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Future scenario of weed management in India

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ABSTRACT

Agriculture is the mainstay of Indian economy because of its high share in employment and livelihood creation. This sector supports more than half a billion people providing employment to 52 per cent of the workforce. With availability of fixed land and decreasing water resources, the goal of 4 per cent growth in agriculture can be achieved only by increasing productivity per unit of these scarce natural resources through effective use of improved technology. The agricultural research system has so far focused mainly on breeding varieties that increase the yield potential of individual crops by enabling more intensive use of inputs. One technology which has a potential to yield substantial increase in the production of foodgrains is proper weed management as weeds alone are known to account for about 15 to 85 per cent losses in the productivity. The paper discusses the future challenges in the area of weed management that require the attention of researchers.

Key words: India, Weed management

India has made impressive strides on the agricultural front during the last six decades. The foodgrain production increased by about 4.5 times from a meager 50.8 million tonnes in 1950-51 to an estimated harvest of about 230 million tons in 2007-08. This increase was achieved despite the fact that the net sown area has plateaued around 140 m ha since 1970s till date. Similarly, there was not much increase in the net irrigated area also which is about 58 m ha at present. Thus, virtually all of the increase in the foodgrain production resulted from yield gains rather than expansion of cultivated area.

Though, the average annual growth rate of foodgrain production since 1950-51 to 2006-07 was 2.5 per cent compared to the growth of population which averaged at 2.1 per cent, it however, decelerated to 1.2 per cent during 1990-2007 which was lower than the annual rate of growth of population, averaging 1.9 per cent. The Approach Paper to the Eleventh Five Year Plan prepared by the Planning Commission, suggested a road map for 9 per cent per annum growth for the economy as a whole, and an agricultural growth target of 4 per cent per annum during the plan period. Agriculture is not only an important

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Dr. Varshney in his long career spanning over more than three decades had held various important positions like National Coordinator of AICRP on prominent grain legume crops; Head, Division of Crop Production at Indian Institute of Pulses Research, Kanpur; Founder Head, Regional Center of Directorate of Pulses Research, Gwalior. He also worked as Editor, Indian Journal of Pulses Research, Kanpur during 1995-2001 and was also elected as General Secretary of Indian Society of Pulses Research and Development. He has published more than 150 peer reviewed research papers in journals of national and international repute in addition to several books and book chapters in the field of weed science and also on tropical grain legumes.

His current activities include providing leadership to the national weed research programme, coordinating the network research with state agricultural universities, collaborating with national and international agencies and providing consultancy on matters related to weed science.

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driver of macro-economic performance; it is an essential element of the strategy to make growth more inclusive. The Approach Paper emphasized that a reversal of the decelaration in agricultural growth witnessed after 1996 is a pre-requisite for success of the 11th Plan.

Therefore, to meet the growing needs of the food security, an annual growth rate of at least 2.0 per cent in foodgrain production is considered essential. As per the projections of IFPRI, Washington, there is a likelihood of shortfall of 41% in the food grain production in the country by 2020. Under the assumption of 3.5 per cent growth in per capita GDP (low income growth scenario), the demand for foodgrains in the year 2020 is projected to be at the level of 255 mt comprising 112 mt of rice, 82 mt of wheat, 39 mt of coarse cereals and 22 mt of pulses (Paroda and Kumar 2000). The country has high population pressure on land and other resources to meet its food and development needs. Low and stagnant yield per unit area across almost all crops has become a regular feature of Indian agriculture. In this backdrop, the required increase in food production can be realized only through vertical increases in productivity, as the possibilities of horizontal increase i.e., expansion of area are minimal. The vertical increase has got tremendous scope which can be achieved with better genotypes and providing farmer-friendly input technology. One such technology which has a potential to yield substantial increase in the production of foodgrains is proper weed management as weeds alone are known to account for nearly one third of the losses caused by various biotic stresses.

Environmental impact of weeds

Weeds are plants that are undesirable to human activity at a particular time and place, and therefore, weeds will always be associated with human endeavours. In agriculture, weeds cause huge reductions in crop yields, increase cost of cultivation, reduce input efficiency, interfere with agricultural operations, impair quality, act as alternate hosts for several insect pests, diseases and nematodes. Weeds compete with crop plants for various inputs/resources like water, nutrients, sunlight *etc.*

In addition to agriculture, weeds also affect and interfere in the management of all the terrestrial and aquatic resources. They endanger the native biodiversity by choking and deliberate takeover of the native plants and also by corrupting and invading open lands, road sides and recreational areas like public parks. They affect the aquatic resources by interfering in fisheries/aquaculture, navigation and irrigation water management besides reducing the esthetic and recreational value of water bodies. Weeds do not spare even animals and steal land, homes and food from them by invading the grazing areas. They cause health hazards like skin allergy, asthma, nasal diseases *etc.*, to both humans and cattle. Weeds interfere with maintenance of various defence, electrical, railway and airport installations besides being a potential fire hazard. Weeds also are a nuisance in forestry reducing their productivity. Out of the total 826 weed species reported in the country, 80 are considered as very serious and 198 as serious weeds (NRCWS 2007). The importance of their management seldom requires any mention especially under the present day high input farming systems.

Economic losses due to weeds

The economic impact of weeds on the Indian economy estimated about two decades ago ranged from Rs. 20 to 28 billion (Sachan 1989, Sahoo and Saraswat 1988). A recent study undertaken at this Centre suggests that nearly one-third of oilseeds, half of the foodgrains, and an equal amount of pulses produced currently are lost due to weeds and proper weed management technologies if adapted can result in an additional production of 103 million tonnes of foodgrains, 15 mt of pulses, 10 mt of oilseeds and 52 mt of commercial crops, per annum, which in few cases are even equivalent to the existing annual production. This amounts to an additional income of Rs. 1,05,036 crores per annum (NRCWS 2007).

These estimates are exclusive of the losses due to weeds in vegetable crops, fruit crops, orchards *etc.* This figure would be far greater if the direct and indirect impact of weeds on aquatic systems, forestry and industrial sites are also included. Besides, huge amount of money is spent on controlling the weeds. At a conservative estimate, an amount of Rs. 100 billion is spent on weed management annually in India, in arable agriculture alone. The potential yield losses due to weeds can be as high as about 65 per cent depending on the crop, degree of weed infestation, weed species and management practices (Yaduraju *et al*. 2006).

Future scenario of weed management

Some of the key issues related to weeds and their management, that are likely to assume importance in the near future and which also require scientific research and technological redressal are as discussed below:

1. Invasive alien weeds

Invasive alien weeds (IAWs) are plants that are moved from their native habitat to a new location and in the absence of their co-evolved predators and parasites they eventually become established and spread rapidly causing tremendous harm, often irreversible to the environment, economy and in some cases to human health (IUCN 2000). As per Convention on Biological Diversity (CBD 1992)

alien invasive species are the biggest threat to biodiversity next only to human resettlement. A large number of alien invasive weeds have invaded our ecosystems and are threatening their survival and productivity. As per an estimate, the annual loss due to alien invasive species was reported to be to the tune of US$336 billion in six countries: United States $137, South Africa $7 billion, U.K. $12 billion, Brazil $50 billion and India $117 billion (Pimentel *et al*. 2000). Ecosystems will survive in spite of man, but mankind cannot without the support of agricultural, managed and natural ecosystems. An estimated 8000 species of plants are believed to behave as weeds in agriculture, out of which about 250 species are considered to be potentially dangerous (Westbrooks 1998). A perusal of publication 'Geographical Atlas of World Weeds' by Holm *et. al*. (1979) indicates that there are 975 weeds in different parts of the world which have not been recorded or reported in India yet. Before it is too late, there is an urgent necessity for the development of a national strategy/ action plan for meeting the challenges posed by the silent green invaders (Prasad Babu 2003).

a) Management of IAWs that have already entered the country

Majority of the important weeds in India have been introduced into the country in the past either accidentally or deliberately. Several exotic weeds, many of them potentially harmful, have gained entry into India in the recent past as contaminants in wheat imports from Australia (Moolchand *et. al*. 2000).

Some of the major alien invasive weeds that have entered the country include *Lantana camara, Eichhornia crassipes*, *Savlinia molesta, Parthenium hysterophorus, Chomolaena odorata, Mikania micrantha, Mimosa spp. etc.* These weeds (except aquatic ones) have invaded vast areas of forest, grassland, wastelands, and in some areas orchards and plantation crops too. *Lantana* was introduced in the year 1908 and since then it has invaded almost all parts of the country. *Chromolaena odorata,* earlier restricted to NE region and Western Ghats is now fast spreading to other areas. Besides wastelands, grasslands and cleared forests, it is proving to be major weed in orchards and plantation crops. In non-crop areas of Western Ghats it has almost replaced *Lantana camara*. 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 NE and South India (Yaduraju *et al*. 2003). Similarly, *Parthenium hysterophorus* is a serious weed which has spread to about 35 m ha throughout the country (Sushilkumar and Varshney 2007).

Even in the wheat imported recently during 2006-07, seeds of five regulated weed species, *viz.*, *Cenchrus tribuloides*, *Solanum carolinense*, *Viola arvensis*, *Cynoglossum officinale* and *Ambrosia trifida* have been intercepted by the Plant Quarantine Officials. To assess the potential risk due to the introduction of these quarantine weeds, a National Invasive Weed Surveillance (NIWS) programme was sanctioned by the Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi, with a budget of Rs. 666.45 lakhs for a period of two years (2008-10). National Research Centre for Weed Science, Jabalpur is the implementation authority at national level in joint collaboration with the state agricultural universities and some general universities in Gujarat, Maharashtra, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Orissa, West Bengal, Madhya Pradesh and Chattisgarh. These are the ten states in which the imported wheat was distributed through public distribution system (NRCWS 2008).

These exotic weeds are a serious threat to the biodiversity or native flora. Hence, management of such IAWs is a great challenge to the weed research scientists in the country as these are not only adversely affecting the human and cattle health but some have now also entered the crop fields, thus reducing crop yields.

b) Management of future introductions of AIWs

Increasing trade and globalization coupled with liberalization policies will further increase the risk of invasion by such weeds leading to decrease in native biodiversity, reduced productivity of different ecosystems, reduced input-use efficiency and increased production cost. It is observed that a record number of major weeds which exist in other countries, are at doorstep awaiting entry into the country. Therefore, we should be careful in preventing their introduction into the country. In order to prevent future introductions, more weeds, particularly the ones that are problematic in related countries, need to be subjected to rigorous Weed Risk Analysis (WRA). There is also an urgent need to design safeguards and strengthening of quarantine regulations to lower the risk of their entry (NRCWS 2007).

2. Herbicide residues in soil, water and food chain

Herbicides are the most successful weed control technology ever developed as they are selective, cost effective, fairly easy to apply, have persistence that can be managed, and offer flexibility in application time. Herbicides have come as a big boon to farmers in areas where the labour supply is limited and wages are high. They are eco-friendly if applied at proper dose, method

and time, besides being quite safer in comparison to other pesticides like insecticides. In India, around 96% of the herbicides are slightly to moderately toxic while more than 70% of the insecticides are highly to extremely toxic.

Currently wheat and rice crops account for about 60 and 20% respectively of the total herbicide consumption in the country, the third crop being soybean which accounts for about 4 per cent. The data on herbicide consumption shows that they are being used in approximately 20 million hectares, which constitute about 10% of the total cropped area (Yaduraju *et al*. 2006).

As herbicide use in other crops at present is very low, there exists a very good scope for their increased use in future. Some of the challenges relating to the enhanced herbicide use are discussed below:

a) Herbicide resistance in weeds

Although herbicides have played a vital role in improving crop yields and overall production efficiency, over-reliance and repetitive use of the herbicides belonging to the same class can also led to the development of herbicide-resistant weed biotypes. In India, though herbicides are not used so extensively as in developed countries, but the continuous use of butachlor as well as isoproturon can lead to the development of resistance in *Echinochloa colona* and *Phalaris minor*, respectively, thereby posing a serious threat to the sustainability in rice-wheat system in the country. As the plant systems have their own in-built mechanisms for their defence, there is every likelihood that herbicide resistance in weeds will continue to be a problem in the forseeable future as well. We need to be watchful of similar problems.

b) Herbicidal toxicity to succeeding crop and environment

Although herbicides are a boon to the agricultural community in substantially increasing crop yields, their use is not without potential problems. Some of the unintended negative impacts of herbicide use are persistence in soil, pollution of ground water, toxic residues in food (contamination), feed and fodder and adverse effect on non-target organisms. The potential of herbicides in contaminating the ground water have gained considerable attention in recent years. Herbicides that are highly water soluble and weakly adsorbed to soil particles such as sulfonyl urea and imidazolinone have potential for contaminating the ground water. There are indications that few herbicides not only damage the microbial population but crops too when applied in succession. However, several experiments conducted with different crops and herbicides in India, revealed that most of the herbicides applied at recommended doses are non-toxic to the succeeding crops except some sensitive crops like cucumber, pea and mungbean to applications of herbicides like pendimethalin, fluchloralin, atrazine in the preceding crops (Jayakumar *et al*. 1988, Janardhan *et al*. 1999, Basavarajappa and Nanjappa 1994). Studies on herbicide *viz.* sulfosulfuron, metsulfuron, flauzifop-p-butyl, butachlor, pendimethalin, *etc.* also revealed that their residues were below the MRL value in soil, food grains and biological matrices when applied at recommended rate but persisted in the soil and crop produce when applied at higher rates (Sondhia and Singhai 2008, Sondhia 2008a and 2008b, Sondhia 2007, Sondhia and Dubey 2006).

c) Competitiveness in world market

In the new WTO regime our products have to be competitive both in price and quality. Weed management forms an important input in crop production. At present the production costs are very high as weeding operations are performed mainly by manual labour which is not only becoming scarce in supply but also expensive. The country is, therefore, losing on crop production heavily due to inappropriate weed management technologies being adopted. There is big scope for reducing the cost of production by adapting improved weed management technology which would also enhance the efficiency of other inputs like fertilizers and irrigation as weeds waste both these resources. In addition to herbicides, resource conservation technologies like zero- tillage can cut down the production cost substantially without penalizing productivity. The presence of pesticide residues is another major issue in world trade, which may be used as a non-tariff barrier affecting food exports. Although herbicide consumption in the country is very low at present, bulk of the herbicide use is in wheat, rice and soybean while commercial crops like groundnut and some spice crops (e.g. fennel) also consume some quantity of herbicides. However, as the country is exporting all these commodities we must ensure that these do not contain any herbicide residues.

d) Threat to native biodiversity

It is observed that a large number of indigenous flora possess medicinal and aromatic properties. The increased use of herbicides in the crop fields is likely to pose a serious threat to the existence of such useful native flora, which are existing since time immemorial.

3. Shift in weed flora

The weed shift in some of the emerging systems of farming which are becoming more popular with farmers needs intensive research.

a) Rainfed farming

Since the availability of water to agriculture will be greatly reduced in future, the importance of rainfed and

dryland agriculture will result in shift in weed flora, development of problem weeds difficult to control such as weedy rice, *Orobanche*, *Striga*, *etc.*, besides reduced efficacy of herbicides due to moisture stress.

b) Organic farming

The 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, integrated weed management practices involving non-chemical methods such as mechanical and cultural (zero tillage, conservation tillage, plant residue management, growing intercrops, cover crops and green manure crops) would gain importance.

c) Conservation agriculture

Increased adoption of resource conservation technologies like zero tillage, bed planting *etc.*, will lead to reduced cost of cultivation, better management of problem weeds like *Phalaris minor* in rice-wheat system. In addition it may also result in weed flora shift favoring the perennial weeds besides increasing the herbicide use.

4. Global climate change and crop-weed interactions

Over the past 150 years since the beginning of the industrial revolution the amount of carbon dioxide in the atmosphere has been increasing, largely as a result of land-use change and anthropogenic emissions from the burning of fossil fuels. With the current increasing use of fossil fuels, it is estimated that the concentration will reach 700 ppm by the middle of the 21st Century (IPCC 2001). The most important consequence of this rise in CO_2 is warming the surface temperature of the Earth. This is expected to increase on average by 0.4-0.6°C per decade throughout the 21st Century (IPCC 2001). Increasing CO_2 along with associated changes in temperature will most likely alter the structure and function of agricultural and forest ecosystems and, thus, will affect their productivity and their role as stable sinks to CO_2 sequestration. Both CO_2 and temperature are key variables affecting plant growth, development and function. CO_2 is essential for photosynthesis. Both CO_2 and temperature are key variables affecting plant growth, development and function. CO_2 is essential for photosynthesis, which sustains plant life (the basis of the entire food chain). Thus, increasing levels of CO_2 will directly influence plant physiology, through its effect on photosynthesis, transpiration and respiration, which seem to be the only processes by which elevated CO_2 can be sensed directly by plants and ecosystems (Drake *et al*. 1997). However, rising temperature will have contrasting influences on these primary processes.

As weed populations show greater variations, it is possible that with a changed global climate weeds too will achieve a greater competitive fitness against the crop plants and development of new weed types. The growth response of *Parthenium hysterophorus* (C_3) and *Amaranthus viridis* (C_4) to CO_2 enrichment (550±30 ppm) was studied in open top chambers (OTC) at National Research Centre for Weed Science, Jabalpur (Naidu and Paroha 2008). The study showed that elevated CO_2 enhanced the growth and biomass production in both the weed species. In case of *Parthenium hysterophorus*, the plant height at elevated CO_2 increased by more than 100% while the leaf area by 49% and number of leaves by a huge 291% under elevated CO_2 as compared to ambient conditions. The root length increased by 56% while the root biomass by 700%. There was a tremendous increase (274%) in the flower production under elevated CO_2. In case of *Amaranthus viridis* the growth enhancement under elevated CO_2 started after 60 DAS which continued throughout the growth period.

5. Herbicide tolerant crops and development of super weeds

Imparting resistance to normally herbicide susceptible crops to produce herbicide-tolerant crops (HTCs) has been the most extensively exploited area of plant biotechnology. Resistance genes for several herbicides or herbicide modes of action have been incorporated into the genome of corn, cotton, canola and soybean which are now commercially available. Remarkably, the global biotech crop area increased more than sixty-seven fold in the first decade of commercialization from a meager 1.7 million hectares in 1996 to 114.3 million hectares in 2007. Herbicide tolerance has consistently been the dominant trait during all these years.

Introduction of Herbicide Tolerant Crops (HTCs) besides helping in efficient management of problem weeds with minimum risk to the crop and increasing the yields may also lead to development of 'super weeds'. Their management will be essential in the days ahead.

6. Labour scarcity and increased wages

Weed control through manual/mechanical though very effective, has certain limitations such as unavailability of labour during peak period, high labour cost, involves drudgery, unfavourable environment particularly in rainy season *etc.* In addition, the manual labour traditionally being employed for weeding is gradually becoming scarce and expensive owing to rapid urbanization and industrialization. Liberalization policies and welfare activities initiated by the Government coupled with diversification of agriculture *etc.* will further limit the labour availability. At present, an estimated 8 to 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 to 10 days in a year. According to some estimates, by the year 2020, nearly 50% of the population would be living in urban areas, creating unprecedented shortage of labour force for use in agriculture. Therefore, in future, management of weeds through improved technologies involving herbicides and improved weeding tools will attain more significance which will result in labour saving, better and timely weed control and increased food production besides promoting gender equality and reducing human drudgery. The economic analyses of the data obtained from large number of trials and demonstrations carried out in farmers' fields through out the country have also reflected higher levels of productivity coupled with benefit:cost ratios of over 2:1. In addition, the labour saved (about 20-40 man days per hectare) through adoption of improved weed management practices, can be utilized in other related and more productive enterprises such as livestock rearing, poultry, fishery, mushroom cultivation, sericulture, bee keeping *etc.* which would yield greater income. This will also raise the esteem of women and provide them with more free time which can be devoted towards children, sanitation, health care *etc.*

7. Biological control of weeds

Technologies employing natural systems, biological organisms, bio-pesticides would gain importance to overcome or reduce the dependence on herbicides, wherever possible. There is sufficient scope for managing weeds at least in non-cropped areas through the use of exotic insect pests as has been successfully proved in the management of *Parthenium* by the Mexican beetle (*Zygrogramma bicolorata*), water hyacinth by *Neochetina* spp. and *Salvinia* by *Cyrtobagous salviniae* (Gangavisalakshi and Sushilkumar 2007). There are innumerable reports of excellent control of *Parthenium* by the Mexican beetle (Sushilkumar 2005, Sushilkumar and Varshney 2007) and that of water hyacinth by *Neochetina* spp. (Sushilkumar and Varshney 2008). Looking to the various advantages of this technology, the work on biological control of weeds has to be further intensified in the future. However, any biocontrol agent has an associated risk to change its behaviour and host specificity which may have to be looked into with great depth and vision.

8. Management of parasitic weeds

Parasitic weeds are posing problem in the productivity of some of the major crops and cropping systems (Bhan and Sushilkumar 1998). *Cuscuta* spp. is a major problem in niger in Orissa, parts of Madhya Pradesh and Chhattisgarh; in lucerne in Gujarat; in blackgram/greengram in rice-fallows of Andhra Pradesh (Kumar 2000) and in berseem, lentil, linseed and chickpea in parts of Madhya Pradesh. Some species of *Cuscuta* also infest ornamental plants, hedges and trees. *Orobanche* spp. is a major parasite in tobacco in parts of Karnataka, Andhra Pradesh, Tamil Nadu, and Gujarat, mustard in parts of Gujarat, western Uttar Pradesh, Rajasthan, Haryana, *etc.*, and more recently in tomato and potato in Karnataka (Hosmani *et al*. 1993). *Striga* spp. infest mostly sugarcane, maize, sorghum and pearl millet grown in dry areas in some parts of Karnataka, Madhya Pradesh and Chhattisgarh. *Loranthus* is noticed on economically useful tree crops in southern states. The most preferred host trees are mango, neem, teak, *Cassia* spp., rose wood, *Dalbergia* spp., *Albigizzia* spp., *Terminalia* spp., rain tree, *Pongamia* spp., Gulmohar, *Madhuca* sp., *Ficus* sp., *etc.* The problem of perennial weeds is increasing enormously. It is necessary to develop the management technology for such weeds.

9. Aquatic weed management

India has a total area of about 7 million hectares under different kinds of water bodies such as reservoirs, tanks, lakes, ponds, oxbow lakes, derelict water and brackish water. In addition about 1.7 lakh km is under rivers and canals. However, the area under these aquatic bodies is increasing with the building up of dams, canals and tanks for irrigation and fisheries production. The aquatic weeds increase the loss of water through transpiration, interfere in navigation, affect fisheries, mar recreational value of water, severely impede the flow of water in canals, thereby reducing availability of water to agriculture (Bhan and Sushilkumar 1996). Beside the major aquatic weeds like water hyacinth and *Salvinia*, of late others like *Alternanthera philoxiroides* are also gaining importance (Sushilkumar *et al*. 2003). In view of the restricted use of herbicides in aquatic bodies due to the multifaceted use of water for purposes like fish culture, irrigation, domestic use *etc.*, use of biological agents through insects like *Neochetina spp.* and hydrophilic mite *Orthogalumna terebrantis* against water hyacinth, *Cyrtobagous salviniae* on *Salvinia molesta* (water fern) and herbivore fishes such as a common grass carp (*Ctenopharyngdon idella)* against small floating and submerged weeds should be given preference over herbicide use (Varshney *et al*. 2007). In depth and more comprehensive eco-friendly research work is required to be carried out on the management of such weeds.

10. Exploitation of weeds for beneficiary use

Weeds like water hyacinth, *Chromolaena, Lantana, Parthenium*, *Ipomoea*, *etc.*, are rapidly spreading through out the country at the cost of other useful vegetation. Proper utilization of such biomass through appropriate

technologies like vermicompost, mulch, phytoremediation, *etc.*, may help in supplementing chemical fertilizers besides adding organic matter to the soil (Sushilkumar *et al*. 2005, Rajkhowa *et al*. 2005, Gajalakshmi *et al*. 2002). Weeds like alligator weed *Alternanthera philoxeroides* can be used as fodder for animals as it has high nutritional value (Sushilkumar and Vishwakarma 2005). Utilization of weeds as a source of ayurvedic medicines, bio-pesticides and bio-fuel also has enough potential. Technology for using weeds for making paper, particle boards, furniture *etc.*, has to be developed ahead. Such activities are expected to raise income and employment opportunities.

11. Awareness raising and technology transfer

The weed management technologies have not reached the farmers at the same pace as happened in case of varieties, fertilizers and insecticides. One of the main reasons could be that unlike other pests, the losses caused by weeds are invisible and many a time these are ignored by the farmers in spite of the fact that they cause maximum losses. Lack of awareness regarding losses caused by weeds and ways to control them are still the major reasons for poor adoption of weed management technologies. Therefore, there is a great need to popularize the cost-effective weed management technologies.

National Research Centre for Weed Science as well as its 22 outreach centres situated in different state agricultural universities (SAUs) throughout the country regularly conduct various field demonstrations to popularize and create awareness regarding the improved weed management technologies among the farming community. Besides, a Parthenium awareness week is also organized all over the country every year during 6-11, September under the leadership of NRCWS. During the week, several activities are held like lectures by experts through mass media on the ill effects of *Parthenium*, demonstration of available technologies on its management, release of publications and distribution of Mexican beetles, publicity campaign through print and electronic mass media like news papers, All India Radio (AIR) and national as well as regional television channels (Varshney and Sushilkumar 2007).

Summary and future strategy

There is tremendous scope to increase the agricultural productivity by adapting the improved weed management technologies that have been developed in the country by National Research Centre for Weed Science, Jabalpur as well as its 22 Cooperating Centres working at different SAUs under the All India Coordinated Research Project on Weed Control (AICRP-WC). Despite the enormous magnitude of the losses due to weeds, policy makers have not yet felt the significance of weed management as happened in case of varietal breeding and other inputs such as irrigation, fertilizers and seeds.

The Department of Agriculture & Cooperation, Ministry of Agriculture, Government of India has recently launched a Centrally-sponsored scheme on National Food Security Mission (NFSM) in pursuance of the resolution of the National Development Council (NDC) to increase the production of rice, wheat and pulses by 10, 8 and 2 million tonnes, respectively, by the end of the Eleventh Five Year Plan period. The Mission aims at increasing foodgrains production of the above crops through area expansion and productivity enhancement; restoring soil fertility and productivity; creating employment opportunities; and enhancing farm level economy to restore confidence of farmers of targeted districts. Currently 95.7 mt of rice, 76.8 mt of wheat and 15.2 mt of pulses are being produced in the country. Assuming a modest 10% increase per annum by the proper management of weeds alone, the production of these three crops can be enhanced in one year by about 9.6 mt in rice, 7.7 mt in wheat and 1.5 mt in pulses, which are almost equal to the targets aimed to be achieved in a 5-year period by the NFSM. This amply demonstrates the extent to which weed management can contribute to increased food production.

The challenges confronted by the weed researchers are many and multi-pronged with limited opportunities requiring a concerted and multi-disciplinary effort to tackle the future weed problems. Some of the important emerging areas which require intensified and in depth research efforts are the effect of global climate change on crop-weed interactions, protocol development for weed risk analysis, weed management in precision as well as organic agriculture, herbicide tolerant crops (HTCs), and use of remote sensing techniques in weed management and variable rate technology for herbicide application. At the same time there is an urgent need to enhance funding, both public and private towards weed management research. There is enough economic justification not only for the investment, *per s*e made in the field of weed control but also for its enhancement. An *ex-ante* analysis of research conducted at National Centre for Agricultural Economics and Policy Research (NCAP), New Delhi, on rice-wheat system in India, has convincingly shown that the expected rates of return to research investment in the area of weed control range from 62-74%, a figure much higher than those due to water management (45-48%) and nutrient management (56-68%) (Pal *et al*. 1998). The higher rates of return in this area justify not only the investment incurred on weed control research but also builds a strong case for increasing the investment.

As reported elsewhere in this paper, proper weed management technologies can result in an additional income of Rs. 1,05,036 crores per annum prorata, which can increase the share of agriculture in India's GDP by 15%. Thus, the increase in agricultural productivity will eventually result in significantly increasing the country's overall GDP and its growth rate. The socio-economic status of the farming community especially the rural poor will improve. Human drudgery involved in manual weeding will decrease and more gender equality will prevail, providing more time for rural women and youth to take up other subsidiary and more remunerative activities like sericulture, bee keeping *etc.* Our environment will be clean and native biodiversity will be preserved. At the end, proper weed management would strengthen the food security scenario and also alleviate the fears of food insecurity in the country by resulting in significantly increased food production.

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