Technical bulletin no. 16

DWR SUCCESS STORIES

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Preface

Weeds are one of the major biotic constraints in agricultural production. As per the available estimates, these cause up to 37% of the total losses in yield, besides impairing produce quality and other various kinds of health and environmental hazards. Considering the growing menace of weed infestations in cropped and non-cropped lands, the Indian Council of Agricultural Research decided to establish the National Research Centre for Weed Science, which came into existence on 22nd April, 1989. This centre was further upgraded as Directorate of Weed Science Research on 23 January, 2009; and renamed as ICAR- Directorate of Weed Research on 26 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 research.

Over the last few decades, the Directorate has played a pioneering 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, environmental impact of herbicides and utilization of weeds. Adoption of these advanced weed management technologies has been promoted on large areas through on-farm research and demonstrations, which has raised agricultural productivity and livelihood security of the farmers. In fact, weed management technologies are the most demanding in the present context in view of the large-scale labour scarcity for manual weeding and increased cost of cultivation. 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 hazards, and safety concerns about herbicides tolerant crops.

In the present publication, success stories of adopting such advanced weed management technologies over the years have been compiled. It is hope that this document will be beneficial to all stakeholders including scientists, field functionaries and farmers for solving the weed related problems and reducing the crop losses by adopting these advanced weed management technologies. The success stories given in the publication are outcome of hard work done by scientists and staff of ICAR-Directorate of Weed Research who have developed and disseminated the technologies among the farmers and documented their success in the form of success stories. Comments as well as any suggestion for further improvement will be highly appreciated.

Place: Jabalpur

Date: 20 March, 2018

(P.K. Singh)
Director

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Improved weed management technologies brought prosperity to Tagar Village in Jabalpur

The people of Tagar – Mahagawa village under the Block Panagar District Jabalpur are mainly based on agriculture for their livelihood. The farmers of these villages are still using ancient agricultural practices for growing crops, therefore, the overall farm productivity was meager. Residents of Tagar village especially the youth were migrating to town areas for employment due to unprofitable farming and less area under cultivation. ICAR-Directorate of Weed Research, Jabalpur, has identified this village with an objective to make the farmers aware about the modern agricultural practices with special reference to weed management for increasing the crop productivity and profitability.

Rice-wheat system was the major cropping pattern of the village, and hardly farmers were growing any other crops, mainly due to heavy infestation of weeds. Farmers were mostly using family labours for manual weeding in their crop during *kharif* season and kept the *rabi* crop un-weeded. They were not aware about advance weed management practices available like mechanical weeding and use of herbicides.

Technologies

Detailed survey was made by the ICAR-DWR team through personal interaction with the villagers to assess various aspects like population, size of holding, socio-economic status, prevailing agricultural and horticultural practices, knowledge level on weed management and other agricultural technologies, animal husbandry, etc.

Discussion with villagers

Problem identification and discussion with the villagers

Preliminary survey of field sites

On the basis of survey, the problems were identified and strategies were made to rectify the problems. In these, method and result demonstrations of improved weed management technologies were showcased and farmers were very much satisfied with the performance of weed management methods. Thereafter, farmers themselves came forward to adopt new weed management practices in their respective crops.

Subsequently, ICAR-DWR conducted massive awareness programmes, group discussions, farm and home visits, technical campaigns and need based trainings on regular basis, and further intensified field demonstrations, with an objective to achieve higher productivity, profitability and farm prosperity in sustainable manner.

Demonstration of improved weed management technologies

Impact

The efforts made by the Directorate and the cooperation extended by the villagers were extraordinary in order to achieve sustainable weed management in existing cropping system (Figure 1). The adoption level of weed management practices in various crops significantly increased to >80% than its initial level (4–5%). Apart from adoption of weed

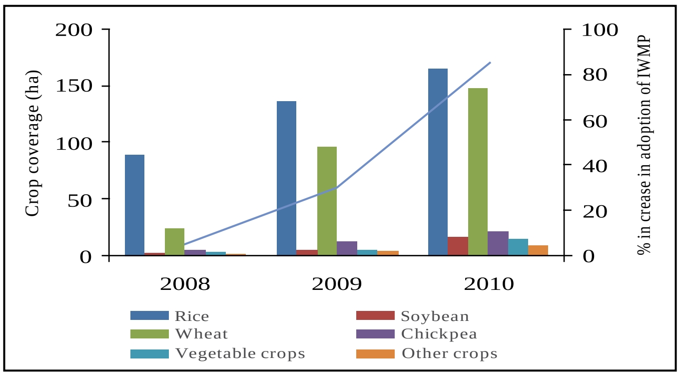


Fig. 1: Acreage under different crops before and after adoption of village

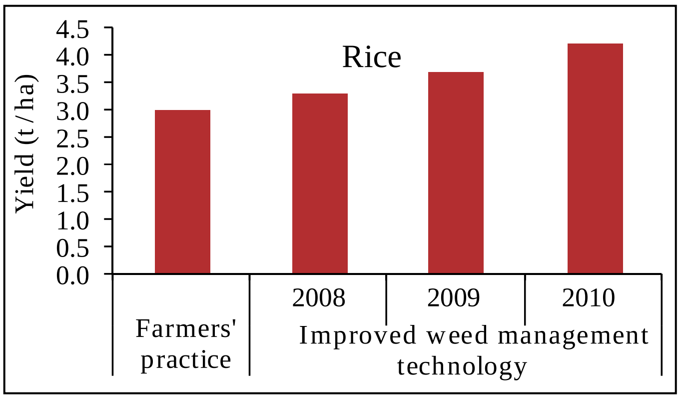


Fig. 2: Performance of rice crop after intervention of IWM

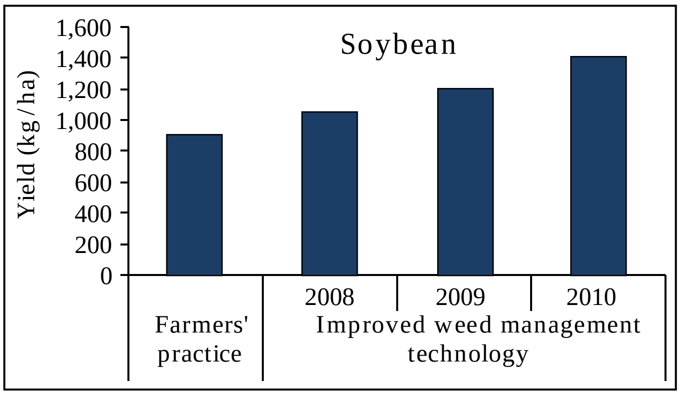


Fig. 3: Performance of soybean crop after intervention of IWM

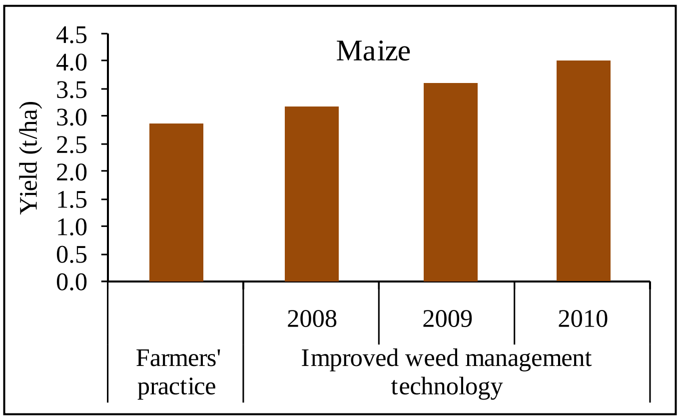


Fig. 4: Performance of maize crop after intervention of IWM

management practices, it brought more area under cultivation to soybean (0.6–8%) and vegetable crops (1–7%) after three years of interventions. After the technological interventions, the average productivity of different crops of adopted village was increased by (10–12%), (23–25%) and (38–40%) in first, second and third year, respectively. These helped them to achieve an additional net return of ` 20,000–25,000 / ha over base year.

After seeing the performance of technologies in demonstration sites, farmers of the village adopted weed management technologies in rice, wheat, soybean, chickpea and vegetable crops. The farmers who left crop cultivation due to weed severity, they started growing and more area was brought under cultivation during *kharif*, which were 89.2 ha (45% of total cultivable area) in base year to 180 ha (after third year). Similarly, the area under *rabi* season crops, also increased from 30.6 ha (16%) to 192 ha (96%). This was happened mainly due to improvement in confidence level of farmers in managing weeds through improved weed management technologies.

Phalaris minor, wild oat and other broad leaved weeds were major obstacle in growing wheat; therefore, majority of the farmers stopped cultivating wheat. Zero-tillage technologies were demonstrated in combination with chemical weed management after seeing the encouraging results of these technologies, the farmers virtually shifted to grow wheat in large scale during *rabi*.

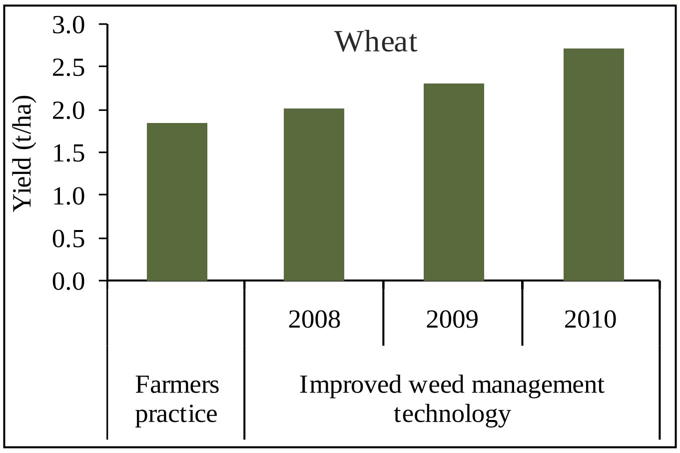


Fig. 5: Performance of wheat crop after intervention of IWM

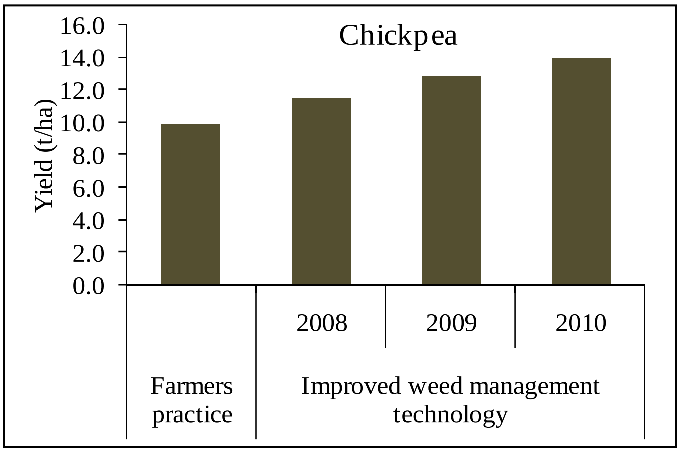


Fig. 6: Performance of Chickpea crop after intervention of IWM

Table 1: Details of Improved Weed Management technologies supplied to the farmers

Particular	Improved Weed Management Technology
Rice	Chlorimuron + metsulfuron methyl *fb* fenoxaprop-p-ethyl at 4 + 60 g / ha (25–30 DAT) Pretilachlor at 750 g / ha at 0-3 days after transplanting (DAT) Bisbyribac sodium at 25 g / ha (17–20 DAT)
Soybean	Chlorimuron + fenoxaprop at 10 + 75 g / ha at 25 days after sowing (DAS) Imazethapyr at 100 g / ha (at 25 DAS)
Maize	Atrazine at 1000 g / ha (0–3 DAS)
Wheat	Clodinofop + metsulfuron-methyl at 60 + 4 g / ha (25 DAS) Isoproturon + 2, 4-D at 500 + 500 g / ha (25 DAS) Sulfosulfuron + metsulfuron-methyl at 25 + 4 g / ha (25 DAS)
Chickpea	Pendimethalin at 1000 g / ha (PE)

The success achieved in the cultivation of rice and wheat also changed the view of farmers about the overall agricultural practices. Earlier, it was common practice to grow some vegetables in their kitchen garden for household consumption only. ICAR-DWR demonstrated soil solarization technique for weed-free seed bed preparation, and also introduced them to many other agricultural agencies like state agriculture/horticulture department, seed companies, IFFCO etc. Consequently, along with the improved weed management techniques, many farmers adopted other modern agricultural technologies and started growing vegetables in commercial scale.

Wheat under zero tillage and herbicide

Row sowing of chickpea with improved weed management practices

Presently by spending a sum of ` 10,000–12,000 for cultivation of brinjal, cauliflower, cabbage, tomato and chilli, farmers are earning a profit of approximately ` 38,000–44,000 / ha. Cultivation of brinjal alone gave a return of almost ` 35,000–40,000 / ha to successful farmers on an investment of only ` 8000 / -. All these successes have created an environment of diversification in agriculture in this village.

The outcome of the technological support provided by the ICAR-DWR, Jabalpur boosted the confidence level of youth which seriously retained them in agriculture. Besides more than two and six folds increase in *kharif* and *rabi* cropping areas, respectively, a significant increase in the productivity by 10–38% in rice, soybean, maize, wheat and chickpea crops was also achieved in Tagar village within a short span of 3 years of its adoption by ICAR-DWR.

Crop cultivation under conservation agriculture: A viable option for upliftment of economic status of farmers

Rice-wheat is the major cropping system followed in central and eastern part of Madhya Pradesh. In this system, wheat is generally sown in fine seedbed prepared with 4-5 tillage operations. The tillage operations increase the cost of production but they have hardly any benefit for increasing the grain yield of wheat. Further, there is a great concern about reduction in soil fertility, scarcity of farm labour, declining ground water table and high cost of production under conventional agriculture. In order to overcome these problems, it is essential to adopt technically-feasible, economically-viable and ecologically-permissible technology which ameliorates late sowing of wheat, minimizes weed infestation, lowers cost of production, and improves fertilizer and water-use efficiency.

In areas around Jabalpur and its adjoining districts like Mandla, Katni, Seoni and Narsinghpur, harvesting of rice and wheat is mostly done through combine harvesters, and the crop residues are invariably burnt before sowing the next crop which causes serious environmental hazards besides loss of previous organic matter and soil nutrients. ICAR-Directorate of Weed Research, Jabalpur introduced happy seeder machine to demonstrate the conservation agriculture technology with improved weed management (IWM) practices among farming community for sowing of wheat and greengram under On-farm research programme during 2012-2016. Sowing was done without any tillage operation (ploughing) for land preparation and removing / burning the standing crop stubbles of the previous crop.

Sowing of wheat under CA

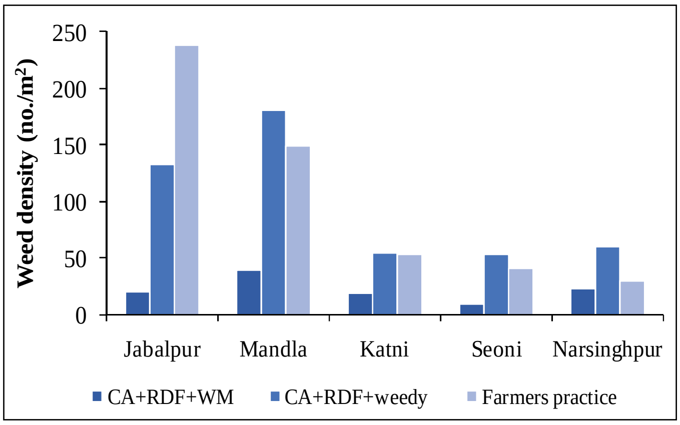
Wheat crop under CA at initial days

Demonstration on wheat under CA

Demonstration on greengram under CA

Wheat crop under conservation agriculture system

Demonstrated fields had very good emergence and establishment of crop. Weed populations in conservation agriculture trials with improved weed management practice were less compared to farmers practice. Ready-mix combination of clodinafop + metsulfuron at 60+4 g / ha were used at 25 days after sowing (DAS) to control weeds in the field. This molecule controlled the weed flora effectively as compared to the farmers' practice (conventional tillage with 2,4-D as a weed control measure) (Fig. 1). Conservation agriculture technology gave higher grain yield and B:C ratio over the farmer's practice (Table 1).



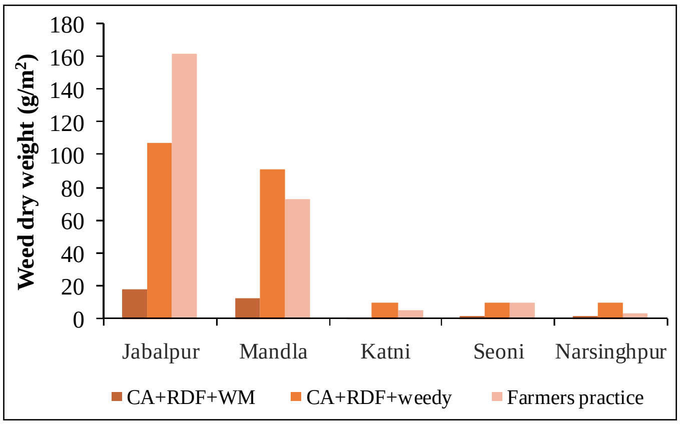


Fig. 1: Weed density and weed dry weight as influenced by conservation agriculture and weed management practices in wheat (CA: conservation agriculture; RDF: recommended dose of fertilizer; WM: weed management)

Table 1. Productivity of wheat (t/ha) under conservation agriculture in OFR during *rabi* 2013-16

Treatment	Jabalpur		Mandla		Katni		Seoni		Narsinghpur	
	Grain yield	B:C ratio	Grain yield	B:C ratio	Grain yield	B:C ratio	Grain yield	B:C ratio	Grain yield	B:C ratio
CA + RDF + WM	4.93	3.80	4.20	3.16	5.14	3.44	5.05	3.44	4.10	3.46
CA + RDF + weedy	3.51	2.90	3.30	2.87	4.34	3.15	2.91	2.15	2.76	2.68
Farmers practice	3.22	2.22	3.50	2.30	3.49	1.81	2.83	1.78	3.75	2.40

CA-Conservation agriculture; RDF- Recommended dose of fertilizer; WM-Weed management

Greengram under conservation agriculture system

Conservation agriculture technology was demonstrated in greengram during summer season following wheat harvest. Sowing with happy seeder in the residues of wheat resulted in very good emergence and establishment of greengram crop. The density and dry biomass of weeds in conservation agriculture were less compared to conventional agriculture (Fig. 2). Conservation agriculture along with improved weed management practice (imazethapyr at 100 g/ha at 15-20 DAS) was very effective, economical and provided higher seed yield and B:C ratio as compared to that of in farmers practice (Table 2).

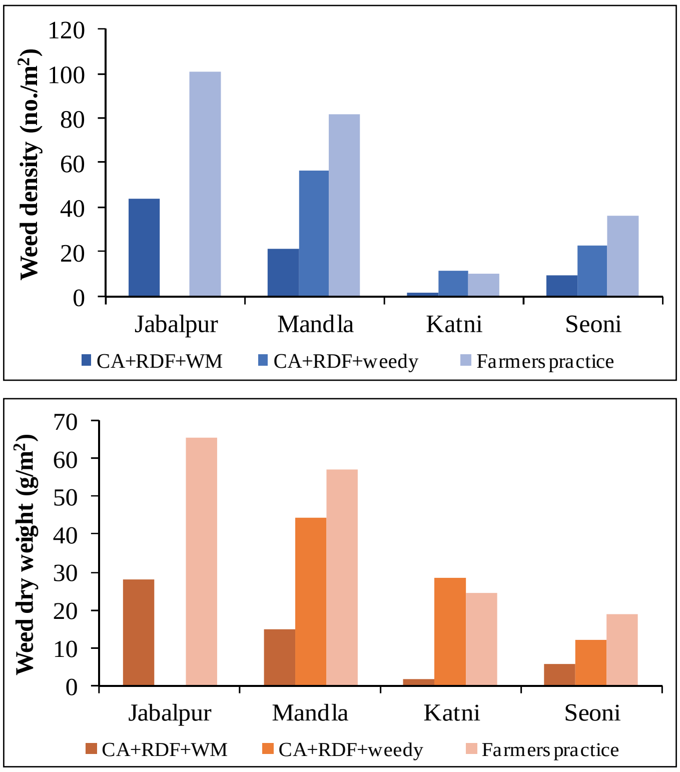


Fig. 2: Weed density and weed dry weight as influenced by conservation agriculture and weed management practices in summer greengram (CA: conservation agriculture; RDF: recommended dose of fertilizer; WM: weed management)

Table 2. Productivity of greengram (t/ha) under conservation agriculture in OFR during summer 2013-16

Treatment	Jabalpur		Mandla		Katni		Seoni	
	Seed yield	B:C ratio	Seed yield	B:C ratio	Seed yield	B:C ratio	Seed yield	B:C ratio
CA + RDF + WM	1.25	2.94	1.35	3.63	1.26	3.90	1.70	2.82
CA + RDF + weedy	-	-	1.03	3.09	0.95	3.32	1.35	2.44
Farmers practice	0.72	1.43	0.89	2.18	0.87	2.10	0.88	1.31

CA-conservation agriculture; RDF- recommended dose of fertilizer; WM-weed management

Impact

Conservation agriculture technologies saved time and cost of land preparation, and favoured early sowing which helped to utilize residual soil moisture. Unlike conventional zero-till seed drill, Happy Seeder facilitated sowing in the previous crop residue, which served as mulch and thus helped in managing weed menace and improved soil health.

The successful demonstration of this technology was realized by following the principles of learning by doing and seeing is believing. After the successful introduction of this technology, about 700 farmers from Jabalpur have started growing wheat under conservation agriculture for more than 2000 ha of land and stopped burning the residues of previous crop in the season (2016-17). The farmers of this locality are highly enthusiastic about

Farmer's opinion

The conservation agriculture technology was introduced by ICAR-DWR, Jabalpur in our locality during 2012-13 and 2013-14. We have harvested 4.5 t/ha of wheat and 1.4 t/ha of summer greengram by adopting this technology. Initially the farmers were fearing about sowing without tillage and teasing us, but due to good tillering, leaf colour and good growth of plants after first irrigation, they also became interested to know about technology. By adopting this technology farmers could increase the productivity while saving time and reducing cost of cultivation. This technology also helped in timely sowing, conserving soil moisture. It requires less water, saves tillage wheat and greengram sowing under conservation agriculture. The technology adoption by farmers is very encouraging and the performance of this technology has become a point of discussion amongst the farmers of this locality.

cost and time, and it reduced the soil erosion due to the retention of surface residues, thus reducing organic matter depletion. Now the farmers from this locality as well as from other localities have started adopting this technology on large scale.

The OFR trials in wheat and greengram conducted by the Directorate under conservation agriculture have made significant impact on farmers of Jabalpur, Mandla, Katni, Seoni and Narsinghpur region. Farmers are positive in their attitude about this technology. Saving time, cost, fuel during land preparation, labour and the overall profitability gains have shown positive change in the attitude of farmers towards this technology.

Improved weed management practices with resource conservation technologies increased the productivity of major crops in Jabalpur

Jabalpur is located in the central plateau region of India. The farmers of this region are mainly growing rice, soybean, maize and sugarcane in *Kharif* season and wheat, chickpea, lentil, peas and mustard during *Rabi* season. Very limited farmers are cultivating greengram and other vegetable crops during summer season. The main constraint is open cattle grazing during the season. In this region, soils are deep black cotton in nature and medium to heavy in texture (vertisols). For crop cultivation, farmers generally follow conventional package of practices like intensive ploughing of the land, clean cultivation (removal or burning of previous crop residues and stubbles), fixed crop rotations, diminutive use of organic manures and moderate use of chemical fertilizers, and application of pesticides including herbicides. Harvesting of major crops mostly done by combine harvester and crop residues are invariably burnt in most of the areas. Due to the rising cost of cultivation, the profitability margins are generally low (` 10000 – 20,000/ha/annum). Keeping this in view, it was felt to promote the adoption of resource conservation technologies in order to reduce the cost of cultivation and to improve soil health, besides other environmental benefits.

Technology

On-farm research trials were undertaken from 2012 onwards in six different localities, which are about 50–100 km away from Jabalpur district headquarter. In each locality, 2–3 villages and 5-8 farmers from each village were selected based on the interest shown by them and suitability of the land. Various integrated or improved weed management practices with resource conservation technologies such as direct-seeding of rice, brown manuring with *Sesbania*, zero-till sowing of crops, residue retention on soil surface, growing of summer legumes like greengram or *Sesbania* in the crop rotation were demonstrated in diversified cropping systems. Nearly 100 such on-farm research trials were conducted during 2012–15 and the details are given in below table.

An area of 1 acre (0.4 ha) was selected for each on-farm trial cum demonstration and 3-4 interventions were introduced as per suitability and requirements of the farmers. Observations on weed growth and crop yield were recorded, economic feasibility of the improved package of practices was analyzed and responses of the farmers were collected.

Locality	Village	Crops / cropping system	Major interventions
Jabalpur District			
Majholi	Pola, Dhora, Hinota, Gathora	Soybean-chickpea	Line / zero till sowing, recommended seed rate and fertilizer, improved weed management
Bankhedi	Amna, Dhanwahi	Rice-wheat	Line / zero till sowing in wheat, recommended seed rate and fertilizer, improved weed management
Panagar	Mahagawa, Kariwah, Chanti, Beher, Bharda, Padaria	Rice-wheat-greengram	Resource conservation technologies, improved weed and fertilizer management, recommended seed rate
Shahpura	Bhamki, Kisrod, Magarmuha, Noni	Rice-wheat / chickpea	Resource conservation technologies, improved weed and fertilizer management, recommended seed rate
Gosalpur	Podi-nindora, Bhadam, Khajari	Rice-wheat	Resource conservation technologies, improved weed and fertilizer management, recommended seed rate
Kundam	Khukham, Padariya, Ranipur, Kalyanpur	Maize-wheat	Line sowing, recommended seed rate and fertilizer, improved weed management
Other Districts			
Katni	KVK	Wheat	Resource conservation technologies, improved weed and fertilizer management, recommended seed rate
Narsinghpur	KVK	Wheat-summer greengram	Resource conservation technologies, improved weed and fertilizer management, recommended seed rate
Damoh	KVK	Wheat	Resource conservation technologies, improved weed and fertilizer management, recommended seed rate

A *Kisan Gosthi* involving 75-100 farmers was organized at each locality during *kharif* and / or *rabi* season of every year to discuss the findings and receive feedback from the farmers. Visits of the key officials were also arranged; and the events were covered widely in the print and electronic media.

Impact

Based on the findings of the last 3 years, the following observations were made:

- Direct seeding of rice (DSR) should be done by mid-June to get an assured crop stand. As compared to manual transplanting, DSR reduced the cost of cultivation by ` 2500 / ha. And on the other hand, DSR also increases net profit by 15–20% as compared to conventional transplanting method.
- To manage the repeated weed flashes in DSR sequential application of pre-emergence herbicides (pendimethalin / pretilachlor) followed by post-emergence herbicides (bispyribac-Na / fenoxaprop *fb* 2,4–D / metsulfuron + chlorimuron) are recommended. If weeds are not managed effectively, one manual weeding can be performed under such adverse situation to minimize weed seed bank.
- Zero-till sowing of wheat with happy seeder in anchored rice residue showed an outstanding growth of wheat crop and yielded 15-20% higher than that of conventional wheat cultivation. By reducing the tillage operations, the cost of cultivation for zero-till wheat was also trimmed down by ` 4500 / ha. For successful weed management post–emergence herbicides like sulfosulfuron, clodinafop, sulfosulfuron + metsulfuron, mesosulfuron + iodosulfuron and clodinafop + metsulfuron can be applied based on the nature of weed flora present in the field.
- Sowing of greengram crop by 'Happy seed-drill machine' immediately after the harvesting of wheat through combine harvester produced a seed yield of 1.3-1.5 t / ha within 65 days. Weeds in greengram were managed efficiently with the application of post-emergence herbicide like quizalofop / imazethapyr at 25 days after sowing.

Conservation agriculture–based technology like zero-till cultivation of crops in the presence of previous crop residue with improved weed management practices is the most promising technology. This technology has spread over more than 1000 ha and the Happy Seeder machines are now in great demand in those areas. Farmers are highly convinced with this technology, as it save time, provide better weed control, maintain soil moisture status, improve soil fertility and environment friendly.

Aquatic weedy plants: Potential phytoremediating agents for multi-pollutant removal from waste water

Millions of untreated sewage from human habitation and industrial effluents are carried through drains in Indian cities. In Jabalpur, around 143 lakh litres of waste water is discharged daily through various open drains which discharged into the river Narmada and Pariyat causing deterioration of its water quality. Its continuous use as irrigation water to the field crops has become a general practice around peri-urban areas of Indian cities which enhanced the available metal status of agricultural soils by 2 to 100 times. Heavy metals, unlike organic pollutants, cannot be destroyed or changed to other forms that are harmless. They can operate as stress factors in a plants environment which can be seen by the adverse reaction shown by the plants. Sensitive or non-tolerant plants die or have reduced growth at a particular metal concentration, at which resistant or tolerant plants show little or no adverse effect on growth. In this sense the very survival of weed species with increased biomass in waste water containing heavy metals is a testimony that they have the ability of absorbing and accumulating pollutants including heavy metals. Among these, *Eichhornia crassipes* and *Pistia stratiotes* are the most efficient weeds grown in aquatic environment which were found to be the potential scavengers of heavy metals from aquatic body.

The removal of contaminants by macrophyte treatment of waste water at source is easier than from soils where these get accumulated by adsorption. Though the metal hyperaccumulator plants are very useful for phytoremediation of heavy metals have many shortcomings such as low biomass, edible nature and difficult to harvest. Moreover, the metal hyperaccumulator plants identified in temperate regions cannot perform in other climatic situations like tropical and sub-tropical.

Intervention/Technology

Survey of sewage contaminated sites was carried out in Jabalpur and adjoining areas. Villagers including farmers expressed their concern of water pollution in human habitation area of Amkhera, Urdua, Kachpura locality.

Discussion with the farmers/villagers during survey of contaminated sites in Jabalpur and adjoining areas

In order to treat the pollutant water by aquatic weeds at contaminated site, a pilot scale macrophyte based water treatment system is established at Urdua village of Panagar locality of Jabalpur. The treatment system comprises of the collection tank, settling tank followed by treatments zone. The aquatic weeds viz. *Eichornia crassipes* and *Pistia stratiotes* were planted in separate treatment tanks. The waste water from river is pumped into collection tank, settling tank and retained in treatment zone in which aquatic plants were grown. Thus, water was treated by the aquatic plants and then it was used to irrigate the field of vegetable crops. The water samples were also collected from inlet and outlet zone of each tank after 7 days during first run and daily up to 5 days during second run of the treatment system. After harvest of these weeds species *Typha latifolia* was grown. The various water parameters were analyzed by multi-parameter water analyzer model Photolab RS12A (WTW make).

Aquatic weed growth in treatment tank

Impact

The concentration of sulphate, sodium, chloride and chromium was lower in aquatic weeds treated water than that of untreated water during 1^{st} run of the system after 7 days of hydraulic retention time (HRT). Among the two weed species *Eichornia crassipes* performed better than *Pistia stratiotes*. The concentration of sulphate, sodium, chloride and chromium was lowered by 6, 31, 29 and 0.54 ppm, respectively in the *Eichornia crassipes* treated water.

The pH, EC, temperature and total hardness of the drain water was not influenced with the treatment of aquatic weedy plants (Table 1). Whereas, the *Eichhornia crassipes* treatment with 5 days HRT effectively reduced the concentration of total dissolved salts (TDS), sulphate, sodium, chloride and chromium concentration by 18.0, 66.6, 39.1, 43.1 and 78.3% respectively of drain water (Table 1 &Fig. 1). And it also reduced the turbidity of the drain water by 89% (Table 1).

Table 1. Water quality after 5 days in aquatic weed based treatment system (II run)

Treatment	pH	EC (dS/m)	Temperature (°C)	TDS (mg/L)	Total hardness ($CaCO_3$)	Turbidity (Ntu)
Drain water	6.27	0.876	27.8	480	49.0	64.2
Collection tank water	6.43	0.838	27.2	462	45.6	58.3
Settling tank water	6.52	0.88	27.3	452	48.3	56.5
Treated water (*Pistia*)	6.53	0.877	27.3	455	43.6	20.4
Treated water (*Eichhornia*)	6.69	0.785	27.3	394	45.0	6.9

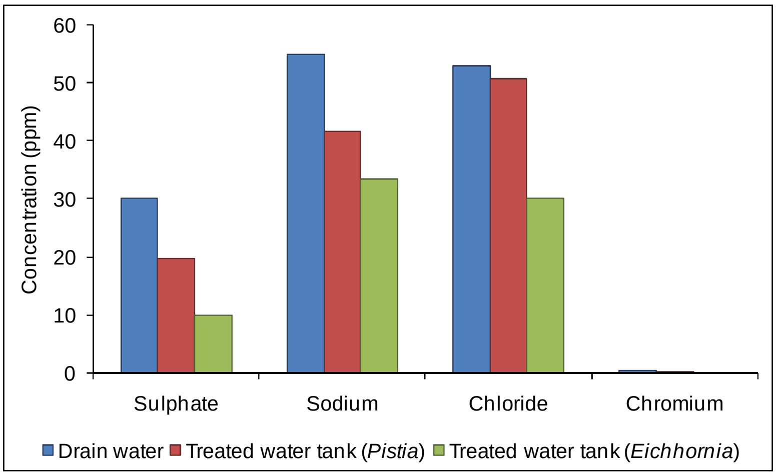


Fig. 1. Performance of aquatic weed based system for heavy metal reduction in waste water.

The remediation of water contaminated with heavy metals was done using higher terrestrial plants like *Typha* grown in hydroponic culture and absorbing, concentrating or precipitating the metals from sewage by means of adult plant roots (rhizofiltration) and seedlings. The growth of a large and dense plant root body of *Typha* is suitable for the effective removal of heavy metals from waste water by rhizofiltration, which was tested after harvesting of earlier plants in pilot scale treatment system. The *Typha* treatment system reduced the chromium, nickel and lead to the extent of 66.1, 73.4 and 36.4% respectively as compared to the untreated drain water (Fig. 2).

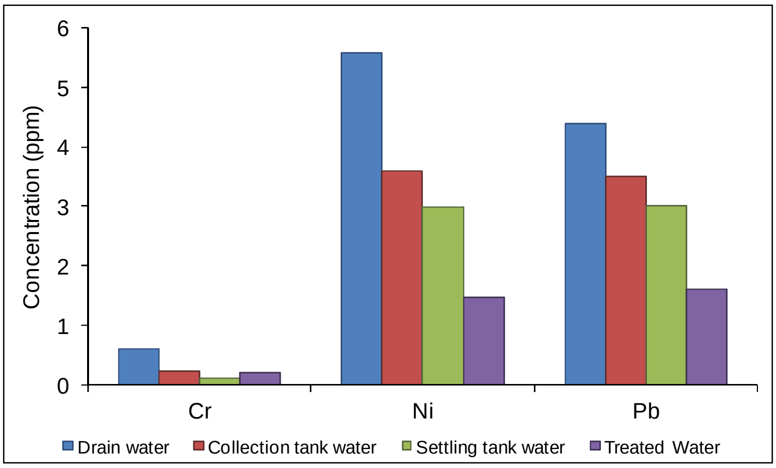
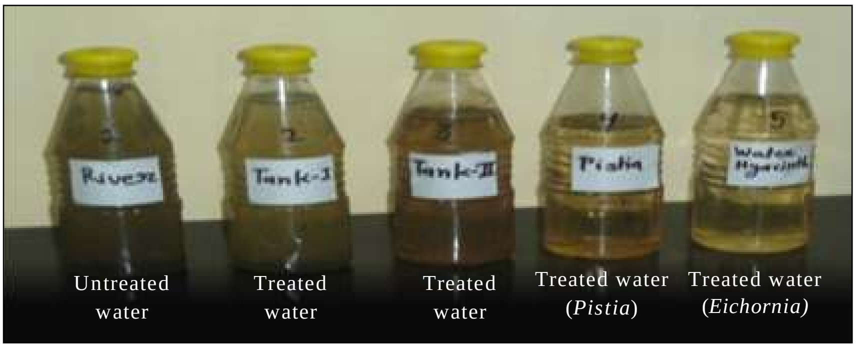


Fig. 2. Performance of *Typha* based system for heavy metal reduction in waste water after 2 days hydraulic retention time



Quality of water observing the farmer

The farmers in Urdua locality are convinced with the quality of treated water which is apparently clear, odourless and with reduction of pollutants which can be used for irrigation purpose.

The treated water was used for cultivation of vegetable like fenugreek, cauliflower, brinjal and other green vegetables. When results of water purifying system for the irrigation purpose were shared with the farmers, they were highly satisfied and very much impressed by seeing the performance of the system. They understood that higher aquatic and terrestrial plants such as *Eichhornia crassipes*, *Arundo donax* and *Typha latifolia* effectively accumulate the heavy metals like chromium, nickel, cadmium and lead which indicated their potential as heavy metal phytoremediating agents.

Zygogramma bicolorata: A potential and environmentally-safe beetle for controlling *Parthenium*

Parthenium hysterophorus L., commonly known as carrot weed or congress grass in India has been considered as one of the worst weeds responsible for causing health problems in human beings and animals besides loss to crop productivity and plant biodiversity. The weed has invaded about 35 million hectares of land in India since its first occurrence in 1955. Now it has become one of the main weeds in almost all types of agricultural lands besides infesting wasteland, community land, road and railway track sides and forests. The weed is responsible for causing many diseases like skin allergy, hay fever, breathing problems in man and animals besides depleting crop production and loss of biodiversity.

Parthenium infested site

Biological control of weed is the intentional manipulation of natural enemies by man for the purpose of controlling harmful weeds. Biological control does not advocate complete eradication of the unwanted organism, but rather mean to maintain its population at lower than average that would occur in the absence of the bio- control agent. It has been considered the most economic and practical way of managing *Parthenium*. Now a days much emphasis has been given to control *Parthenium* through various biological agents among which *Zygogramma bicolorata* (Coleoptera:

Chrysomelidae), popularly known as Mexican beetle in India has emerged one of the effective bioagents.

Parthenium infested site

(a)

(b)

(c)

(a) Eggs, (b) larvae and (c) adults of *Zygogramma bicolorata*

Efforts of ICAR-Directorate of Weed Research, Jabalpur in release, establishment and spread of beetle in India

The classical biological control through the host-specific leaf-feeding beetle (*Zygogramma bicolorata*) was started with the introduction of the beetle from Mexico in India in 1982. Field releases of the beetles were initiated in 1984 at Bangalore. Further, efforts made by ICAR-Directorate of Weed Research, Jabalpur helped in the establishment of beetle in many parts of Madhya Pradesh, Uttar Pradesh, Haryana, Delhi, Punjab, Rajasthan and Lower Uttarakhand. Initially, it was thought that Mexican beetle will work only in moderate climate and will not be able to establish well in the areas having low and high temperature extremes below and above 15 and 35°C, respectively. But our surveys betrayed this assumption as beetle was found to cause large-scale defoliation in many parts of India representing, Andhra Pradesh, Bihar, Chhattisgarh, Delhi, Haryana, Jharkhand, Karnataka, Punjab, Maharashtra, Madhya Pradesh, Tamil Nadu, Uttar Pradesh, lower hills of Himachal Pradesh, Uttrakhand and Jammu parts of J&K.

Since 2001, ICAR-DWR distributed the culture of beetle to many parts of India including centres of All India Co-ordinated Research Project on Weed Management (AICRP-WM), Institutes of Indian Council of Agricultural Research (ICAR), Municipalities, Non-Government Organizations (NGOs), Krishi Vigyan Kendra (KVKs) and farmers by postal services in the specially designed containers and in person to different stakeholders (total number of about 11 lakh). These introductory releases have helped to spread beetles in new areas. About two million beetles were released during 2009 in Nagpur district of Maharashtra state alone by ICAR-DWR to establish the beetle in the region on the request of Maharashtra Agriculture Department.

Impact

In areas, where sufficient population of bioagent was released, large-scale defoliation of *Parthenium* had taken place and reduced *Parthenium* density was observed in due course. Spectacular success of *Parthenium* suppression by Mexican beetle has been experienced in many areas after its introduction. The flowering period, flower number, height and density of *Parthenium* are severely affected by insect population. Plants in the study area that had produced about 4720 flowers in 20-week flowering period, produced only 168 flowers during a decreased six-week flowering period. There was also a decline in the density of weed growth. *Parthenium* mean height and density was reduced after beetle's invasion from 1.93 m and 77/m^2 to 0.48 m and 15.5/ m^2 respectively. The flower production and dry weight was reduced up to 93.3 and 67% than the control. This repeated defoliation of *Parthenium* over a period of four years allowed germination of other native vegetation due to continuous attack of beetle for four years during rainy season.

(a)

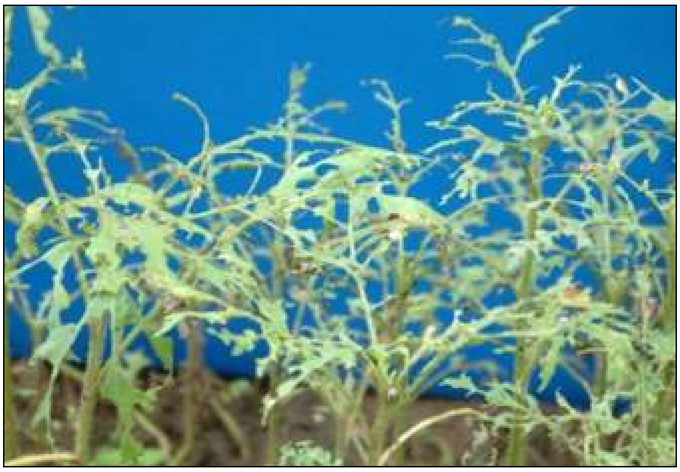
(b)

(c)

Sequence of restoration of biodiversity due to continous work of bioagents at a site

(a)

(b)



(c)

(d)

Young flush of *Parthenium* is nipped in the bud by the beetle

Parthenium population was drastically decreased by more than 80% and the land which used to be dominated only by the *Parthenium*, had other vegetation among which *Casia tora* was most predominant. The most interesting behaviour of beetle in north and central India was one extra generation of beetle during February-March which further helped in early population build-up of the beetle in the same area during rainy season. In such sites, *Parthenium* flush, which germinated during June-July rains, was killed by the beetle during mid-August and new flushes of *Parthenium* germinated in August and early September were nipped in the bud. Drastic reduction in flower production of second and third flush of *Parthenium* during rainy season is brought out by gregarious feeding by the early larval stages of the insect on the terminal and axillary buds. This feeding does not allow growth of the young plants and they are nipped in the bud. Mexican beetle was found to defoliate large area of *Parthenium* in the forest Pench National Park near Seoni in Madhya Pradesh in 2009.

It has low spread and establishment in Assam, Gujarat, Kerala, and West Bengal. *Z. bicolorata* has nil to negligible spread in Andaman & Nicobar, Arunachal Pradesh, Goa, Meghalaya, Mizoram, Manipur, Sikkim *etc*. In Tamil Nadu and Andhra Pradesh, *Z. bicolorata* has been well spread only in western and northern regions. In general, the incidence and spread of *Z. bicolorata* was recorded very limited in all the coastal regions besides cold and hot deserts of India. On the basis of current distribution of *Z. bicolorata* in India, it is suggested that the geographic range of this bioagent can extend to other *Parthenium* infested areas in coastal region, arid region and north-east states as well as in the Andaman & Nicobar Islands, where the agent is currently in very low states or not known to occur. The spread

Programme organized by ICAR-DWR for the irradication of *Parthenium*

and establishment of *Z. bicolorata* is likely to extend more in Andhra Pradesh, Bihar, Chhattisgarh, Delhi, Haryana, Himachal Pradesh, Madhya Pradesh, Rajasthan, Uttar Pradesh and Uttarakhand.

As an impact of country wide '*Parthenium* Awareness Programme'; conducted every year by ICAR-Directorate of Weed Research, Jabalpur and with the efforts of Punjab Agricultural University (PAU), Mansuran village, situated on the Ludhiana-Pakhowal road in Ludhiana district, has become the 'First *Parthenium* Free Village' of Punjab. While entering into the village Mansuran from any side, one can see the field boundaries, road-sides and public places like parks, premises of Gurudwara Sahib, schools, college, hospital, co-operative society, markets, vacant plots, ponds, etc. free from *Parthenium* infestation.

(a)

(b)

Parthenium-free Mansuran village in Ludhiana

Economic and environmental benefits of biological control

At present, beetle has established firmly in many parts of north, central and south India (around 25% of the *Parthenium* infested sites). Beetle has contributed significantly to suppress *Parthenium* in large area and helped indigenous species to re-establish, thus saving loss of biodiversity. The total benefits by the biological control in six years had been of ` 62.34 million over initial investment. Further, the return would have increased many folds if benefits derived in the form of environmental safety and sustainability is taken into consideration. Further, it is to be noted that if *Parthenium* germinates in more than one flushes after commencement of rains till the end of rainy season, then at least two applications of herbicides are required to control *Parthenium* which would further double the estimated cost.

Control of water hyacinth using *Neochetina* spp.: Environmentally safe method

In 1990s, many ponds of Jabalpur *viz.* Mahanadda, Ranital, Gulouatal, Man Singh tal etc. were found full of water hyacinth. This weed is a free-floating, annual or perennial aquatic plant. It is of Brazilian origin but has naturalized throughout the world. Water hyacinth was introduced into India as an ornamental plant in West Bengal in early 20th century but by now it has spread in all types of water bodies throughout the country. The weed may spread through flooded water, rivers and irrigation channels and by mechanical means. Water hyacinth may also spread through mud, which may contain buried seed. This weed is estimated to cover over 0.4 million hectares of water surface in India. It propagates both by vegetative and sexual methods. In vegetative method, one or many stems (stolen) come out from main plant and produce daughter plants and grow independently. The plant is also reproduces by seeds. A single water hyacinth plant can produce a few to 5,000 seeds. The seeds may sink to the bottom mud where they can remain viable up to 20 years. Under ideal conditions water hyacinth plants can double their number in 10-12 days.

Water hyacinth has been considered to be the most harmful aquatic weed in India. It now occurs in fresh water ponds, tanks, lakes, reservoirs, streams, rivers and irrigation channels. Water hyacinth has also become a serious menace in flooded rice fields, considerably reducing the yield. It has entered into major river systems–Brahmaputra, Cauvery, Ganga, Godavari, Satluj and Beas. Due to construction of dams on major river systems water hyacinth is no longer flushed out to sea. It interferes with the production of hydro-electricity, blocks water flow in irrigation projects (40–95%

Plant of *water hyacinth*

reduction), prevents the free movement of navigation vessels and interferes with fishing and fish culture. In many tourists lake like Ootakmand (Ooty) and Loktak, weed has hindered the tourism and restored the lakes, Government had to spend crores of rupees in its removal and subsequent maintenance. The weed is responsible for great water loss due to evapo-transpiration (1.26–9.84%) from the luxuriant foliage of water hyacinth. The losses caused by the water hyacinth are several times more than its beneficial role in purifying water. It is estimated that 20-25% of the total utilizable water in India is currently infested with water hyacinth while in the state of Assam, West Bengal, Odisha and Bihar, it is 40%. It affects irrigation and navigation besides being responsible for drastic reduction of fish production and increase in diseases caused by mosquitoes. In view of the high cost of manual control and water pollution problems associated with use of herbicides, attention has now been turned to biological control. Keeping this in view, five ponds of about 100 hectares in Jabalpur were controlled 3 to 5 times using *Neochetina* spp.

(a)

(b)

Severe infestation of *water hyacinth* in rivers and ponds

Release, establishment and spread of bioagent *Neochetina* spp. in India

The biological control through this host-specific weevil in India was started with the introduction of two species of weevils of Argentina origin from USA during 1982 and 1983. Field releases of the beetles were initiated in 1984 at Bangalore. Further efforts were made by the ICAR-Directorate of Weed Research, Jabalpur in helping the establishment of this bioagent in many parts of country through its distribution by posts or in person. It has shown spectacular success in controlling water hyacinth in Hyderabad (Telangana), Bengaluru (Karnataka), Loktal Lake (Manipur) Sagar & Jabalpur (Madhya Pradesh) and Ramgarh (Uttar Pradesh) besides many other parts of India.

Exotic weevils *Neochetina* spp. are potential bioagents for controlling water hyacinth in water bodies. Initially 500-1000 adults can be released in a water body infested with water hyacinth for establish and population build up of the insect. Biological control of water hyacinth occurs in cycles. First cycle of control of water hyacinth may be achieved within 24 to 36 months after introduction of the bioagents depending on the density and type of water bodies. After first wave of control, subsequently regrowth or fresh growth may be controlled by the bioagents in less time. Adult feeds on leaf tissues while grubs make tunnels in petioles thus gradually killing the weed.

Biology of the weevil: Adults of *N. eichhorniae* and *N. bruchi* deposit their eggs below the epidermis of the petioles and laminae near the base. Whitish eggs of both the species hatch in about a week, larvae are white or cream coloured with a yellow-orange head. Full-grown larvae come out and pupate on live roots of water hyacinth by cutting small lateral rootlets for making a small spherical cocoon around themselves. Under ideal conditions the larval and pupal periods are completed within two months. The adults of *N. eichhorniae* and *N. bruchi* live for 125–145 and 128–138 days and lay about 880 and 688 eggs, respectively. The mean egg production was 4.5 eggs per day. The adults of *N. eichhorniae* and *N. bruchi* are superficially very similar but *N. bruchi* is slightly larger and can be distinguished easily by the broad, creasent–shaped or chevron like tan band across the elytra. Both the species may co-exists in the same site but work at different niches, thus not compete with each other for resources and space.

(a)

(b)

Bioagent Neochetina spp.

Impact

Water hyacinth is completely defoliated on sufficient population build-up of bioagent after its release in a water bodies like lakes and perennial ponds. In such ponds, where large-scale defoliation of water hyacinth had taken place, the weed density was observed to be reduced in due course. Spectacular success of water hyacinth suppression by *Neochetina* spp. has been experienced in many areas after its introduction. The flowering period, flower numbers, height and density are severely affected by the bioagents. The flower production was reduced up to 95%

than the control. This repeated killing of water hyacinth in cycles over a period of four to five years allowed complete clearance of the weed from the water bodies.

Water hyacinth infected pond

Water hyacinth infected by *Neochetina*

Neochetina spp. has controlled water hyacinth from many large ponds at Jabalpur namely Mahanadda, Ranital, Gulouatal, Man Singh tal, *etc.* in Jabalpur after its introduction in 1995–1996. In Mahanadda tal, no reoccurrence of water hyacinth has been observed till 2008. Inhabiting people in the surrounding areas of the pond appreciated the efforts of the institute in controlling of water hyacinth problem which was persisting for last many years.

Pond before release of weevils

Brown patches amidst the *water hyacinth* indicating start of damage creating

The same pond cleared from *water hyacinth* by the weevils

A sequence of the weevils' action depicted through the photographs

	
Grubs damage petioles	Adults feed on leaves

Economic benefits of biological control by *Neocehtina* spp.

At present, *Neochetina* spp. has established in many parts of North, Central and South India. The bioagent has contributed significantly to manage water hyacinth in many ponds and lakes. It saves lakh of rupees for removal of weed manually or mechanically. And overall, the net economic return is several times more than the actual by considering environmental safety issue.

Limitations

Neochetina spp. after release in aquatic bodies, start breeding soon and enhance their population in due course. Bioagent requires sufficient time to build-up the population which ultimately capable to bring out the visible effect on water hyacinth. Therefore, it works well in perennial ponds instead of small ditches and ponds which dry every year. Such ponds should also be avoided to release the weevils because pupation takes place in floating roots and in such ponds, roots are anchored in the soil which affects the pupation and hence population build-up. Initial releases if made on small and succulent growth of water hyacinth in undisturbed ponds/water bodies may bring out definite success. Release should be avoided in those ponds where water chestnut crop is taken because farmers remove the water hyacinth every season.

Technological interventions in maize cultivation brought prosperity in tribal farmers

Khukkham village of Kundam tehsil of Jabalpur district of Madhya Pradesh is a tribal locality, where villagers mainly depend on agriculture for their livelihood. The soil fertility and organic carbon content were very meager. The soil type of the studied area was red and lateritic in nature. The farming of the tribal farmers totally depends on rain water. Farmers are illiterate and have poor knowledge about modern agricultural technologies. The farmers generally used to grow only local maize varieties without application of any fertilizer and modern weed management practices. They occasionally practice one or two hand weeding at later stage of crop growth to collect the weed biomass as fodder. The grain yield of maize crop was very low (1.0 to 1.25 t/ha) due to lack of proper support and guidance on suitable agronomic practices. The ICAR-Directorate of Weed Research, Jabalpur has been working with farmers through on-farm research (OFR) cum demonstration trial under *"Mera Gaon Mera Gaurav"* programme to help the tribal farmers to overcome these challenges by promoting the adoption of low-cost agronomic approaches along with integrated weed management practices. And this technology can increase the productivity and reduce the cost of cultivation. Hence, the OFR cum demonstrations were laid out in the tribal farmers field in maize crop.

Farmers of Khukham, Ranipur, Paderia and Ragertola villages *viz.* Sambhoprasad (50 year), Patiram Bhavedi (70 year), Ganesh Maravi (44 year), Laxman Nareti (42 year), Bhagchand (39 year), Nutanguatam (38 year), Khimmu Singh (35), Kamal Singh Maravi (50), Makku Singh (37), Parvatidevi (32 year), Sumerti Bai (46 year), Tiria Devi (41 year) and Phulia Bai (45 year), have 2-3 hectare of land without irrigation facilities, poor technical knowledge, resources and agriculture implements. They generally grew maize crop during *kharif* season by using traditional system of cultivation without any scientific inputs and implements. These group came in contact with ICAR-DWR scientists under OFR cum demonstration programme and posed their agricultural problems. After studying profile of their fields, available resources, existing technical knowledge and status of used inputs during last three year for maize production their fields were selected for OFR cum demonstration for harnessing maize productivity in a participatory mode during *kharif* season of the year 2012 to 2014. The inputs like seeds of hybrid maize, fertilizers, herbicides like atrazin and 2,4-D for weed management, seed drill for line sowing and other technical and logistic support were provided / supplied to the selected farmers by the Directorate. Regular field visits were also made by the team of scientists to observe the growth and performance of the crop.

Impact

Before intervention, they earned only ` 24,000 / ha with benefit: cost ratio around 1.26 by cultivating local low yielding maize using broadcast method under very subsistence management. The plant population in farmers practice was generally very poor due to the use of bullock drown plough for sowing purpose, which did not account for appropriate spacing. And they also practiced improper nutrient management for the maize crop. The farmers were oblivious about the modern weed management techniques. After intervention, they planted the maize crop using seed drill machine and also applied herbicides and fertilizers at the right time and right dose. With the support and technologies of the Directorate the grain yield of maize crop was 3.5 t / ha. By spending ` 0.30 lakh / ha as total cost of production including land preparation, input cost, labour etc.; farmers earned the net income of ` 0.60 lakh / ha and B:C ratio 2.9. Now, the farmers are very happy with new hybrid maize cultivation and became a source of inspiration for all the other farmers of the locality. Moreover, they are really acting as a motivator for thousands of other farmers of the locality to adopt the scientific cultivation method provided by Directorate not only for maize but also for other crops in the surrounding areas of Khukkham, Ranipur, Paderia and Ragertola of Kundam tehsil of Jabalpur.

Farmers practice and Improved weed management practice

Scientists observing the field

Soil solarization made the vegetable cultivation profitable

Mr. Satyendra Yadav, a vegetable grower in Amkhera village of the Jabalpur district has 110 acres of land with irrigation facilities. He grows all type of vegetables in entire area. He was experiencing problem of pests including weeds in his farm. Mortality of vegetable seedlings to the tune of more than 50%was suffered from various biotic and abiotic stresses which resulted complete failure of plantation. He also found the remaining plants very weak for further development. Thereafter, he contacted the Directorate and discussed the problems with the scientists. Then, he came to know about use of soil solarization technique in production of vegetable nursery and high value crops.

He adopted soil solarization technique in his farm by covering the wet soil with thin transparent polyethylene (TPE) films during the summer months. The film is laid close to the soil surface and sides are tucked in soil to prevent any heat loss. The process raises the surface soil temperature to lethal level for many soil pathogens, nematodes and weed seeds. This is best practiced in summer months (April-June) when solar radiation is high, the sky is clear and the land is vacant. Duration of 4-6 weeks is sufficient to give satisfactory control of weeds. Besides controlling soil borne diseases and weeds, soil solarization is also reported to enhance availability of nutrients in soil and favour beneficial micro flora, ultimately resulting in increased plant growth response in many crop plants. It also conserves soil moisture. Later he realized and share his views with the other farmers of the locality, *i.e.*

- Provides excellent control of many weeds in *kharif* and *rabi* seasons.
- Controls many soil borne pathogens responsible for causing root rot, wilt etc.
- Has proved effective control against parasitic weeds.
- Provided healthy seedlings of subsequent crop.
- Ecological safe and environment friendly method.
- Conserves soil moisture.
- Found improved quality and healthy nursery with adequate plant population for plantation.

After seeing the performance of vegetable crops obtained by Mr. Satyendra Yadav, other farmers of the locality were also used this technique to control weeds in vegetables nursery and high value crops. They also realized that in this technique cost can be reduced by re-using the polythene sheets in the same or different years and by resorting the thinner films. Savings on land preparation and pest control (cost on herbicides, insecticides, fungicides and nematicides) in each season/year and enhanced crop yield are also considered for wide adoption of this technique by vegetable growers. Using this technique, yield enhancement of about 100–125% in onion, 50–55% in ground nut, 70–75% in sesame and 77–78% in soybean have been observed by soil solarization.

Soil solarisation in field

Okra crop after soil solarisation

View of soil soalrization

Solarized sesame

Non-solarized sesame

Precautions

It is important to note that, it is a pre-plant treatment and planting or sowing could be undertaken after removing the TPE films. The soil disturbance following solarization be kept to the minimum for best results. It is a surface phenomenon and hence any tillage (except for opening furrows for placing seeds) would nullify the effect.

Productivity increase in direct seeded rice through improved weed management in Bankhedi

Rice (*Oryza sativa* L.) is a principal source of food for more than half of the world population and one of the staple crops in India. Several factors including shortage of labour and water have resulted in change in the method of crop establishment, from manual transplanting of seedlings to direct seeding in the prepared field. Direct seeding of rice (DSR) may involve sowing pre-germinated seed into a puddled soil surface (wet seeding) or shallow standing water (water seeding), or dry seed into a prepared seedbed (dry seeding). Adoption of DSR has resulted in a change in the dominance of weed species in rice crops viz., *Echinochloa* spp., *Cyperus difformis* etc. which are widely adapted to conditions of DSR. The relatively rapid emergence of weedy rice has been observed in several regions practicing DSR, and this poses a severe threat to the sustainability of the production system.

DSR demands timely application of effective herbicides at right doses and in correct manner. This helps in ensuring herbicide efficacy and in turn increase in yield, besides increasing profitability of the farmer. Technologies developed by ICAR-DWR, Jabalpur are given below which manage grassy and broad leaved weeds in direct seeded rice very effectively. Those are:

- *Sesbania* co-culture by broadcasting of *Sesbania* at 25 kg / ha at the time of sowing of rice and knock-down *Sesbania* after 30 DAS with 2, 4–D at 500 g / ha, suppresses the wide range of weeds.
- Fenoxaprop (60 g / ha) at 25 days after sowing (DAS) effectively manage the majority of grassy weeds in DSR.
- Bispyribac sodium (25 g / ha) at 15-20 DAS manage the wide spectrum of weeds in DSR.
- Sequential application of pendimethalin (1 kg / ha) at 0-3 DAS followed by (*fb*) metsulfuron-methyl (4 g / ha) at 25 DAS manage the narrow and broadleaved weeds.

- Pendimethalin 750 g / ha at 0-3 DAS *fb* bispyribac sodium 25 g / ha at 15–20 DAS minimize the wide spectrum of weeds in DSR.
- Fenoxaprop (60 g / ha) + [chlorimuron + metsulfuron (4 g / ha)] at 25 DAS minimize the broad spectrum of weed in DSR.

Intervention/Technology

On-farm research and demonstration of above weed management practices in DSR was undertaken in rice-wheat cropping system at Dhanwahi village of Bankhedi locality situated at 40 km from Jabalpur. Above weed management practices were demonstrated at farmer's field of this locality. The technology included four treatments viz. application of pendimethalin at 750 g / ha at 0-3 DAS *fb* bispyribac sodium at 25 g / ha at 15–20 DAS, bispyribac sodium at 25 g / ha (farmers' practice), *Sesbania* co-culture *fb* 2,4–D at 500 g / ha at 30 DAS and weedy check.

Performance

The lowest weed population was recorded with application of pendimethalin at 750 g / ha *fb* bispyribac sodium at 25 g / ha, having higher gross returns (` 68,120 / ha) and benefit cost ratio (2.58) over farmers' practice (` 52269 / ha and 2.03, respectively). Successful demonstration on sequential application of pre-and post-emergence herbicides convinced the other farmers of the locality to adopt the improved weed management practices in DSR over farmer's practices for achieving high yield and return (Table 1).

Table 1. Weed density, grain yield and benefit-cost ratio (B:C) in DSR at Dhanwahi village of Bankhedi locality during *kharif* 2013

Treatment	Weed density (no. / m²)	Panicles (no. / m²)	Grain yield (t / ha)	Gross returns (Rs.)	B:C ratio
DWR recommendation – I Pendimethalin 750 g / ha *fb* bispyribac Na 25 g / ha	6.3*	212.5	5.20	68120	2.5
DWR recommandation – II *Sesbania* co-culture *fb* 2,4-D 500 g / ha	22.1	187.6	4.45	58295	2.2
Farmers Practice Bispyribac Na 25 g / ha	22.1	191.0	3.99	52269	2.0
Weedy check	79.1	138.2	2.33	33408	1.4

*Values are means of 15 replications

Impact

- Application of pendimethalin 750 g / ha *fb* bispyribac sodium 25 g / ha in DSR helped the farmers to gain profit of about ` 15,851 / ha.
- This technology effectively reduced weed growth and enhanced the crop growth and yield.
- The technology is suitable for different agro-climatic conditions where rice is the main crop during rainy season.
- Use of herbicides to manage weeds reduced dependency of farmers on labourers.
- These improved weed management technologies are cost effective, time saving and less stressful.
- Economic benefits accrued may help raise the standard of living of farmers.
- This technology encourages the farmers for direct seeding of rice by minimizing the cost of cultivation for puddling and manual transplanting. It also reduced the water requirement of crop.

Pendimethalin 750 g/ha *fb* bispyribac sodium 25 g/ha

Farmers practice (Bispyribac sodium 25g/ha)

Crop performance at different treatments

Improved weed management in soybean-chickpea system: A way to achieve sustainable productivity

In India, soybean and chickpea occupies 8.3 and 7.4 M ha of area under cultivation and produces 8.9 and 5.9 Mt of seed, with an average productivity of 1.06 and 0.8 t/ha, respectively. Both the crops are being a nutritionally rich crop can play a greater role in boosting oil seed and pulse production in the country. Soybean occupies third place among the nine oilseed crops of India. Among the major states, Madhya Pradesh leads in area and production of soybean and chickpea. Inadequate weed control in both the crops has been found to cause about 40-70% reduction in seed yield depending upon the nature and intensity of its infestation. Due to initial slow growth, the available space between the rows allows the weeds to establish and proliferate with limited hindrance, which offers serious crop-weed competition.

Intervention/Technology

Soybean

On-farm research (OFR) trials and demonstrations were conducted in soybean at 5 farmer's field each in the villages of Pola and Dhora of Majholi locality of Jabalpur district. Farmers of the locality generally practiced broadcasting of seed, whereas, in OFR trials line sowing with seed drill were done. Chlorimuron-ethyl at 10 g/ha + fenoxaprop-p-butyl at 100 g/ha at 20–25 DAS in village Pola, and imazethapyr at 100 g/ha at 20 DAS in village Dhora were applied. In order to control weeds, farmers of both the localities perform weeding by cycle wheel hoe depending upon the field condition. In each location, crop was infested with mixed weed flora, *viz. Echinochloa colona, Dinebra retroflexa, Cyperus* spp., *Digera arvensis, Commelina communis, Euphorbia geniculata, Cynotis* spp., *Cucumis melo* and

Parthenium hysterophorus. Results revealed that improved weed management practices registered lower weed growth and higher seed yield of soybean over farmers' practices at all locations (Table 1). The net returns of ` 26,020-33,115/ha were obtained under improved weed management practices at both the sites which were much higher as compared to farmer's practices (` 15,325–21,183/ha). Similarly higher B:C ratio was recorded with improved weed management practices over farmers practice. It was concluded that with the adoption of improved weed management techniques, higher income of ` 11,314/ha could be achieved over farmers practice.

Table 1. Demonstration of improved weed management technology in soybean in Majholi locality of Jabalpur.

Practice	Weed density (no./m^2)	Weed biomass (g/m^2)	WCE (%)	Seed yield (t/ha)	Net returns (Rs)	B:C Ratio
Village: Pola						
Farmers practice	112	46.5	-	1.38	15325	1.81
Improved technology	18	6.1	86	1.86	26020	2.27
Village: Dhora						
Farmers practice	89	36.4	-	1.62	21183	2.31
Improved technology	42	14.6	56	2.14	33115	2.63

Chickpea

Five OFR trials cum demonstrations were conducted in the village Pola of Majholi locality of Jabalpur District. Treatment consisted of pre-emergence application of pendimethalin at 750 g/ha. Fields were infested heavily with *Vicia sativa*, *Convolvulus arvensis*, *Chenopodium album* and *Lathyrus sativa*. Results revealed that pendimethalin effectively controlled the weeds and gave higher weed control efficiency and overall average benefit of ` 17040/ ha with benefit : cost ratio of 2.93 over farmers practice (Table 2).

Table 2. OFR cum demonstration of improved weed management technologies in chickpea at Majholi locality of Jabalpur

Practice	Weed density (no./m²)	Weed biomass (g/m²)	Seed yield (t/ha)	Economic benefit over FP (Rs)	B:C Ratio
Village: Pola					
Farmers practice	149	134	1.13	-	2.01
Improved technology	50	29	1.70	17040	2.93

Impact

In soybean, with the adoption of improved weed management technique, higher income of ` 11,314/ha was achieved over their own practice. While in chickpea, farmer received overall average benefit of ` 17040/ha with B:C ratio of 2.93 over farmers practice.

After successful demonstration, the farmers of the locality were very much satisfied with the demonstrated weed management technologies in soybean-chickpea cropping system. In addition to this, farmers were appraised with the benefits of line sowing in these two crops which they were experiencing for the first time. They appreciated the sowing technique and experienced the advantages of line sowing for weed management (through mechanical tools), and in improving the yield.

Farmers observing the soybean crop with improved weed management technique

Performance of improved weed management technique in chickpea

Cultivation of *Physalis* (Cape gooseberry): a profitable and viable option for farmers

World population is growing at an alarming pace and poses a threat to food and nutritional security, especially in developing countries like India. Globally, almost 80% of our plant food supply comes from just 20 kinds of plants; hence, there is lack of diversification as a source of food. Malnutrition, especially among the poor populations in India is another serious concern, as most of them survive mainly on core grains like wheat and rice. In order to tackle such problems, diversification of food is essential, to ensure availability and access to a variety of food types to poor people. Weedy relatives of some crops are a source of food that has hitherto been not adequately studied. There are many 'wild' species in the world, which have colonizing abilities (i.e. weedy traits) and are suitable for human consumption. Exploring the opportunities for farming such species will help in providing better nutritional quality to poor populations. We explored the above possibilities with *Physalis peruviana* (Cape gooseberry), locally known as *'Ban Tipariya'*, *'Panchkota'*, *'Chirpoti'* and *'Rasbhari'*.

Extensive surveys were conducted for collection of germplasm of *Physalis* spp.. Samples were collected from the different agro-climatic zones of India. Three distinct *Physalis* spp. were collected from 50 locations.

Physalis minima

Physalisperuviana

Physalis alkekengi

Fruits of all the three species are edible. Out of these three species, *Physalis minima* is a common weed in *kharif* crops (rice and soybean). Another species, *P. alkekengi* was traced only at high altitudes of Leh (Jammu & Kashmir). Out of the three, species only *P. peruviana* is under cultivation at small scale near metro cities of North and Central India. Prevailing market rate of *Physalis* fruits is nearly ` 100/kg which should be enough to create temptation among farmers for better revenue. During surveys of farmers' field, we found that farmers were not satisfied with the performance of *Physalis* crop mainly due to non-availability of quality germplasm and the duration of the crops is longer which extends from October to April. Sowing of the *Physalis* in the month of October is practically problematic as fields occupied by previous season (*kharif*) crops. Similarly, towards end of its growing season, farmers have to sacrifice spring/summer crops (mostly pulses).

Therefore, farming of *P. peruviana* could not be adopted at large scale. We started working to address the above problems. Total of 30 *P. peruviana* accessions have been collected from different locations across the agro-climatic zones and characterized for high yield and fruits quality. The raw fruits can be eaten, offer good taste to consumers and rich in minerals, Vitamin C and β- carotene. Some of the quality parameters of fruits are given in Table 1.

Table 1. Proximate analysis of fruits of *P. peruviana*

	Ca (mg/100 g)	Mg (mg/100 g)	P (mg/100 g)	Fe (mg/100 g)	Vit C (mg/100 g)	β- carotene (mg/100 g)
Minimum	20.3	5.34	28.9	0.28	19.4	6.02
Maximum	28.5	10.2	32.4	1.21	50.2	13.1
Mean	25.4	7.86	30	0.56	29.3	9.01

Out of 30 *P. peruviana* accessions, best four were selected on the basis of yield potential; and further studies were conducted related to different agronomic package of practices. However, we could not find any accession which can be grown within the time window available with farmers. To tackle this problem, we had developed an innovative three-steps technology which considerably shorten the field occupancy from 6 month to 4.5 month (first week of November -mid of March).

Two steps-planting technology for *P. peruviana*

Step I: Seedling grown in plastic bags having 1 kg soil mixed with good quality vermi-compost.

Preparation of field by digging of pits (6" diameter and 6" depth)

Step II: Transplanting of 45 days old seedlings just after removing plastic bags without disturbing root ball of the rhizosphere (first week of November).

(Sowing time: 10 - 20 September)

Fruiting stage (mid December)

Fruit maturity (starts from mid January and ends by first week of March)

Performance of crop at last week of November

Optimized package of practices

Operation	Time window
Sowing of seeds in plastic bags: Plastic bags were filled with one kg of soil and vermi-compost mixture supplemented with DAP. Initially 3-4 seeds were sown in each pot. After germination, only single healthy plant was maintained. Pots were kept in semi-shade conditions to avoid exposure to direct sunlight and high temperature. Water was applied as and when required. After attaining 5-6 leaves at 45 days after sowing, seedlings were ready for transplanting.	Mid September
Transplanting seedlings in fields: Pits (6" diameter and 6" depth) can be prepared manually or with the help of mechanical digger. After removing of polythene, seedlings with root bolls need to be transplanted carefully. By doing this, transplanting shock can easily be avoided which helps in speedy growth of transplanted seedlings in field conditions. A square planting with spacing of 90 cm × 90 cm were found suitable.	First week of November
Fertilizers: Optimum dose of fertilizers is 80: 40: 20 ($N:P_2O_5:K_2O$).	• Full dose of P and K, and one third of N as basal application • Remaining N in two splits at 20 and 40 days after transplanting (DAT) by point placement method.
Weed management: Weed management can be achieved by protected spray of glyphosate at 1 kg/ha followed by one mechanical weeding	Protected spray of glyphosate : At 20 DAT Hand hoeing : At 30 DAT
Irrigation: As and when required. Normally 3-4 irrigations are sufficient. Extra irrigation may be required in frost prone areas.	Depending of water availability irrigation may given on 20-30 days interval
Harvesting: *Physalis* shows indeterminate habit of fruiting, therefore, fruits can be picked up when outer cover of the fruits become yellowish.	Mid January to first week of March

Yield potential and economic analysis

Planting geometry	90 cm x 90 cm
Approximately number of plants / ha	12,000
Potential yield of fruits / plant	1.2 kg
Realized yield of fruits / ha	10 t / ha
Prevailing whole sale rate of fruits	` 30 / kg
Total gross income	` 3,00,000 / ha
Total cultivation cost + marketing cost	` 1,80,000 / ha
Net income	` 1,20,000 / ha

The cultivation of *Physalis* is a profitable avenue for framers. In addition, being rich in minerals and β-carotene, fruits of *Physalis* would help in fighting malnutrition and would add new item in food basket. By using good quality germplasm and adopting the innovative two-steps planting approach (as discussed above), farmers can achieve a net income of ` 1,20,000 / ha without sacrificing any crop in cropping pattern.

Weed Manager : A quick way to reach the farmer

In today's agriculture, data are available to the farmers through many sources such as print media, audio/visual aids, newspaper, TV, internet, mobile etc., but the formats and structures of data in these sources are dissimilar. Recently, social media has become the key information and networking source for the agricultural and allied sectors. People in agricultural community are embracing social media and utilizing it to promote knowledge of the lab among the farmers as well as to create networking with other agricultural professionals. Rural extension workers have also begun to utilize mobile app not only to combat the feeling of isolation which arises due to the nature of their works but also updating their professional knowledge.

Today, with increasing dissemination of smart phones in India and affordable prices, it has been considered necessary to create mobile apps to disseminate information. Apps are not only useful for stakeholders located at remote area where desktop PCs are not available, but would also be available to farmers and all other stakeholders for extracting information from the web. In the light of need of the day, a mobile app named as *Weed Manager* was developed by the ICAR–Directorate of Weed Research, Jabalpur to provide information and recommendation on weed management.

Weed Manager is a software based program that contains formally encoded knowledge of experts in weed management, and is able to use this knowledge to provide help to a non-specialist in the domain along with farmers.

Technology

The mobile app provides advice on major dominant weeds of different crops, and their control by chemical methods. With the help of scientists of ICAR-Directorate of Weed Research, Jabalpur, data were collected on crops/cropping systems, dominant weeds, herbicides availability in the market and crop–wise recommendations of herbicides for weed control. Data were also obtained from the data repository maintained at ICAR-Directorate of Weed Research, Jabalpur as well as from the published information on weed management. Further, some other related information was also collected from literature (Naidu, 2012).

For *Weed Manager*, the domain expert is the "Agricultural Scientists in the field of Weed Science". The knowledge engineer coded the information in the form of rules or some other representation scheme. System editor (Software expert) served as intermediate between the domain expert and the mobile that emulates their expertise. He acquired the information about the weeds in the form of facts and rules through consultation and analysis; and then prepared a knowledge base for the system. The process was repeated until a sufficient body of knowledge has been collected to build the expert system. The basic requirement to operate this app is to have an Android device with net connectivity, and the app *Weed Manager* may be downloaded from the directorate website (www.dwr.org.in). After completion of download, run the setup file for the installation. After complete installation, an icon ( ) will appear on mobile screen.

Steps to download the app are as follows:

Visit Directorate's web site (www.dwr.org.in) to download the Application

Fig. 1. View of website

Fig. 2. Icon of *Weed Manager*

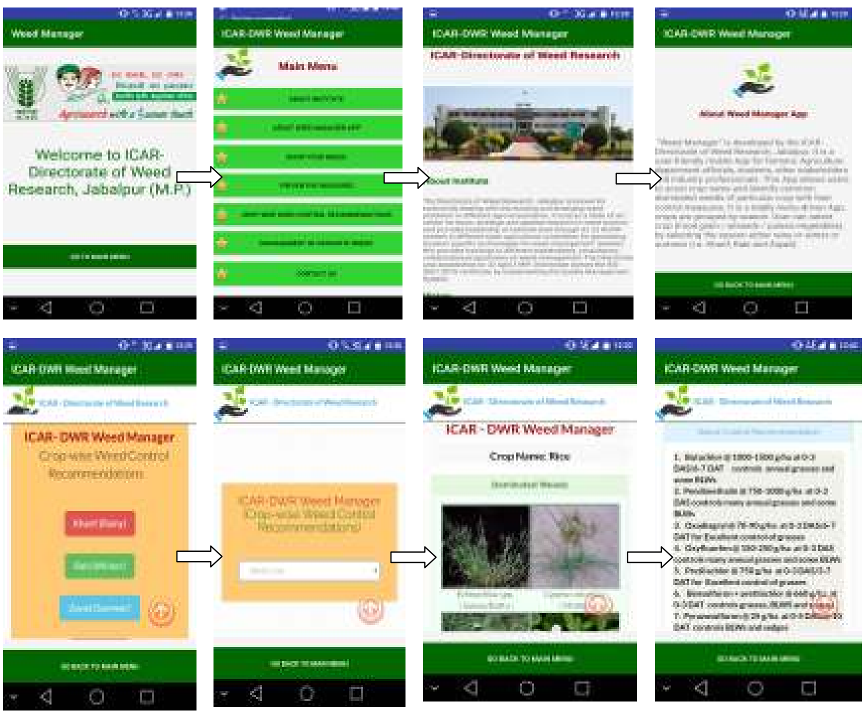


Fig. 3. Data flow diagram in *Weed Manager*

It is a user–friendly mobile app for farmers, agriculture department officials, students, other stakeholders and industry professionals. This app allows users to scout crop name and identify common dominated weeds of that particular crops with their control measures.

Decision making on weed control is challenging. Broad-spectrum of weeds found in many fields, and availability of a number of herbicides in the market make the selection of a particular herbicide difficult. *Weed Manager* can assist in making right decision to manage weeds. It provides advice for the control of weeds specific to the crop including chemical control and showed the best herbicide with optimum dosage and method of application.

It is entirely menu–driven app, where crops are grouped by season. User can select crop after selecting the season either rainy or winter or summer (i.e. *kharif, rabi* and zaid). After selecting season, user can choose the crop. Details on weed management recommendations will be displayed for that crop. Main features of this app (*Weed Manager*) are as follows :

- The App is easily accessible and simple in use
- It is designed according to need of the user
- While using App, user can select crop after selecting the season (i.e. *kharif, rabi* and zaid)
- It provides multiple, high quality photos of dominated weeds along with recommendations for weed management.

Impact

From the date of release in April 2017, till date, 1781 users have downloaded the app throughout the world. The app was evaluated on the basis of different criteria on app's performance. Further, following classification was obtained based on the data collected from users :

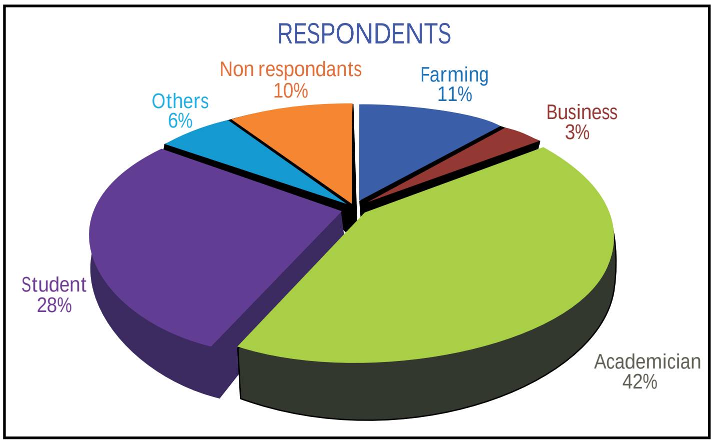
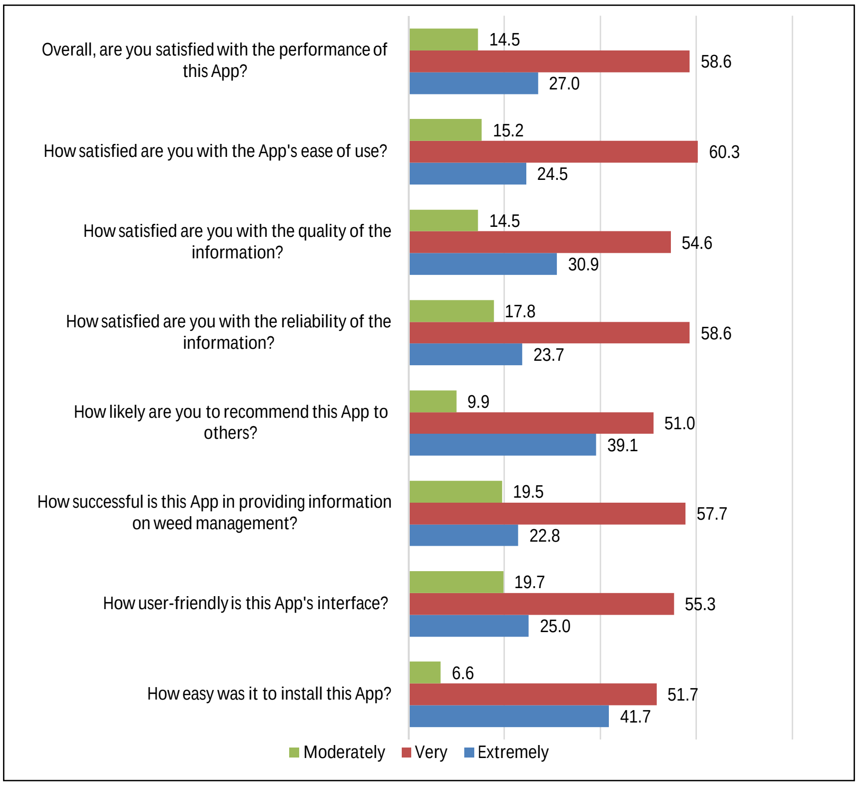


Fig. 4. Distribution of respondents

It is clear from the Fig.4 that most of the users (42%) are academicians who use this app for accessing weed management information for their academic purposes including research and extension. Around 28% users are student who are doing their research work on weed management including some graduate students. Only 11% farmers are using app to get information which help them to reduce the yield losses due to weeds. The reason for less number of farmers as app users, could be the language of the app which is 'English'. Most of the farmers cannot read and understand English.

Further performance of the app can be described by following graph:



*Numbers are in percentage

Fig. 5. Performance of the App

Weed Manager is capable to transfer crop specific weed management technology to stakeholders efficiently. It is developed to help researchers, farmers, extension workers and students with crop-wise weed related problems and provides recommendations for their management. The services of this app will ensure door-step delivery of information on weed management. It also helps in dissemination of up-to-date scientific information on weed management in a readily accessible and easily understandable form to various stakeholders. With the help of the mobile app, farmers can produce quality agricultural produce without losing their crop yield due to weeds by using best weed management practices. Further, modification and additions to current system will be a continuous process based on the information and feedback received from users.

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