some of the traditional practices like crop rotations, intercropping, mulching, organic manuring, etc., the soil health as well as weed scenario has undergone a sea change in many parts of the country. It is therefore expected that future weed problems due to adoption of modern cultivation systems will be far more complex and challenging.

Crop-weed Interaction under Changing Climate

India is the world's fourth largest economy and fifth largest greenhouse gas (GHG) emitter, accounting for about 5% of global emissions. The emission of GHGs will affect climate, leading to global warming. The long-term threat of increasing temperature on weed spectrum should be viewed seriously. Climate change is expected to promote proliferation of new weed species and cause shifts in the composition of weed flora. As weeds are highly dynamic and adapt quickly to new conditions, the management solutions have to address an ever-changing scenario. It is expected that growth of C_3 plants would be enhanced more by CO_2 enrichment as compared to C_4 plants. The differential effect of CO_2 enrichment on C_3 and C_4 plants may have significant implications for crop-weed interaction, since majority of crops belong to C_3 whereas large numbers of weeds belong to C_4 category. Some reports are available on the individual effects of CO_2 and temperature on crop-weed interaction. However, the combined effect of these two factors is yet to be studied in depth. Therefore, it is essential to undertake basic and strategic research including physiological, biochemical and molecular aspects to evolve weed management technologies in the context of climate change. There is need to generate information with respect to herbicide bio-efficacy, herbicide resistance development, behaviour of bio-agents, and herbicide persistence vis-à-vis climate change.

Weeds in Conservation Agriculture Systems

It is widely believed that adoption of modern agricultural practices like intensive tillage, clean cultivation, fixed crop rotations and other

faulty management practices including imbalanced fertilizer application and indiscriminate use of irrigation water have led to serious resource degradation problems. In view of these, conservation agriculture (CA) technologies involving minimum soil disturbance, permanent soil cover through crop residues or cover crops, and dynamic crop rotations are being advocated for achieving higher and sustainable productivity. Globally, CA systems have been adopted on 154.8 million ha (Table 1), and the area is further expanding rapidly due to their potential benefits on crop productivity and farm profitability. The CA-based management practices have demonstrated their potential in arresting land degradation, improving resource-use efficiency, crop diversity, soil health, farm profitability and adaptation, and mitigation of climate change effects.

Table 1. Global adoption of conservation agriculture systems

Country	Area (million ha)	% of global area
USA	35.6	23.0
Brazil	31.8	20.5
Argentina	27.0	17.4
Canada	18.3	11.8
Australia	17.7	11.4
China	6.7	4.3
Russian Federation	4.5	2.9
Paraguay	3.0	1.9
Kazakhstan	2.0	1.3
Others	8.2	5.3
Total	**154.8**	**100**

Source: www.fao.org

In India, efforts to develop, refine and disseminate CA-based technologies have been underway for nearly two decades. The major efforts have been on no-till wheat under rice-wheat rotation of Indo-Gangetic plains. Several studies have projected weeds as the major constraint in adoption of CA technologies. Tillage operations affect weeds by uprooting, dismembering, and burying them deep enough to prevent emergence, by moving their seeds both vertically and horizontally, and by changing the soil environment. Any reduction in tillage intensity or frequency may, therefore, have an influence on weed management. As the density of certain annual and perennial weeds increases under CA, effective weed control techniques are required to manage weeds successfully. Crop yield losses in CA due to weeds may

vary, depending on weed dynamics and intensity. Some studies have shown that with the development of post-emergence broad-spectrum herbicides, weeds can be effectively controlled in CA-based systems. However, use of herbicides alone may result in weed shift in favour of specific species and resistant weeds. There is a need for developing effective and economic integrated weed management practices including various approaches, viz. preventive measures, cultural practices (tillage, crop residue as mulches, intercropping, competitive crop cultivars, herbicide-tolerant cultivars, planting dates, crop rotation, etc.), and herbicides under CA technology.

Monitoring and Management of Resistance to Herbicides in Weeds

Intensive use of herbicides in many regions of the world has led to an increasing number of herbicide-resistant weed biotypes. A large number of weeds have developed resistance against the popularly used herbicides since the first such report in 1982. Isoproturon resistance in *Phalaris minor* in some parts of the country was a costly lesson learnt, as the weed devastated the wheat crop and threatened the sustainability of rice-wheat system for nearly a decade until some new alternate herbicides were introduced. This kind of phenomenon may continue to be a problem in the foreseeable future as well. Emergence of similar problem in other crops and cropping systems is to be monitored based on long-term findings. Now it is widely agreed not to depend on one particular method of weed management but to integrate them suitably. With respect to the use of chemicals, there is greater wisdom in rotating the herbicides, using herbicide mixtures and integrate with time tested management practices such as crop rotation, tillage, organic manuring etc. There should be broad-based special resistance management groups, consisting of both private sector and core scientists to monitor the resistance development and solutions.

Zero-tillage area is increasing in India which will lead to increased use of non-selective herbicides, viz. glyphosate, glufosinate and paraquat as a pre-plant application. There are currently 459 unique cases (species x site of action) of herbicide resistant weeds globally, with 143 dicots and 103 monocots (Heap, 2015). Weeds have evolved resistance to 22 of the 25 known herbicide sites of action and to 157 different herbicides (Figure 2). Herbicide resistant weeds have been reported in 86 crops in 66 countries. Therefore, it is important to monitor the impact on the evolution of resistance against non-selective herbicides under zero-till conditions and develop management strategies accordingly.

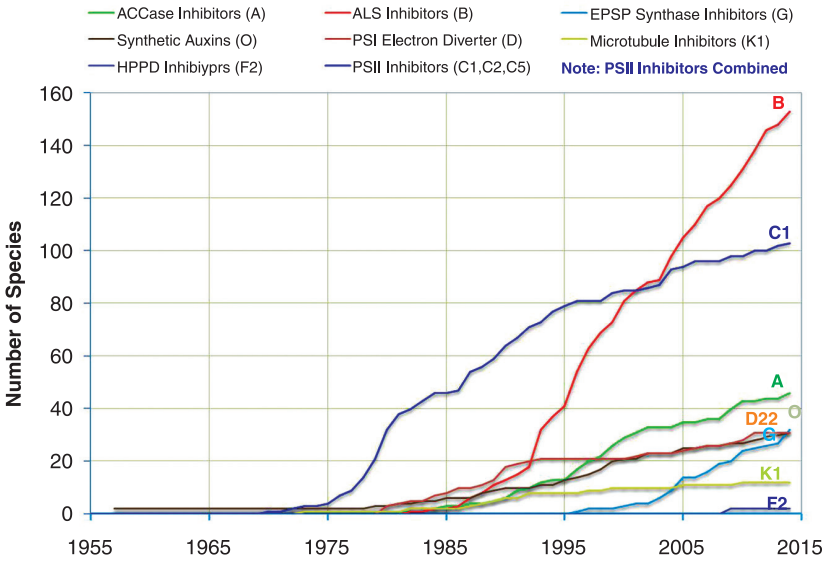

Fig. 2 Number of resistant weed species for several herbicide site of actions (HRAC codes) *Source:* Heap (2015)

Herbicide Tolerant Crops and Evolution of Super Weeds

There is need of a second Green Revolution to sustain productive agriculture in India. The first Green Revolution was based on high-yielding varieties, and it is thought that second Green Revolution will be based on genetically engineered crops. There has been a boom in adoption of GM crops over the last 20 years as the total area covered with these crops has increased from 1.7 million ha in 1996 to more than 181.5 million ha in 2014 (Figure 3). These crops have already

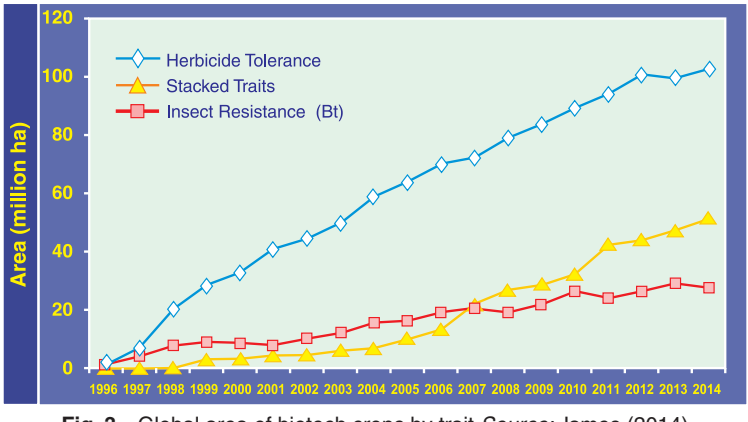

Fig. 3 Global area of biotech crops by trait *Source:* James (2014)

been adopted in 30 countries and India stands fifth with a 11.6 million ha area covered with Bt cotton. Three major traits for which GM crops have been made and commercialized are: herbicide tolerance, herbicide and insect tolerance together, and insect tolerance alone.

Imparting resistance to normally herbicide susceptible crops to produce herbicide-tolerant crops (HTCs) has been the most extensively exploited area of plant biotechnology. The HTCs make efficient management of problem weeds easy with minimum risk to the crop. Resistant genes for several herbicides or specific modes of action have been incorporated into the genome of various crops, viz. maize, cotton, canola and soybean. Consequently, worldwide area under HTCs is increasing rapidly. However, apprehension is being raised regarding the possibility of development of 'super weeds' due to introduction of these crops. Next 3-4 decades belong to such issues but we are not yet ready to face the anticipated challenges. In USA and other countries, glyphosate resistant weeds have already appeared in areas grown with HTCs for many years. There is a need to do *Ex ante* impact assessment of HTCs in India. Also information on gene flow from HTCs to their wild/weedy relatives is needed.

Growing Infestation of Parasitic Weeds

Parasitic weeds are posing serious problems in some of the major crops and cropping systems. *Cuscuta* is a major limitation for cultivation of niger in Odisha; lucerne in Gujarat; blackgram and greengram in rice-fallows of Andhra Pradesh; and niger, berseem, lentil, linseed and chickpea in parts of Madhya Pradesh and Chhattisgarh. Some species of *Cuscuta* also infest ornamental plants, hedges and trees. *Orobanche* is a major root parasite in tobacco, tomato and potato in parts of Karnataka, Andhra Pradesh, Tamil Nadu and Gujarat; and in mustard in parts of Gujarat, western Uttar Pradesh, Rajasthan, Haryana and Madhya Pradesh. Serious infestation of *Orobanche* in many mustard growing areas of Rajasthan (Jhunjhunu) and Haryana are causing huge losses in productivity. The weed emerges from soil in the middle and later stages of growth by which time, it has already caused enough damage to the host plant. Biology of this weed is not well understood and there is no simple solution for its management world over. *Striga* infestation is causing problem in sugarcane, maize, sorghum and pearlmillet grown in dry areas in some parts of Karnataka, Madhya Pradesh, Chhattisgarh and Tamil Nadu. *Dendrophthoe* is noticed on economically useful tree crops such as mango, neem, teak, *Cassia* spp., rose wood, *Dalbergia, Albizia, Terminalia, Pongamia*, Gulmohar, *Madhuca, Ficus*, etc. It is necessary to

develop management technologies for these weeds which are spreading to newer areas and parasitizing many other host plants.

Environmental Impact of Herbicides

Agriculture in India has undergone a major transformation from subsistence farming to a highly intensive, mechanized production system relying heavily on external inputs and energy resources. Thus, production has become dependent on agro-chemicals like pesticides and fertilizers. A change from a high-input and chemically-intensive agriculture to a more sustainable form is not only desirable but also a necessity for environmental safety.

Presently herbicides use in India is meager as compared to the global scenario (Figures 4a and 4b). The consumption of insecticides takes the major share (>two-third), while the herbicides use is only <20%. However, the herbicide use is expected to increase by 15-20% per annum in the future. The herbicides registered in India are of low mammalian toxicity, and most of these are applied early in season, so that the waiting period can be attained by the harvest time. However, herbicide persist in the soil long enough to produce the residual effect. There is every chance of herbicide molecule being transported to different compartments of environment, including ground and surface water. There is always a potential risk of food and water contamination due to herbicide use. Not only the indiscriminate use of herbicide affects the environment, but it also influences the weed biology adversely. It definitely changes the shape of plant kingdom in terms of development of resistance, shifting of weeds, and effect on non-target weed flora causing imbalance in biodiversity. But farmers are now opting for chemical herbicides in place of more expensive mechanical or manual weed control. Therefore, it is a big challenge to use herbicides in the safest way so that we may serve the purpose of ensuring food and biological security.

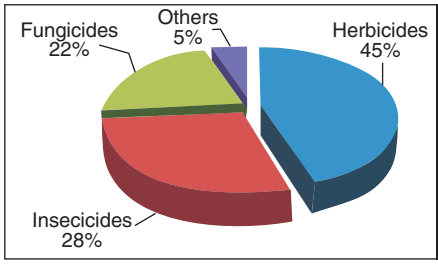

Fig. 4a Global scenario of pesticide use
Source: www.pan-uk.org

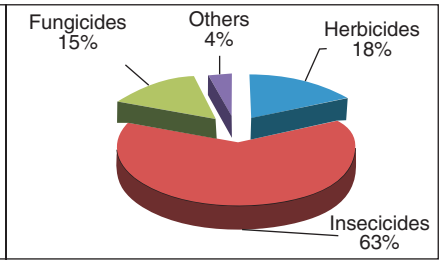

Fig 4b. Indian scenario of pesticide use
Source: www.dnb.co.in

So far there are no reports of accumulation of toxic concentration of herbicides in soils or foodgrains in India. However, the adverse effects of their overdose or long-term use cannot be discounted. Systematic research on long-term herbicide usage on soil health and water bodies is needed. Widespread and increasing use of herbicides is likely to cause greater concern about potential ecological effects. Hence, how herbicide use offsets the delicate ecological balance should also be an area of priority. To avoid the potential ill-effects, strict registration and stringent regulatory mechanisms are to be followed.

Monitoring herbicide residues in environment and food chain should continue to be an important activity as new chemicals are expected to be introduced into the market. Long-term herbicide trials have to be planned in major cropping systems under different agro-ecological regions of the country, which would yield a wealth of information on the long-term implications of herbicide use, including effect on crop productivity, weed flora shifts, resistance of weeds, etc. In addition, degradation pathways and mitigation strategies of herbicide residue hazards need to be developed to lessen their effect on the environment.

Weeds in Organic Farming Systems

Growing concern for human health and sustainability of agricultural production is giving way for organic farming in some parts of the world. In view of this, adoption of non-chemical methods involving tillage, crop rotation, residue management, soil solarization, intercrops, cover crops and green manure crops is necessary. However, it is a big challenge to make these methods effective and economical. Notwithstanding the high cost, soil solarization may become popular in future at least in nurseries and high-value crops in organic agriculture. The success achieved in controlling *Phalaris minor* using zero tillage technology in Indo-Gangetic plains should be explored in other crops and weed species. In maize, growing cowpea as an intercrop for fodder or green manure has been found to suppress the weeds significantly. In wheat, better weed control and higher total productivity can be obtained by intercropping with berseem. Inclusion of *Sesbania* grown as an intercrop (brown manuring) in upland direct-seeded rice can be adopted for managing weeds and obtaining higher productivity. There is ample scope of developing system-based approaches and mechanical tools as part of integrated weed management strategies in organic farming systems. Development of efficient ecological weed management approaches and their integration with mechanical and biological control measures will be essential to make organic farming systems economically viable.

Obnoxious Weeds in Terrestrial and Aquatic Environment

Obnoxious weeds such as *Lantana, Parthenium, Ageratum, Chromolaena, Mikania* and *Mimosa* have invaded vast areas of forest, grasslands, wastelands, orchards and plantation crops. *Parthenium* is categorized as one of the seven most difficult weeds of the world. It is estimated to have spread on over 35 million ha of geographical area throughout the country. Previously a problem on road sides and non-cultivated areas, *Parthenium* is now entering into the field crops. *Chromolaena odorata* was earlier restricted to north-eastern region and Western Ghats but it is now fast spreading to other areas. Similarly, *Mikania micrantha*, which is popularly called 'mile-a-minute' weed on account of its rapid growth, is a big nuisance in forestry and plantation crops in north-eastern and southern India (Yaduraju et al., 2003). *Lantana camara* has invaded large areas of non-crop lands in north-western Himalayan region. *Ageratum* has become a big nuisance in both cropped and non-cropped areas. Weedy rice is an emerging problem in direct-seeded rice in many states. The control of these weedy forms is difficult as the plants are hard to distinguish from the sown crop at the early growth stages. Widespread infestation of these weeds has not only threatened agricultural production systems but also biodiversity, human and animal health. Containing the spread of these obnoxious is a great challenge, requiring newer innovative approaches.

Globalization and Introduction of Alien Invasive Weeds

There are a large number of weed species found in many other regions of the world but these have not yet been reported in India. However, increased exchange of foodgrains and seeds following globalization of agriculture is bound to result in introduction of such alien invasive weeds (AIWs). The sanitary and phyto-sanitary agreement of WTO suggests that the countries should not only update their quarantine laws but also incorporate the elements of pest risk analysis for making regulatory decisions for both import and export. Therefore, there is an urgent need to analyze the risk factors associated with different exotic weeds to design safeguards and to lower the risk of their entry.

Many countries like Australia, New Zealand, and USA have developed strong protocols for weed risk analysis (WRA) and for identification of quarantine weeds. There is a need to strengthen our capacity on WRA and develop more stringent guidelines and standards for prevention of introduction of AIWs into the country. Several weeds of invasive nature existing in the different parts of the world have not yet entered into the country. Increasing trade and globalization coupled with liberalization

policies will, however, increase the risk of AIWs. Some exotic species, a few of them potentially harmful, might have gained entry into India as contaminants in wheat imported from different countries. Recent wheat imports during 2006-07 have reportedly led to introduction of five regulated weed species, viz. *Cenchrus tribuloides, Solanum carolinense, Viola arvensis, Cynoglossum officinale* and *Ambrosia trifida*. Studies are needed to: (i) assess ecological impact of invasive species, (ii) monitor changes in spread of invasive weed species over time and predict area which is likely to be invaded, (iii) develop preventive measures, and (iv) ecologically-based invasive plant management practices.

Continuous Monitoring and Development of Databases

A huge database on weeds in the country has been built based on the survey and surveillance through the All India Coordinated Research Project on Weed Management. Accordingly, a National Database on Weeds has been developed which provides information on the occurrence and diversity of major weeds in different crops, cropping systems as well as non-cropped areas of the country along with their distribution status. There is need to continuously upgrade this database to include non-cropped and aquatic areas, weed shift and introduction of new alien weeds. Such up-to-date information would be of immense use for policy planners, researchers and local administrators.

Weed management packages should aim at more viable ecological solutions and integrating them with herbicides. To achieve this, monitoring of weed dynamics after the introduction of control methods is essential for developing epidemiological based data. It has been observed that there is considerable variation in the floristic composition of weeds not only from different regions but also from field to field in the same eco-region. This highlights the role of crop management practices in general, and weed management practices in particular. Weeds are not static but respond to management practices. A minor weed may emerge as a major one after some years under a set regime. The impact of herbicides on weed flora shift is also very conspicuous. Herbicides exhibit varied effect on weeds depending upon their morphological, physiological and biochemical characteristics. There is urgent need to intensify the research on biology and ecology of weeds for developing sound integrated management practices.

Dissemination of Weed Management Technologies

Improved weed management technologies have not yet reached the farmers at the same pace as it happened in case of high-yielding varieties,

fertilizers and insecticides. Lack of awareness among the farming community is the major reason for poor adoption of weed management technologies. Many extension agencies do not pay much attention to weed management. In some places, the herbicides are not available locally to those farmers who are interested to use them. Therefore, there is a strong need to work in collaboration with herbicide industry/ private sector to correct this imbalance. On the other hand, the cost-effective weed management technologies through field demonstrations, electronic media, trainings and participation in *Kisan Melas* need to be popularized. It is important to involve farmers in developing, testing and refining technologies keeping in view the location-specific problems and resources available with the farmers. Since private sector is emerging as a strong force in technology generation, acquisition and transfer, suitable mechanism of linkage between public and private sector in assessing and transferring appropriate technologies in a complementary fashion should be developed. Although the increasing consumption of herbicides introduced into the market is a reflection of the popularity of the herbicides, systematic studies to assess the societal impact of improved weed management technologies is required. Information about safe use of herbicides and application technology for higher efficacy and integrating chemicals with other methods of weed management are also to be disseminated.

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Operating Environment

Weeds are as old as the agriculture itself but the methods and concept of controlling weeds have changed over the years. The past weed control practices in India were characterized by intensive use of manual labour and animal power. Both of these are now in short supply and are increasingly becoming uneconomical. The manual labour traditionally being employed for weeding is gradually becoming scarce and expensive owing to rapid urbanization and industrialization. An estimated 8-10 billion man-days are engaged in weed control in a year, which in other words, means that every Indian is involved in weeding for at least 8-10 days in a year. According to available estimates, by the year 2050 nearly half of the population would be living in urban areas (Figure 5), creating unprecedented shortage of labour force for use in agriculture. On the other hand, to meet requirement of additional food for increasing population, it is expected that cropping intensity will increase in future. This will further increase the demand for workforce in agriculture sector. However, ground reality in respect of manpower supply is going in reverse direction. During 1970, 72% of total workforce was engaged in agriculture, which came down to 53%

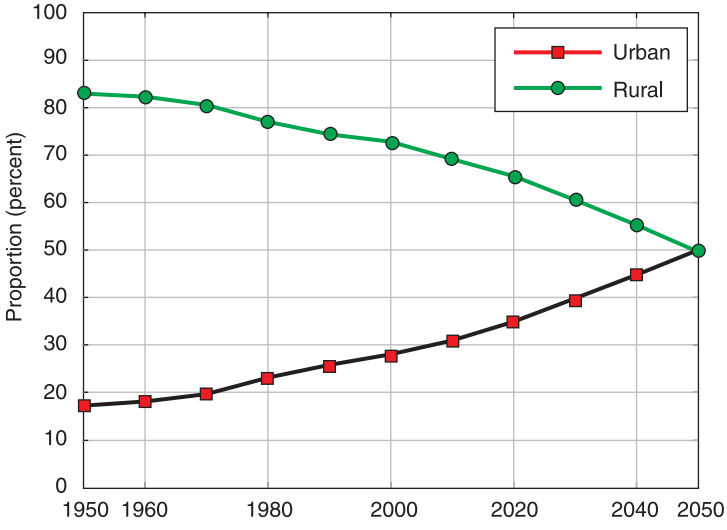

Fig. 5 Projected urban and rural population in India
Source: www.esa.un.org

by the year 2010. If the trend continues, only 27% workforce will be available for agriculture by 2050.

Introduction of the social welfare programme like MGNREGA has aggravated the already serious constraint of manpower supply in agriculture. There are evidences that the younger generation of farming families are showing disinterest in their household agriculture activities, and preferring to take up even the petty non-agricultural works as a means of earning. Besides, manual weeding is laborious, time-consuming and always not practical because of adverse soil and climatic conditions. The weeds are more competitive with crops during the initial stages of their growth. Controlling weeds during this time is very essential for realizing maximum crop yield. Because of this, chemical weed control is rapidly gaining ground in the country. Therefore, future weed science research and related technological developments need to match emerging weed management scenario of the country.

Stakeholders express serious concerns about weed management in real field situations. In fact weed related problems have become the issues of common discussion in the meetings, seminars, trainings, workshops, *Kisan Mela* and *Sangosthis*. The farmers are in dire need of cost-effective weed management technologies for increasing productivity and profitability. Following issues have emerged based on interaction with various stakeholders:

- Non-availability of labour for weed control
- Rising costs of manual weeding
- Invasion of new weed species
- Application techniques of herbicides
- Combined use of herbicides with other pesticides
- Non-availability of herbicides and mechanical tools
- Spurious and costly herbicides
- Large packings of herbicides
- Registration of new molecules
- Lack of awareness and extension efforts
- Weeds in no-man's lands

Operating environment in the coming decades is likely to be more uncertain, complex and difficult for weed management. The scarcity of labour for manual operations will increase further, and chemical weed management will become more important. However, there will be increased instances of herbicide resistance development in weeds and occurrence of herbicide residue hazards with increased use of chemicals. It is likely that herbicide tolerant crops might become a reality in

Indian agriculture after some of the anticipated concerns are suitably addressed. Changing climate is an issue which will intensify weed problems considering the better adaptive behaviour of weeds compared with crop plants. Alternate production systems involving crops of high economic value, zero-tillage, fertigation, protected cultivation and other advanced technologies will become more predominant, and thus present an entirely different weed management scenario. Problematic weeds in non-cropped lands may further intensify due to their prolific regeneration and uncontrolled growth.

Chemical Weed Control

Herbicides have become a boon to farmers in areas where the labour availability is limited and wages are high. The use of herbicides has been increasing in India enormously in the last few decades (Figure 6). The major impact has been in north-western India where most of the agricultural operations are done by migrant labourers. The advantages of herbicides over the other methods are appreciable in closely-planted crops like rice and wheat. In many regions, these crops are sown by broadcasting, thus making manual weeding more difficult.

Wheat and rice account for major share of the total herbicide consumption in the country (Figure 7). It has been estimated that herbicides are being used on more than 20 million ha, which constitute about 10% of the total cropped area in the country. There is urgent need for chemical-based technologies for managing weeds in pulses, rainfed areas, parasitic weeds like *Orobanche*, and weedy rice.

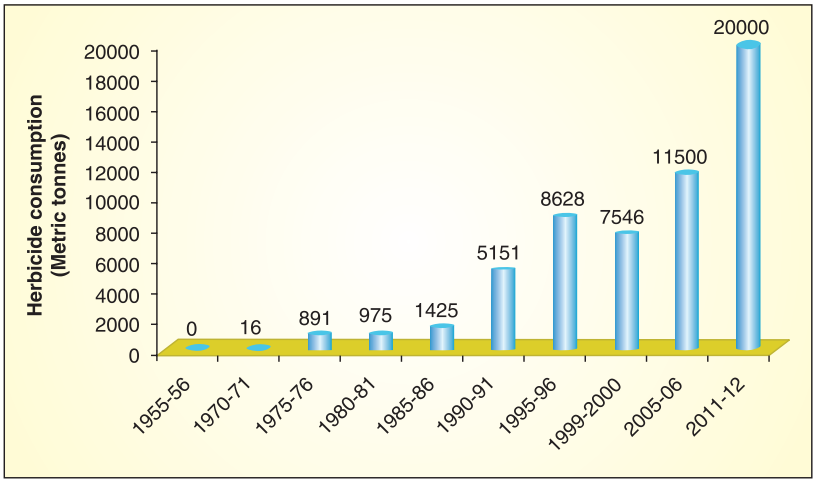

Fig. 6 Herbicide consumption in India over the years

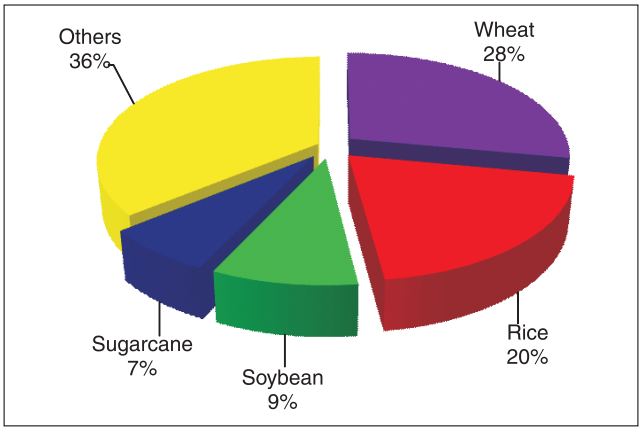

Fig. 7 Crop-wise herbicide use in India
Source: Yaduraju (2012)

Herbicide Resistance in Weeds

Over-reliance and repetitive use of the herbicides belonging to the same group can lead to development of herbicide-resistant weed biotypes. Development of resistance in *Phalaris minor* to isoproturon was noticed on nearly 1.0 million ha of wheat in parts of Punjab and Haryana. Continuous long-term use of isoproturon for over two decades during 1970s and 1980s resulted in the development of resistance during early 1990s. New herbicides like clodinafop, fenoxaprop and sulfosulfuron have successfully contained the problem and restored the productivity of wheat in this region. This technology alone is estimated to have saved wheat production to the extent of 1.5 million tonnes annually. There are now reports that the *Phalaris minor* is also showing multiple resistance to these herbicides as well. Similarly, the anticipated resistance of *Echinochloa colona* to butachlor may pose a threat to rice production. As the plant systems have their own built-up mechanisms for defense, there is likelihood that this will be a serious problem in the foreseeable future. Some herbicides provide high risk of resistance development, while others especially with more than one mode of action provide less risk. It is needed to categorize the herbicides, based on high risk, medium risk and low risk for resistance development.

Herbicide Residue Hazards

Herbicides are much safer chemicals than other pesticides because of their application at relatively lower rates, early in the season not directly on the flowering or edible parts, and degradation by the time the crops is harvested. The herbicides have much higher LD_{50} values to

be of any potential harm to the human beings and livestock. However, some of the unintended negative impacts of herbicide use are persistence in soil, pollution of ground water, toxic residues in food, feed and fodder, and adverse effect on non-target organisms. Some herbicides like atrazine, diuron, alachlor, imazethapyr and metolachlor have been detected in ground water. Herbicides that are highly water soluble and weakly adsorbed to soil particles such as those belonging to sulfonyl-urea and imidazolinone groups have potential for contaminating ground water. Notwithstanding these apprehensions, herbicides are likely to remain as one of the major tools in weed management as these offer huge benefits to the farmers. Accordingly, herbicide use is likely to increase substantially in the future, and their judicious use is of utmost importance. But this warrants research on dose-response equations, interaction of herbicides with plant and soil, modeling of weed spectrum changes, and weed dynamics and herbicide use in long-term conservation agriculture systems.

Changing Climate

It is now a widely accepted fact that climate is changing, which is likely to have consequences on crop-weed associations and agricultural productivity. Increasing level of CO_2 directly influences plant physiology through its effect on photosynthesis, transpiration and respiration. However, rising temperature will have contrasting influences on these primary processes. Due to greater adaptability, weeds will achieve a greater competitive fitness against the crop plants with a changed climate. For instance, *Parthenium hysterophorus* (C_3) and *Amaranthus viridis* (C_4) showed enhanced growth and biomass production under elevated CO_2, resulting in increased flower production (Naidu and Paroha, 2008). Many crops such as rice and maize face the dual problem of increased competition from weeds and reduced yield in a harsh environment due to global warming.

Alternate Production Systems

Organic farming and conservation agriculture systems are being advocated for arresting soil degradation and improving soil quality. Changes in farming practices often lead to weed flora shift in the crop field, which in turn also dictate the requirement of new weed management technology. Surface germinating weeds (small-seeded dicots and grasses) may increase due to adoption of conservation tillage practices. Development of non-chemical methods such as mechanical and cultural, viz. soil solarization, tillage, residue management, intercrops,

cover crops and green manure crops is expected to gain importance in organic farming. Conservation agriculture may favour the shift towards perennial weeds besides increasing the herbicide use. The CA-based technologies are essentially herbicide-driven, machine-driven and knowledge-driven, and therefore require vastly improved expertise and resources for adoption on large areas. Conservation agriculture is often hailed as the future agriculture or the agriculture of the future, for which, development of efficient weed management technologies is of paramount importance in diversified cropping systems.

Problematic Weeds in Non-cropped Lands

Many invasive, obnoxious and harmful weeds like *Lantana, Ageratum, Parthenium, Mikania, Chromolaena, Mimosa,* etc. have encroached terrestrial areas by replacing the native flora, and threatening the existence of wild animals. Aquatic weeds increase the loss of water through transpiration, interfere in navigation, affect fisheries, mar recreational value of water and severely impede the flow of water in canals. India has a total area of about 7 million ha under different kinds of water bodies such as reservoirs, tanks, ponds, lakes, and brackish water. In addition about 1.7 lakh km is under rivers and canals. The area under aquatic bodies is increasing with the building-up of dams, canals and tanks for irrigation and fisheries production. Managing these weeds using manual or mechanical means is not possible due to heavy expenditure involved. There exists scope for managing weeds in non-cropped areas through the use of bio-agents.

Directorate has done commendable work on bio-control of *Parthenium* by releasing the Mexican beetle in different parts of the country during the last 10 years. However, this bio-agent is not expected to completely eradicate *Parthenium*. Australia is using a number of bio-control agents against *Parthenium*, which need to be explored under Indian conditions. *Sclerotium rolfsii*, a necrotrophic fungus, incites severe collar rot diseases in many plants including *Parthenium*. Several competitive plants, such as *Cassia tora, Cassia serecia, Tagetus* spp. etc. have also been reported to suppress *Parthenium* effectively. There is urgent need to search and evaluate alternative bio-agents to contain the *Parthenium* problem in our country.

Gall fly (*Cecidochares connexa*) for biocontrol of *Chromolaena odorata*, and rust fungi (*Puccinia spagazzinii*) against *Mikania* have been imported, which are undergoing trials in India. It is anticipated that biological approaches would gain prominence for the control of problematic weed species. Screening of efficient, effective and host-specific bioagents and

subsequently establishing them in target areas is a challenging task. Till now, there are no suitable and host-specific bioagents in India for the invasive weeds like *Chromolaena, Mimosa* and *Lantana*, which are posing a threat to biodiversity.

In view of the restricted use of herbicides in aquatic bodies due to the multiple use of water for fish culture, irrigation, domestic purpose etc., biological agents should be given preference to herbicide application. Insects like *Neochetina* spp. and *Orthogalumna terebrantis* against water hyacinth, *Cyrtobagous salviniae* against *Salvinia molesta*, and herbivore fishes such as common grass carp (*Ctenopharyngodon idella*) against small floating and submerged weeds have shown promise in the biocontrol of aquatic weeds. *Alternaria eichhorniae, Cercospora rodmanii, Fusarium oxysporum* and *Alternaria alternata* are also promising in controlling water hyacinth. However, efforts are after comprehensive research required to develop efficient, eco-friendly and integrated methods using different bioagents.

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Opportunities

A great deal of change is occurring in weed management for the last few decades. In fact, serious research in weed science was undertaken in our country during 1970s when 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 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 effective weed management with the adoption of conservation agriculture, organic farming and precision farming systems.

There have been commendable contributions of weed research towards agricultural production and natural resource management through the development of weed control technologies. However, these were mostly based on herbicides which are causing weed shift, risk of herbicide resistance and environmental contamination. There is urgent need to develop new methods to control weeds in view of the growing concerns of food safety and water quality. To do this, more emphasis should be given on basic and strategic research to develop new weed control technologies. The time has come to reorient weed research from being merely weed control technology oriented to a broad-based scientific discipline. For this, weed scientists have to move beyond a dominating focus on herbicide efficacy testing, and must address the basic science underlying complex issues, viz. ecological weed management, molecular biology and physiology of weedy traits, invasion biology, and ecosystem restoration. Increased cooperation between these complementary groups of scientists will pave the way of making weed science more relevant to the complex vegetation management issues of forthcoming decades. Rapid development taking place in various branches of science and

technology would provide ample opportunities to tackle the complex issues in the field of weed management.

Following opportunities are available for weed management in Indian agriculture:

- Herbicides are becoming increasingly important for weed management due to labour scarcity in many parts of the country. Safer low-dose synthetic molecules of various modes of action are being introduced to replace more hazardous conventional herbicides. New low-dose and high-potency molecules and formulations have become available in the last 4-5 years. It is expected that more such new generation chemicals will become a reality in near future.
- Research on controlled release formulation is essential for precision weed management. The controlled release of herbicide molecules in application zones provides long-term control of weeds avoiding repeat application of herbicides. These formulations minimize herbicide residues in the environment, increase the efficacy and longevity of the herbicide by protecting it from environmental degradation, and decrease the application cost. Research and development of nano-herbicides and other slow release chemicals is continuing, and is expected to yield results in the coming years.
- Precision farming based on remote sensing techniques for site-specific weed management are being developed. This will greatly help in avoiding wastage of herbicides and minimize residue hazards.
- Herbicide tolerant crops are being grown in many parts of the world. It is expected that such crops will be introduced into India in near future after the legitimate concerns are adequately addressed. This may change the spectrum of weed management programmes in India.
- Innovative production systems like conservation agriculture and organic farming are being developed for enhancing resource-use efficiency, crop productivity and environmental sustainability. Weed management in such systems would require greatly enhanced knowledge and application.
- New generation machines for tillage, sowing, interculturing, spraying, harvesting and residue management are being developed, which will provide cost-effective means of weed management.
- Search of bioactive botanicals and microbial metabolites, which may act as lead molecules for herbicide development, is an essential component of weed management programme. Research on biotechnology can provide breakthrough for development of bioherbicides, which are host-specific and environment friendly.

Similarly, new strains of bioagents effective against problem weeds will be identified.

- Emphasis is being given to develop solar energy-aided microwave generating devices for the control of target weeds. The success of it may reduce herbicide consumption many folds. This device coupled with sensor technology will be the part and parcel of precision and automated weed control technology.
- New tools aimed at more effective transfer of technology for weed management are available in the era of ICT. Farmers will have easy and quick access for such tools in the coming decades. A weed management data repository and effective Management Information System (MIS) will be established.
- Trained and qualified manpower will be available to guide stakeholders in weed management.
- In view of non-availability of labour and other constraints like water, the scientists and farmers are being driven to develop more innovative weed management strategies.
- Efficient diagnostic techniques for monitoring herbicide residues would lead to safer chemical weed control and cleaner environment. Effective decontamination techniques for active and transformation products will provide opportunity for mitigation of residue hazards.
- Climate change research would provide further insights into crop-weed association, herbicide and bioagent efficacy for developing effective weed management technologies.
- Weed utilization techniques are available for effective conversion of weed biomass into enriched compost, medicinal use, bioremediation and industrial application.

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Goals and Targets

Directorate of Weed Research has to play a pivotal role in developing integrated weed management technologies for improving crop yields and reducing the problems in other ecosystems. Much needs to be done in future to work out effective strategies in the light of new emerging weed problems and address issues related to globalization and WTO. The Directorate will further strengthen collaboration with the SAUs and ICAR institutes located in different regions of the country, which will act as outreach centres to generate the location-specific recommendations. Weed menace in forestry, pasture, grassland, and non-cropped areas is threatening biodiversity and causing adverse impact on human and animal health as well as quality of environment. The Directorate is marching ahead with renewed vigour to face complex challenges of weeds in all ecosystems.

Targets

Weed problems are likely to increase due to increased emphasis on high-input agriculture on one hand and globalization will bring new weed problems on the other. To meet the future challenges in weed management in the era of increased environmental awareness, DWR will focus on the following key areas:

Development of sustainable weed management practices in diversified cropping systems

i. Integrated weed management for conservation agriculture based cropping systems
ii. Developing and up-scaling economical and eco-friendly weed management technologies in different field and horticultural crops/ cropping systems under rainfed and irrigated ecosystems and in non-crop situations
iii. Improving input-use efficiency through weed management
iv. Standardization of spraying techniques for low-dose high-potency herbicides, and mechanical tools for weed management

Crop-weed dynamics and management under the regime of climate change

i. Weed biology and crop-weed interaction under elevated CO_2 and temperature

ii. Shift in weed flora, herbicide and bioagents efficacy under changing climate scenario

Herbicide resistant crops and weeds

i. Physiological and molecular basis of herbicide resistance development in weeds
ii. Strict monitoring and management of multiple resistance in weeds
iii. Studying potential benefits and risks associated with introduction of herbicide tolerant crops

Biology and management of problematic weeds in cropped and non-cropped areas

i. Biology and management of problematic weeds in cropped areas
ii. Biology and management of problematic weeds in non-cropped areas
iii. Management of alien invasive weed species
iv. Research on aquatic and parasitic weed management
v. Weed utilization

Monitoring, degradation and mitigation of herbicide residues and other pollutants in the environment

i. Impact of herbicides in soil, water and non-target organisms and their mitigation measures
ii. Degradation of herbicides in the environment
iii. Identification of herbicide metabolites and residue hazards
iv. Bioremediation of pollutants using terrestrial and aquatic weeds

Development of weed seed identification and weed risk analysis

i. Biology and ecology of important weeds and their damage potential
ii. Identification of weeds of quarantine significance
iii. Optimizing and standardizing procedure and protocols for WRA

On-farm research and demonstration of weed management technologies, and impact assessment

i. On-farm research and demonstration of weed management technologies for enhanced productivity and income
ii. Impact assessment of adoption of weed management technologies for socio-economic upliftment and livelihood security
iii. Strengthening advisory services of weed management to stakeholders.
iv. Creating awareness among farmers, policy makers, planners, administrators and other stakeholders about utility and losses caused by weeds.

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Way Forward

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 the major future challenges. Herbicide tolerant GM crops may be a possibility in the coming decades after the legitimate concerns are adequately addressed.

A holistic approach with multi-disciplinary, multi-locational and multi-institutional involvement would be imperative to tackle future weed problems. AICRP on Weed Management 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 multi-disciplinary 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 and ISRO in formulating innovative research projects. Efforts also need 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 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 and biotechnology. Evaluation of new low-dose high-potency herbicide molecules and their methods of application for higher efficiency will be addressed in collaboration with the herbicide industry. More emphasis will be given

on developing integrated weed management technologies involving non-chemical methods such as use of cover crops, weed suppressing crop cultivars and mechanical weeding tools. Basic research in areas like allelopathy and bio-herbicides which have relevance for practical weed management will be undertaken through collaborative arrangements with other institutes. Research on biological control of alien invasive weeds in non-cropped situations and aquatic bodies 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 and others will be ensured to achieve the goals. The technical programme for network research on management of aquatic and parasitic weeds, weed management in rainfed agriculture, horticultural and vegetable crops will be finalized after thorough interaction with collaborating organizations.

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 (WRA) and biocontrol related studies; and referral laboratory for herbicide residues studies.

Following strategies would be adopted to accomplish the goal and targets of the Directorate.

Goals / targets	Strategies
1. Developing integrated weed management practices	• Developing guidelines for incorporating non-chemical methods (cultural / mechanical and agronomic manipulation) with chemical methods • Development of sustainable weed management practices in diversified cropping systems • Use of crop and weed residues as mulch material • Integration of new mechanical tools and machines
2. Managing weeds through judicious use of herbicides	• Evaluating new herbicides and facilitate their registration for commercial availability • Optimizing time and dose of herbicide application, and elucidating factors affecting their efficiency

		• Integrating with other methods to reduce dose and increase efficiency • Understanding the absorption, translocation and metabolism of herbicides in crop plants and weeds • Understanding the antagonistic, synergistic and additive response of herbicide mixtures • Developing protocol for judicious use of herbicides • Educating on accurate herbicide application technology and safety
3.	Developing biocontrol measures for managing weeds	• Exploring the potential of pathogens, insects, fish and allelo-chemicals for weed control • Study the host (weed)-biotic agent inter-relationship and interaction with environment and human beings • Emphasis on classical biological control through the importation of biological control agents from the country of origin of the weeds particularly *Parthenium*, water hyacinth, alligator weed, *Mimosa* and *Pistia* • Development of cheap and sustainable mass production of bioagent and the improved ways of its dissemination.
4.	Monitoring environmental quality	• Assessing the possible risk of herbicide residue hazards on environment • Management techniques to mitigate the negative impact of herbicide residues • Developing policy guidelines on herbicide residue limits in food products • Developing agronomic techniques for herbicide residue management • Surveillance on multiple resistant weeds • Screening herbicide resistant strains of biofertilizers • Developing controlled release formulations of herbicides • Developing antidotes against herbicides for soil organisms
5.	Aquatic weed management	• Exploring the potential native and exotic bio-control agents against major aquatic weeds • Developing techniques for enhancing the efficiency of recommended biocontrol agents • Development of integrated weed management practices involving biological, mechanical and chemical methods • Testing of herbicides on bioagent and other non-target organisms like predators, parasitoids, pollinators, microbes, and micro-aquatic fauna in terrestrial and aquatic situations
6.	Understanding the biology and eco-physiology of crop-weed interaction	• Understanding mechanism of weed seed dormancy and methods to overcome dormancy • Understanding weed dynamics and strategies to minimize weed seed bank • Weed-crop dynamics and management under the regime of climate change and herbicide resistance

	• Setting economic threshold limits (ETLs) of weeds in different crops • Understanding biology and ecology of major weeds • Role of allelopathic interactions in crop production and resource-use efficiencies
7. Using biotechnological tools for managing weeds	• Understanding the concept of genetic engineering and its feasibility in weed management • Evaluation of herbicide tolerant crops • Exploring and developing bioherbicides • Impact of herbicide tolerant crops on biodiversity • Monitoring the probable emergence of "super weeds" • Evaluation of weed competitive crop cultivars
8. Weed risk analysis	• Generating data on biology and ecology of important weeds and their damage potential • Optimizing and standardizing procedure and protocols for WRA • Identification of weeds of quarantine significance • Developing user-friendly identification kit for seeds and seedlings of alien weeds.
9. Parasitic weeds management	• Development of integrated management practices for *Striga*, *Cuscuta, Orobanche* and *Dendrophthoe*
10. Utilization of weeds for economic and social benefits	• Utilization of weed biomass as source of nutrients, biogas and biofuel
	• Phyto-remediation of industrial and municipal wastes
11. Monitoring alien invasive weeds and developing control measures	• Assessing extent and level of infestation of alien invasive weeds in different ecosystems • Impact of alien invasive weeds on biodiversity • Developing management strategies especially through bio-control.
12. Developing techniques for managing weeds in conservation agriculture	• Studying weed dynamics under contrasting management systems • Developing integrated weed management packages • Studying interactive effects of multiple production factors on important weeds • Strengthening the research on smarter use of herbicide including adjuvants, mixtures, rotations and emphasis on early season weed management, • Developing precision application technology for increasing herbicide efficiency and effectiveness by maximizing delivery to the targets. • Understanding the impact of conservation tillage systems on the performance of soil active herbicides. • Developing cropping system based sustainable weed management technologies.

13. Developing techniques for managing weed in precision agriculture	• Detection of weeds by remote sensing techniques • Forecasting weed infestations and crop yield losses • Development of variable rate technology for site-specific application of herbicides by integrating GPS and GIS
14. Developing weed database	• Updating national database on weeds and weed seed atlas • Strengthening library and information system • Development of Decision Support Systems, simulation models and information retrieval systems on weed management • Development of databases for on-line dissemination of information on weed management
15. Facilitating dissemination of weed management technologies, knowledge and information	• Capacity building of scientists and Subject Matter Specialists • Training programmes and other HRD activities for different stakeholders • Increased interaction with farmers and stakeholders through innovative approaches • Development of a standard protocol based on economic analysis based technology, validation comprising of OFTs and FLDs for release of weed management packages to the farmers • Socio-economic survey and impact analysis

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