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Agriculture would remain the mainstay to feed the teeming millions in the years to come which is indeed a tremendous and arduous task. The untiring efforts and unflinching zeal of the scientists in research have transformed the agricultural production from mere sustenance to commercial farming. Influx of technologies has transformed the very outlook of the Indian farmer who look towards scientists for support in diverting the farming into profitable enterprise. Traditional crop patterns are giving way to commercial farming which has to face formidable challenges from weeds and other pests. Our scientists always rise to the occasion to provide guidelines to the farmers to save their crops from weed menace.

Weed problems have turned into a continuing struggle for farmers on account of the pressure to raise crops and maximize crop production to meet increasing demand of the fast growing human population. Weed problems vary from crop to crop, region to region and farm to farm. Losses due to weeds are higher than those from insects and diseases (insect 26%, weeds 33%, diseases 20%, other pests 21%). As per the requirements of various crops starting from hand weeding, weed control has gone through a number of changes with the advent of new technology.

The introduction of high yielding semi-dwarf crop varieties responsive to fertilizers and irrigation, coupled with intensive cropping systems, has brought the problem of weeds which inflict tremendous losses in crop yield. The analysis has revealed that the yield losses caused by weeds in India are to the tune of 9.28 million tones in cereals, 0.78 million tones in pulses, 0.57 million tones in oilseeds and 7.20 million tones in fiber and other commercial crops, valued at about Rs.3000 crores annually.

In India, weed management strategies have changed from negligible herbicide use in 1970s to about 12000 tonnes at present which is about 17% of the total pesticide use in India. About 85% of farmers engaged in wheat cultivation and over 95% of those in rice cultivation in Punjab use herbicides. Herbicide use in crops like potato, sugarcane, maize and cotton is also picking up in the state. Almost similar scenario exists in our neighbouring state Haryana. Herbicide use is increasing in other states as agricultural labour is becoming not only scarce but also costly and is not available at the required time. One hoeing in states like Punjab and Haryana costs about Rs. 2000 to 2500/ha and that is why farmers are eager to use herbicides for controlling weeds which provide cost effective increase in agriculture productivity. The growth of chemical weed control is attracting scientists and industry to work on herbicides which are eco-friendly and required in extremely low doses, herbicide mixtures and bio-herbicides. The development of new herbicides is becoming much more expensive with additional chemical regulations, more stringent toxicology standards and increased concern for the environment.

Development of resistance in *Phalaris minor* against isoproturon during the last decade created a new problem but at the same time acted as an eye opener. The solution was worked out with timely recommendation of some alternate herbicides for control of *P.minor* in wheat. It is now suggested that farmers should not depend on one herbicide for a longer time to control weeds in a particular crop. The farmers are also advised to rotate crops in the field, that may help in reducing the weed seed bank of an associated weed.

The state of Punjab need not take pride from the fact that it tops in the herbicide use in the country. The environmentalists and the ecologists have their valid concerns as the compound growth rate of herbicides consumption has been 13.7 against -3.88% of insecticides for the last one decade. Though soil, ground water and crop produce analysis have not revealed any herbicide residue build up, but we can still afford to continue to use herbicides at the present rate. The newer molecules which are used in very low quantity, help in reducing herbicide load in the environment but may create some residue problems in future. Research, therefore, should be focused on new methods of weed control like cultural, biological, soil solarization, use of competitive and smother crops, etc. which could be integrated with chemical weed control to reduce the herbicide load in the environment.

Some perennial weeds like *Cyperus rotundus, Sorghum halepense, Cirsiusm arvense,* and *Parthenium hysterophorus* and parasitic weeds like *Striga, Orobanche* and *Cuscuta* are a serious problem. Similarly, aquatic weeds like water hyacinth (*Eichhornia crassipes*) and *Typha spp.* require special efforts for their control. These may be tackled through integrated weed management approach as herbicides alone may not be fully effective against these. Biology and ecology of these weeds should be studied in greater detail for planning effective weed control measures against these weeds.

Biotechnology has not only helped in propagation or multiplication of elite plant material but has also proved to be a great tool for improving productivity of field crops. With the approval of Bt cotton, the farmers all over the country and particularly in Punjab are going to benefit immensely. Similarly, the use of biotechnology can also help in weed management in more than one way. Development of herbicide resistant crop varieties which are being cultivated globally is one example. But here also the scientists will have to look into the long term consequences of use of genetically modified crops as these will be directly used for human consumption. We should remain alert to the development of resistants in weeds through accidental leakage of trans-genes from herbicide resistant crops to weeds. Since this is an upcoming area of research, it is rightly been considered as a theme area of present National Biennial Conference and I am happy that a satellite workshop is arranged in New Delhi along with this conference to deliberate on this aspect.

The major thrust areas requiring immediate attention of weed scientists are : refinement of existing farm practices with regard to weed management; weed surveys to develop research priorities; study of biology and ecology of major weeds; cropping system approach to integrated weed management; evaluation of new and eco-friendly herbicides and increasing their effectiveness; bio-control approaches in weed management; research on herbicide application equipment and application technique; studies on cost benefit ratios; monitoring fate of herbicides in environment; development of resistance to herbicides in weeds; control of perennial and parasitic weeds and research on weed management in dryland areas.

I am indeed grateful to the Indian Society of Weed Science for providing us an opportunity to hold its National Biennial Conference here at the Punjab Agricultural University, Ludhiana. After going through the schedule of this conference, I am quite confident that the deliberations would provide sound guidelines for future weed management strategies to boost agricultural production.

I hope that the galaxy of weed scientists from different parts of the country will have fruitful deliberations and interaction and will come out with specific recommendations for devising viable weed management strategies in the near future. I take pride in inaugurating this National Biennial Conference of Indian Society of Weed Science and hope the delegates will enjoy their stay on this beautiful campus.

SHAPING THE FUTURE OF WEED SCIENCE

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Honourable vice-chancellor Dr. Kirpal Singh Aulakh, Punjab Agricultural University, Prof. L.S. Brar organizing secretary of the conference, Prof. R.K. Malik, Secretary, Indian Society of Weed Science, my esteemed members of the executive committee (ISWS), members of the pesticide industries, media person, dear participants, ladies and gentleman. It gives me great pleasure and indeed I feel privileged to share some of my view points with you this morning to meet the challenges before us as weed scientists in particular and Indian agriculture in general.

The challenges before Indian agriculture in 21st century are much different than the past. Today, agricultural development faces three major challenges: the persistence to poverty and nutritional insecurity, continuous pressure on and deterioration of natural resources and globalization and its impact on farm sector. The self sufficiency in food grain due to 'gene revolution' and matching agronomic practices failed to bring nutritional security. Still, 26.10% (28.59% rural and 23.62% urban) population live below poverty line*. Approximately 50% of children and women in rural areas are suffering from nutritional disorders.

The future of agriculture development will be dictated more by economic policy reforms in the 'era of globalization'. Future food and nutritional supplies will depend upon intensification (mostly through irrigation) and boosting yields. The crop productivity will largely depend on nutrient supply and management and management of biotic stresses including weeds. Although, marginal income from additional unit of fertilizer and pesticides has shown a decreasing trends in past decades. The consumption of chemical pesticides has come down from 66.36 thousand MT during 1994-95 to 43.59 thousand MT during 2001-02. However, much of the decrease accounted for insecticides and herbicides consumption ended with a positive sign during this period.

Weeds are steady component of our environment. They often lack appeal and urgency of sudden control, a key factor leading to severe yield losses (10-70%) in most crops and cropping systems. Traditional manual and/or mechanical weeding practices are gradually replaced by herbicides in high input agriculture production system. In recent years, there has been an increasing reliance on modern herbicides leading to a reduction in the need

*The task force, constituted by planning commission, defined the poverty line as per capita consumption expenditure level, which meets the average per capita daily calorie requirement of 2400 calorie in rural area and 2100 calorie in urban area.

for 'traditional' techniques of weed control. Cropping patterns have adapted, driven by the possibility to further increase crop output, to rely more and more on these products. Whilst economically this shift has been rewarding to farmers, some negative consequences have emerged which now need to be addressed in the interest of longer term sustainability.

One result of modern agriculture and the reliance on herbicides is the emergence of populations of weeds which are resistant to products designed to control them.

All natural weed populations regardless of the application of any weed killer probably contain individual plants (biotypes) which are resistant to herbicides. Repeated use of a herbicide will expose the weed population to a 'selection pressure' which may lead to an increase in the number of surviving resistant individuals in the population. As a consequence, the resistant weed population may increase to the point that adequate weed control cannot be achieved by the application of that herbicide. Currently there are recorded more than 172 resistant grass and broadleaf weed biotypes in about 59 countries world-wide. Fortunately, we have so for only one weed *Phalaris minor* that has developed resistant against substituted urea herbicide. Nevertheless, India host all the ten worst weeds those have herbicide resistance against a number of active ingredients.

The recent advances in biological sciences referred collectively as 'biotechnology' usher the ways to incorporate resistance gene from unrelated organisms to herbicide susceptible crops. We are now able to adopt the chemistry of a herbicide, whereas previously had to adopt chemistry to biology.

During the eight year period 1996-97 to 2003-04, global area under transgenic crops increased 40 folds from 1.7 million hectare in 1996-97 to 67.7 million hectares in 2003-04 with major expansion under taken in developing countries. During this period, herbicide tolerance has consistently been the dominant trait and 73 percent or 49.7 million hectare of the global GM crops was under herbicide tolerant soybean, maize, canola and cotton. Another, example in HR-rice varieties namely Liberty link (resistance to glufosinate) and Round up ready (resistance to glyphosate) are commercially available for cultivation. For an agronomic point of view, two main reasons are frequently put forward to justify the introduction of herbicide resistance rice (i) to control red rice and other weedy rice, and (ii) to manage herbicide resistant *Echinochloa spp.* that have evolved resistance to particular herbicide. Besides, HR-rice allows the substitution of currently used herbicides with herbicides less detrimental to environment.

Multitude of benefits offered by HRCs need not to be over emphasized. However, it will be an important constituent of future weed management practices, especially in conservation and organic farming.

The another, important, but relatively less employed tool for weed management is 'allelopathy'. The potential of allelopathy for weed control has been well reviewed by scientists across the world. Aqueous extracts from barley, wheat and rice, residues have shown allelopathic potential to inhibit growth of many paddy and uplands weeds. These extracts were particularly effective against P. distinctus, an important perennial broad leaf weed in paddy field. A similar effect of allelochemical from weeds have been reported against serious crop weeds.

I emphasize the use of variation among cultivars in their ability to compete with the weeds as has been demonstrated for many crops. To develop competitive cultivars, identification of traits that contribute to competitive ability in crop plants need immediate attention of all concern. In Australia, a new wheat variety is being developed called 'super wheat' so that it not only can outplace the growth of weeds, thus overcoming biostress from the latter, but also cut herbicide requirement by 50%. Such varieties are need for other crops to reduce over reliance on chemical herbicides a dominant tool in weed management for higher crop yields.

It is beyond doubt, that most high yield agriculture relies on herbicides for higher crop yield. However, environmental issues and recent development in biological sciences will shape the future of agriculture in general and weed science in particular. Therefore, multi-disciplinary research approach needs to be developed to utilize genetic resources along side conventional weeding practices in socio-economic context of farming community for food and nutritional security.

Weed Management for Sustainable Agriculture

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Crop pests (insects, diseases, weeds, etc.) are reported to cause nearly 18 percent loss in crop production which at current price is estimated at Rs. 60,000/- crores annually. Weeds unlike other pests are omnipresent and account for at least one-third of this loss. They cause enormous losses and sufferings to human beings by way of reduction in crop yield and quality, wastage of human energy and resources and increased cost of cultivation. Many weed species also act as alternate host for many insects and pathogens. Concern over environmental and human health impacts of chemical residues, herbicide resistance in weeds and rising costs of crop production and protection have led agricultural producers and scientists to seek strategies for development of eco-friendly weed management practices. A change from a high-input and mainly chemical based intensive agriculture to a more sustainable form of agriculture is not only desirable, but has become a necessity. Efficient weed management approach is expected to contribute significantly in sustaining agriculture. The weed management in field crops will, therefore, require an integrated approach that blends mechanical, biological, ecological and chemical methods in a mutually supported manner into the crop production system with due consideration of economic, environmental and sociological consequences. The important weed management strategies currently followed by the farmers include:

Cultural methods

Cultural weed management is referred to as the use of any methods that directly enhance crop competitive ability against weeds. Despite the great progress made in agriculture, manual and mechanical methods continue to be important weed management option around the globe. Cultural methods are generally used to complement manual and mechanical methods. Cultural practices have pronounced effect on crop-weed interference. These practices are manipulated in such a way that they become more favourable for crop growth and less to weeds. They are not only eco-friendly but also reduce the use of costly herbicides. Some examples of cultural weed control practices are cited in Table I.

Manual and mechanical method

Manual weeding is the most prevalent practice of weed control in India. However, it is laborious, less effective and costly. Mechanical weed control is a viable option only within a certain range of soil conditions, the amplitude of which varies upon soil types and implements used. Excessive soil moisture impedes field workability and may delay mechanical weed control until the crop is too high or weeds are too well developed. In certain cases high soil moisture also increases the risk of crop damage. Therefore, it is important not to rely on direct physical weed control only but to integrate it in an overall crop and weed management strategy arranged at the system scale. Integration of direct weed control with other cultural practices in a system context is the best approach for tackling weed problems anywhere.

Biological control

Biological control of weeds is the deliberate use of natural enemies, primarily insects or fungi, to suppress growth or reduce the population of weed species. The utilization of biological weed control agents in weed management offers several advantages such as specificity for the target weed and no adverse effect on other associated plants including animals and human beings, little enhance of developing resistance in weeds and build of residues in the soil and environment. Complete eradication of weed species is never forgetted in biological approach.

Table 1 Classification of cultural practices potentially applicable in an integrated weed management system based on their prevailing effect (modified from Barberi, 2001).

Cultural practice	*Impact*	*Example*
Crop rotation	Reduction in weed emergence, improving soil fertility	Alternation between winter and spring-summer crops. Effective control of *Phalaris minor* in rice-wheat system. Wheat is replaced with berseem and/or mustard.
Primary tillage	Reduction in weed emergence, farm hygiene	Deep ploughing, alternation between ploughing and reduced tillage, zero tillage and bed planting
Seedbed preparation	Reduction in weed emergence, establishing good crop stand	False/stale seed-bed technique
Cultivation	Reduction in weed emergence	Post-emergence harrowing or hoeing, ridging
Cover crops	Reduction in weed emergence	Cover crops grown in-between two cash crops and used as green manure or dead mulch
Intercropping	Reduction in weed emergence, Improvement in crop competitive ability, Cover risk, Improve soil fertility	Cover crop used as living mulch, intercropped cash crops. Growing sorghum plus cowpea.
Thermal treatment	Reduction in weed emergence, pest control	Pre-emergence or localized post-emergence flam weeding
Mulching/soil solarization	Reduction in weed emergence	Use of black or transparent films (in glass house or field)
Crop genotype	Improvement in crop competitive ability	Use of cultivars characterized by quick emergence, high growth and soil cover rates in early stage
Sowing/planting	Improvement in crop competitive ability	Use of transplants, higher seeding rates, lower inter-row distance, anticipation of, or delay in sowing,/ transplant date etc.
Fertilization	Reduction in weed emergence, improvement in crop competitive ability	Use of slow nutrient releasing organic fertilizers and amendments, fertilizer placement, temporal and spatial adjustment in scheduling fertilizer application.
Irrigation	Reduction in weed emergence, improvement in crop competitive ability	Irrigation placement (micro/trickle-irrigation), irrigation scheduling.

Use of biological control agents is an ideal method for managing pests under organic farming. It is environmentally benign and ecologically and socially acceptable. However, efficacy and economics of biological approach is questionable. The use of insect pests as bio-control agents has application in situations where only one dominant weed is a problem such as in aquatic ecosystem, range lands, forestry or waste lands. The control of *Parthenium hysterophorous* with Mexican beetle (*Zygogramma bicolorata)* and the control of water hyacinth with weevil (*Neochetina spp)* are a couple of successful examples of use insect pests for weed control. The Mexican beetle is very effective on *Parthenium* and excellent control of the weed has been reported from several places in India. However, the insect is active only during the rainy season and it hibernates in soil during the dry and winter months. Several species of fungi have been developed as mycoherbicides (Table 2) in developed countries for the management of few problematic weeds. However, they have a number of limitations that is limited their large scale application and adoption.

Table 2 Mycoherbicide products in use

Products	*Agents*	*Target weeds*
DeVine	*Phytophthora palmivora*	*Morrenia odorata* (Strangler vine or milkweed)
Collego	*Colletotrichum gloesporoides* f.sp. *aeschynomene*	*Aeschynomene virginica* (Northern jointvetch)

Allelopathy

Allelopathy has potential in integrated weed management. It is a harmful, direct or indirect, effect of one plant on another through the production of chemicals that enter the environment. Crop plants have the capacity to produce and exude allelochemicals into their surroundings to suppress the growth of weeds in their vicinity. Olofsdotter and Navarez (1996) screened 111 rice cultivars for allelopathic potential against *Echinochloa crus-galli* (L.) Beauv. In the fields at IRRI and found that 11 cultivars in dry season and 21 in wet season had suppressed the weed growth by more than 50%. Similarly in wheat, Wu *et al.* (1998) reported that out of 38 wheat cultivars screened, some cultivars significantly inhibited both the germination and the radicle growth of *Lolium rigidum* Gaud. The use of allelopathic plants, or substances isolated from them and produced transgenetically, may become an important form of weed control in the future.

Use of herbicides

Herbicides are the most successful weed control technology ever developed. They are selective, cost effective, fairly easy to apply, have persistence that can be managed, and a variety of formulations and types. Herbicides in general are eco-friendly to environment provided applied at proper dose, method and time. With the normal use rate, the quantity of herbicide applied to soil at one time is too small in relation to total soil volume to have any detectable influence on a soil's physical or chemical state. Moreover, the herbicides are applied either before sowing or with in one month after sowing of the crop. They have a tendency to degrade from environment in a few weeks.

Herbicides have become quite popular with the farmers. Chemical weed control has already made a big impact in north-western part of India (Punjab, Haryana, Uttaranchal and western Uttar Pradesh). For instance 55% of the wheat area in this region is currently treated with herbicides. About 8% of soybean area in Madhya Pradesh is under herbicide application. Herbicide consumption has increased from 1400 MT in 1985-86 to about 11,000 MT in 2001-02. No doubt weed control through chemicals is easy, economical and labour efficient, the over dependence resulted in some serious environmental and ecological implications. Development of isoproturon resistant biotypes of the *Phalaris minor* in wheat under rice-wheat cropping system in Punjab and Haryana is one such example. This calls for targeting attention on non-chemical weed management practices and their integration with chemical methods.

Herbicide resistant crops

During the last decade global adoption rates for transgenic crops have been unprecedented and reflect grower satisfaction with the products that offer significant benefits ranging from more convenient and flexible crop management, higher productivity or net returns/hectare, and a safer environment through decreased use of conventional pesticides. These collectively contribute to a more sustainable agriculture. Glyphosate is toxicologically and environmentally benign with low toxicity to non-target organisms, low or no ground water movement and limited persistence. Glyphosate resistant soybean and corn varieties have found success in the USA and some other countries of the world. Considering the several advantages of using the herbicide resistant crops, it is worthwhile exploring their possible use under Indian conditions.

Naturally occurring herbicides

Many secondary plant metabolites and microbial toxins are reported to have good herbicidal properties. These include 'Bialophos' under the trade name 'Herbiaceae' isolated from the fermentation of broths of *Streptomyces hygrocopicus* and *S. viridochromogenes* and shows herbicidal activity against wide spectrum of grasses and broadleaved weeds following foliar application (Mase, 1984). Methoxyphenone, a synthetic derivative of microbial toxin anisomycin is marketed in Japan as a selective herbicide for control of barnyard grass (*Echinochloa crus-galli*) in rice and is easily degraded in soil (Munakata *et al.* 1973). The non-selective commercial herbicide 'Basta' contains ammonium salt of glufosinate, an analogue of 'Phosphinothricin', which is the active ingradient of the microbial herbicide bialophos (Herbiaceae) (Kochar, 1983).

Integrated weed management (IWM)

Considering the diversity of weed problem, no single method of control, whether cultural, manual, mechanical or chemical would be sufficient to provide season-long weed control under all situations. Integrated weed management system as a part of integrated crop management system would be an effective, economical and eco-friendly approach for weed management. The weed management in field crops requires an integrated approach that utilizes effective cultural, mechanical, biological, ecological and chemical methods in a mutually supported manner into the crop production system with due consideration of economic, environmental and sociological consequences.

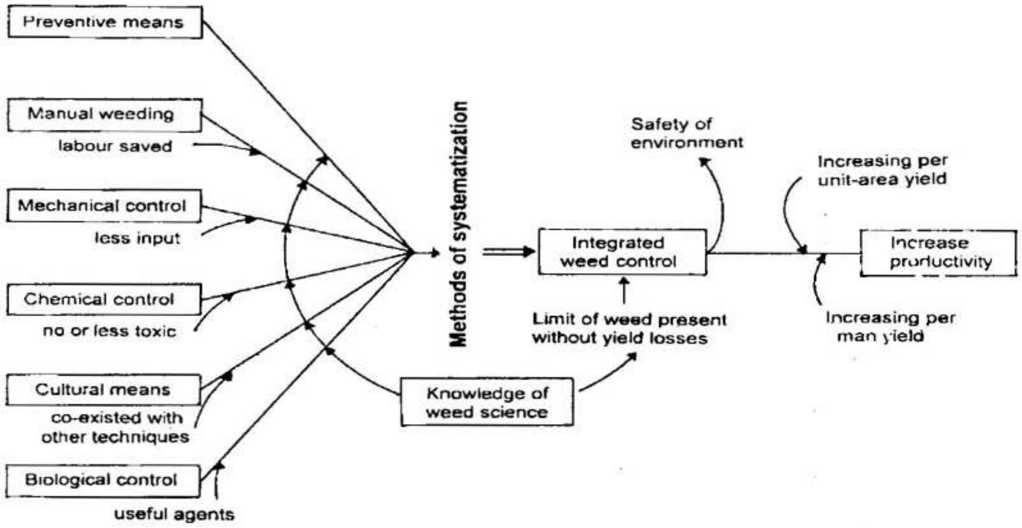

Figure : A concept ional model of integrated weed control. Noda, 1977.

IWM strategy

Integrated weed management is a component of integrated crop management. Basically it has three elements;

- Multiple tactics (competitive varieties, cultural practices and herbicide usage)
- Weed population maintained at levels below that cause economic damage, and
- Conservation of environmental quality

Buchanan (1976) defined integrated weed management (IWM) "as .... the application of many kinds of technologies in a mutually supportive manner. It involves the deliberate selection, integration and implementation of effective weed control measures with due consideration of economic, ecological and sociological consequences". The research approach to the development of an IWM system must take all aspects of the cropping system into consideration. Invariably, each cultural practice influences the competitive ability of both the crop and the weed community leading to a multitude of complex interactions. Efforts must be made to work within the existing production practice to ensure a greater likelihood of acceptance by the farming community. IWM is a knowledge intensive exercise where scientists also feel reluctant to get involved. This requires in depth information on economic threshold limits (ETL) for different weeds, weed seed dynamics in soil, understanding of eco-physiology of crop-weed competition, weed flora shifts in crops and cropping systems etc.

Swanton and Weise, 1991 suggested a research strategy for the development of an integrated weed management system (Fig.2).

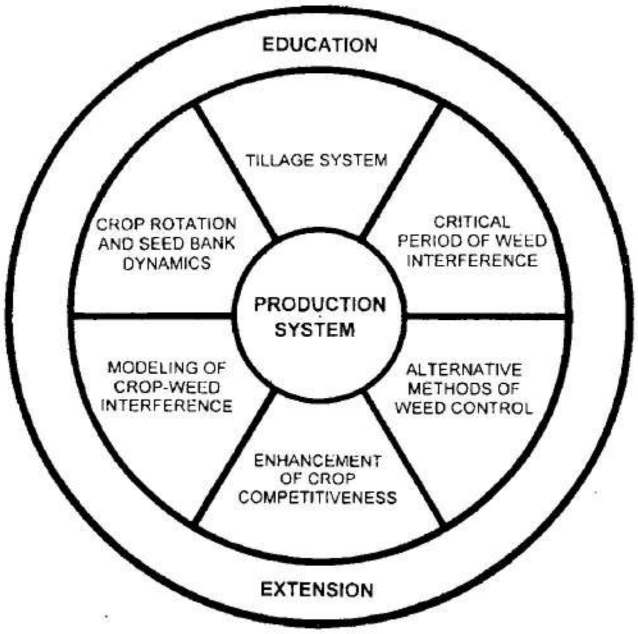

Fig 2 Research strategy for the development of an integrated weed management system

Epilogue

Scientific weed management has played a significant role in sustaining agriculture in the past and this branch of science is likely to play a leading role in the future too. However, experiences gained during last more than 3 decades of vigorous weed science research should be a guiding principle for future planning. Reorientation from purely herbicide based control strategies to integrated weed management approach is called for. The future weed science research needs to be focussed to address the following concerns.

- Reorientation from purely chemical based control strategy into integrated weed management with major focus on biological weed management strategy. The National Research Centre for Weed Science, Jabalpur; the National Research Centre on Integrated Pest Management; New Delhi and Directorate of Biological Control of Pests and Diseases, Bangalore needs to collaborate and formulate a road map for biological weed management in the country.

- There is a need to develop an integrated weed management strategy for crops and cropping sequences targetted under organic farming. A vast treasure of indigenous technical knowledge needs to be blended with recent scientific developments in weed science research for organic agriculture.
- Residue re-cycling of herbicides in soil, plant, water and environment must form an integral part of new weed research programmes.
- Little work has been done on weed control/management in urban landscapes/recreational parks particularly in the urban areas. Many weed species have become health hazards for animal and human populations. There is a need to refocus our efforts to develop weed management package for such situations.
- The other priority areas include: exploiting wed biomass as organic manure/compost, aquatic weed control/management, management strategy for alien weeds, herbicide resistance in weeds etc.

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Wheat Biotechnology for Herbicide Resistance

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Weeds affect growth, yield and quality of crop plants and reduce soil fertility, available moisture, nutrients and also compete for space and sunlight with the crop plants. Crop yield losses due to weeds are difficult to estimate because of interactions with insects, diseases, soils, crops, and the environment. Therefore, the need of the hour is to evaluate and identify the effective strategies for controlling broad leaf weeds in crop plants. Weed population also develops resistance depending on the selection pressure exerted by the herbicide; the herbicide rotation patterns; seed germination dynamics; use of herbicide combinations with different modes of action; initial frequency of naturally occuring resistant individuals in the weed population; and the relative vigor of resistant biotypes of weeds.

New vistas to combat weed menace involves introduction of herbicide resistance genes into crop plants to enable them to flourish even when exposed to the herbicides such as bromoxynil, glyphosate, BASTA (glufosinate), chlorsulfuron etc. and thus enhancing plant productivity. These are broad-spectrum herbicides, meaning that they kill nearly all kinds of plants except those that have the tolerance gene. Moreover, many of these herbicides break down quickly in the soil, eliminating residue carry-over problems and reducing environmental impact. However, for a sustainable production system the key areas of herbicide resistance or weed management involves using an integrated approach; control of herbicide tolerant crop volunteers and also management of out-crossing of transgenics to non-transgenic crops and weeds.

Phalaris minor and Its Control Strategies

Phalaris minor (Little seed canary grass) commonly known as *Gulli Danda* or *Gehun Ka Mama*, is a common weed of wheat–rice cropping systems in the north-western Indo-Gangetic plains of India. It is mostly confined to the states of Punjab and Haryana and accounts for approximately 3 million hectares out of India's 10 million hectare wheat-rice cropping system and affects about 35% of India's wheat production (Malik, 1996; Malik, *et al.*, 1998). *Phalaris minor* is effectively controlled by isoproturon spray. However, its continuous use has resulted in emergence of several resistant biotypes resulting in colossal wheat yield reductions amounting 30 to 80%. The use of new herbicides such as clodinafop, fenoxaprop, sulfosulfuron and tralkoxydim has brought the *Phalaris minor* infestation under control. Inexorably, the persistent use of new herbicides as the sole method of weed control would result in re-emergence of chemical resistance. The new expensive herbicides may also affect their rate of adoption, dosage use, profitability etc. and therefore its apparent that new paradigms for weed control is the need of the hour to provide a sustainable, long-term commercially viable control solution (Vincent and Quirke, 2002; Sharma *et al.*, 2002a; 2002b).

Wheat Transformation

Wheat is a major source of food as it supplies about 73% of the calories and protein of the average diet apart from being used for livestock and poultry feed. Cereals in general, and wheat in particular, were once considered refractile to *Agrobacterium*-mediated transformation (*see* Mahalakshmi and Khurana, 1997), but ever since the first successful report by Cheng *et al.* (1997) there has been no looking back. Though there are reports of various other strategies of wheat transformation such as use of silicon carbide fibers (Singh and Chawla, 1999) and cellular permeabilization (Mahalakshmi *et al.*, 2000) etc, both biolistics as well as *Agrobacterium*-mediated transformation has yielded wheat transgenics for various traits of agronomic importance. In recent years, wheat improvement efforts have focused on raising the yield potential, improving quality characteristics and developing resistance/tolerance to regional abiotic stresses (*see* Patnaik and Khurana, 2001).

Introduction of *Bar* Gene in Wheat

Irrespective of the two major methods of plant transformation, genetic engineering requires the delivery, integration and expression of defined foreign genes into suitable regenerable explants. The varied frequency of DNA delivery in cells of different explants has necessitated the development of methods for efficient selection of cells that carry and express the introduced gene sequences. The selection regimes for transformed cells are based on the expression of a gene termed as the selectable marker producing an enzyme that confers resistance to a cytotoxic substance, often an antibiotic or a herbicide.

Bar as a Selectable Marker Gene — Several selection agent/marker gene combinations have been employed to identify transgenics of which the most commonly used herbicide resistance gene is the *Bar* (bialaphos resistance gene) or *Pat* (phosphinotricin acetyl transferase) that confers resistance to the herbicides bialaphos or BASTA and PPT, respectively, by inhibiting glutamine synthetase. The *Bar* gene detoxifies phosphinothricin (PPT), the active ingredient of herbicides such as Ignite (AgrEvo) and Basta (Hoechst). The *Pat* gene, for phosphinotricin acetyl transferase, provides tolerance against glyphosate and glufosinate ammonium herbicides. Similarly, the enolvylshikimate-phosphate synthase (CP4) gene and the glyphosate oxidoreductase (GOX) provide tolerance to glyphosate by degrading glyphosate into aminomethyl phosphoric acid. These genes thus serve the dual purpose of a selectable marker as well as that of a gene conferring herbicide resistance.

Bar Gene for Herbicide Resistance — The menace caused by *Phalaris minor* and its resistant biotypes in wheat fields can be overcome by an ecofriendly, biodegradable and the broad-spectrum contact herbicide 'BASTA'. Keeping this in mind herbicide resistance, transgenic bread wheat (*T. aestivum*), durum wheat (*T. durum*) (Patnaik and Khurana, 2001; 2003; Patnaik *et al.*, 2005) and emmer wheat (*T. dicoccum*) have been produced by both particle bombardment and *Agrobacterium*-mediated approaches (Khurana *et al.*, 2002a, Chugh and Khurana, 2003a, b) by introduction of the *bar* gene for resistance against the herbicide BASTA and bialaphos.

Many factors are known to influence successful transformation of wheat (Mahalakshmi and Khurana, 1995; 1997; Mahalakshmi *et al.*, 2000; Wu *et al.*, 2003) of which the marker genes play a significant role as inadequate selection often resulted in numerous escapes, which makes subsequent screening tedious. *Bar* gene has been successfully in wheat transformation and therefore was used in our studies also. The constructs with *Bar* as a selectable marker used by our group for *Agrobacterium*-mediated wheat transformation include the pCAMBIA series and its modified vectors — pCAMBIA3301::*PIN2*, pCAMBIA3301::*HVA1* and pCAMBIA3301::*HVA1*. For achieving the biolistics-mediated transformation, the plasmid constructs pDM302 (*Act1-Bar-nos*) and p*Act*1-F were successfully co-transformed in mature embryo-derived calli on MSE-2 (Patnaik and Khurana, 2003). Use of novel explants, such as the use of leaf basal segments (Chugh and Khurana, 2003a,b) and also mature embryos (Patnaik and Khurana, 2001, 2003; Patnaik *et al.*, 2005) has been employed successfully for obtaining wheat transgenics.

Employing the highly regenerable basal segment calli, a comparision was attempted between *T. aestivum* and *T. dicoccum* by introducing *bar* gene for herbicide resistance by particle baombardment and *Agrobacterium*-mediated co-cultivation techniques. The calli were selected on phosphinothricin containing medium, and transgene detected by PCR and Southern hybridization. A higher transformation efficiency of 7.5% was obtained using *Agrobacterium*-mediated co-cultivation and 4% efficiency was obtained with particle bombardment (Chugh and Khurana, 2003a; Khurana *et al.*, 2002b).

Successful generation of transgenics at a frequency of upto 10% has been achieved following co-cultivation with *Agrobacterium* of mature embryos and mature embryo-derived calli for 2-3 days. Paromycin and phosphothricin were used as the selection agents as they did not adversely affect plantlet regeneration and also aided in detection of escapes. Optimization of this method facilitated the introduction of *bar* gene at a frequency of ~8-10% for *T. aestivum* and *T. durum,* and 7% for *T. dicoccum* (Chugh and Khurana, 2003; Patnaik *et al.*, 2005). When bombarded with gold microprojectiles, the *bar* gene was observed to be active in both T_0 and T_1 generations as evidenced by phosphinothricin leaf paint assay. The transmission of *bar* gene to T1 progeny was demonstrated by PCR analysis of the germinated seedlings and was approx. 8.5% in *T. aestivum,* 10% in *T. durum* and 5% for *T. dicoccum* (Patnaik and Khurana, 2003; Chugh and Khurana, 2003).

Table 1 Use of *Bar* as a selectable marker for wheat transformation *via.* biolistics.

Tissue	*Promoter /Reporter*	*Selection /Marker*	*Transformation frequency (%)*	*Reference*
Embryogenic callus (5-7month old)	*Adhl/gus*	*Bar*	4 (Plants regenerated-4)	Vasil *et al.*, 1992
Embryogenic callus immature embryos	*Adhl/gusE35S/ gusUbi/gus*	*Bar*	2.2 (Plants regenerated-7)	Vasil *et al.*, 1993
Imature embryos	*Ubi/gus*	*Bar*	1 (Plants regenerated-65)	Weeks *et al.*, 1993
Immature embryos	*Actl/ gus*	*Bar*	1.1 (Plants regenerated-12)	Becker *et al.*, 1994
Somatic embryos	*35S/ gusActl- gus*	*Bar, nptII*	0.8–1.6 (Plants regenerated-23)	Nehra *et al.*, 1994
Immature embryo	*35S* (duplicated)*Ubil*	*CP4, GOX*	0.15%	Zhou *et al.*, 1995
Cultured immature embryos 4–6 h pre- and 16 h post-bombardment osmotic treatment	*Ubil/gus*	*Bar*	1.52%	Altpeter *et al.*, 1996a
Cultured immature embryos	*Ubil/ gus* HMW-GS *1Ax1* gene	*Bar*	20 Bar positive lines and nine having the 1Ax1 gene out of 21 independent transformed lines	Altpeter *et al* ., 1996b
Immature embryo calli	*35S/ gus*	*hpt, Bar*	5.5%	Ortiz *et al.*, 1996
Immature scutellum tissue	*Actl/gus*; *Actl-Bar*	*Bar*	Independently transformed plants were produced from 1.4% and 1.7% of bombarded embryos	Takumi and Shimada, 1996
Isolated scutella (Durum wheat)	*gus; Bar*	*Bar*	2%	Bommineni *et al.*, 1997
Embryogenic callus	*p35S* : *Bar*; *Barnase* expressed under-*pca55*; *pEl* and *pT72*	*Bar*	1 - 2%	de Block *et al.*, 1997

Contd ......

Tissue	*Promoter /Reporter*	*Selection /Marker*	*Transformation frequency (%)*	*Reference*
Precultured scutella of immature embryos	pGluChi; pRipChi; pAB1	*Bar*	0.7%	Bliffeld *et al.*, 1999
Scutellar calli	*Ubi1/luciferase*	*Bar*	12%	Harvey *et al.*, 1999
Somatic embryos Scutellar tissue	*Ubi/ gusAct1/ gus*	*Bar*	2.1 (Plants regenerated-21)	Barro *et al.*, 1997
Immature embryo	*pAHG11*		8.6%	Chen *et al.*, 1998
Cultured immature embryo	*pEmuPAT/ pDM803 pEmuHPT/ pUbi1-hph; pEmuKON [Ubi-Bar Act1/gus]*	*Bar*	0.25-1.2%	Witrzens *et al.*, 1998
Scutellum	*pBC1-7* [*35S/ (Bperu* and *C1)*];*pAct1-Bar*	*Bar*	0.42%	Chawla *et al.*, 1999a; 1999b
Cultured immature embryo	KSUG *(Ubi/gus)* and KSAB *(Act-Bar)*	*Bar*	14% for l-ssDNA	Uze *et al.*, 1999
Three cultivars and one breeding line of durum wheat	co-transformed with plasmids *Bar* and *uidA*; HMW glutenin subunit genes	*Bar*	0.6%	He *et al.*, 1999
Immature embryos	*Ubi:Bar; Ubi:cp; Ubi:rcn70; Ubi:P#*	*Bar*	9.7%	Zhang *et al.*, 2000
5-7 day pre-cultured immature embryo	pDM 803 (*ubi1-Bar; Act1-gus*)	*Bar*	0.14-0.83%	Gopalakrishnan *et al.*, 2000
Scutellar calli	pAHC25 (*Ubi-Bar; Ubi-gus*) co-transformations with four different plasmids - encoding for *SAMDC* and *ADC* gene	*Bar*	1–17% (mean 4% across varieties)	Rasco-Gaunt *et al.*, 2001
Elite wheat varieties Immature embryos	pAHC25 (*Ubi-Bar; Ubi-gus*)	*Bar*	transformation frequency rose from 0.7% to 5% when old and young donor plants were used respectively; best frequency-7.3%	Pastori *et al.*, 2001
Heat and drought stressed immature embryos of Durum wheat	PUbi-*Bar* developed from pGEM3Zf(+)	*Bar*	0-6.46% (Mexicali) transformation efficiency (1.70%-average value)	Pellegrineschi *et al.*, 2002
Embryogenic calli generation from immature embryos	pAHC25 (*Ubi-Bar; Ubi-gus*)	*Bar*		Melchiorre *et al.*, 2002

Since the success of any transformation process depends upon the ability to select for the regenerants arising from the transformed cells, considerable attention has been devoted to establish regenerating systems prior to transformation. Most of the earlier systems had concentrated on use to immature embryos and immature inflorescence, emphasis in our laboratory has been on the mature seeds, mature seed-derived calli, the basal segment calli, and leaf base segments, which are also available the year round (Khurana *et al.*, 2002; Patnaik and Khurana, 2003; Mahalakshmi *et al.*, 2003; Chugh and Khurana, 2003a, b; Patnaik *et al.*, 2005). These systems have been used for not only particle bombardment and *Agrobacterium*-mediated co-cultivation, but also to explore new and novel methods of transformation like cellular permeabilization (Mahalakshmi *et al.*, 2000).

Table II *Bar* as a selectable marker for *Agrobacterium*-mediated wheat transformation.

Tissue	*Promoter / Reporter*	*Selection / Marker*	*Transformation frequency (%)*	*Reference*
Precultured immature embryos	LBA4404 (pCAMBAR *Ubi-TLP*)	*Bar*	Three Southern positive plants	Mei *et al.*, 2000
Immature inflorescence tissue	*Agrobacterium* strain AGLI harbouring binary vector pAL154, pAL155, pAL156 and pAL186	*Bar*	Optimization of parameters	Amoah *et al.*, 2001
Wheat suspension cells	pTO134 containing CaMV*35S*::*gfp* and a 35S::*Bar*	*Bar*	1.8	Weir *et al.*, 2001
Immature embryos and embryo-derived calli	AGL-1, EHA105 and LBA4404 harboring expression vector p3301 or pBTAaB	*Bar*	3 out 6 plants were positive plants	Wang *et al.*, 2002
Immature embryos	AGL1 harbouring the pGreen-based plasmid pAL156	*Bar*	0.3 to 3.3 [44 transgenic wheat plants in two winter wheat varieties]	Wu *et al.*, 2003
Immature embryos	*aroA*::CP4 gene	*CP4, GOX*	transformation efficiency of 4.4%	Hu *et al.*, 2003
Immature embryo-derived calli of spring wheat cv. Veery5	LBA4404 carrying either binary vector pHK22 or superbinary vector pHK21	*Bar*	Transformation efficiency 3.9%	Khanna and Daggard, 2003

The transformation efficiencies achieved by our group ranged between 0-4% by particle bombardment, is comparable with those reported by other researchers (0.3% and 3.3%, Wu *et al.*, 2003; 1.6%, Cheng *et al.*, 1997; 1.8%, Weir *et al.*, 2001). The highest transformation efficiency by microprojectile bombardment in the range 1-17% has been reported by Rasco-Gaunt *et al.* (2001) followed by 14% transformation efficiency by Uze *et al.* (1999). The *Agrobacterium* mediated transformation reports have been able to achieve 3.3% transformation efficiency (Wu *et al.*, 2003), and those obtained by us are by far the highest for wheat. Thi s could be attributed to use of highly regenerable receipient explants as the target tissues, e.g. mature embryos, embryo-derived calli, basal segment calli, etc. Since selection of the transformants is crucial, starting with tissues displaying high efficiency regeneration is essential for success.

Use of herbicides as selection agents does have its shortcoming, i.e. the large number of escape plantlets – in the range 50-95% (Nehra *et al.*, 1994; Altpeter *et al.*, 1996a; Barro *et al.*, 1997; Witrzens *et al.*, 1998). However, a lesser escape frequency (35%) has also been achieved with selection on 4 mg/l gluophosinate ammonium (Rasco-Gaunt *et al.*, 2001). The presence of escapes in the present study can be ascertained the MSE-2 medium used for callus induction - that contained casein hydrolysate (200 mg/l), which perhaps weakened the role of bialaphos as a selective agent during embryoid formation especially if calli were too big or if too many calli were cloistered and allowed to differentiate in one petriplate.

Guidelines for Effective Transgenics Systems

Explicit guidelines must be adhered to when using transgenics systems including follow-up on integrated weed management program that encompasses stringent application of herbicides, suitable cultural practices and crop rotations for effectual management of weed populations. The various strategies include employment of control volunteers in the season following a transgenic crop cultivation and also practices that minimize the likelihood of out-crossing to similar crops or related weeds. Many factors influence the ability of a given plant to out-cross with others, including spikelet type, timing of flowering, stigma receptivity, pollen production, pollen dispersal, pollen viability and environmental factors. However, opinions differ on the use of molecular approaches such as the transgene technology as a sustainable and effective strategy for combating the menace of weeds since reports of containment of contamination *via* horizontal gene transfer to other out crossing crops pose a bigger challenge. Moreover, hybridization within the genus *Triticum* has been shown to be generally less than 6% since wheat is primarily self-pollinated and the potential for out-crossing with related species is improbable. Even *Triticale*, the well-known inter-generic combination, has not been reported as of yet to serve as a bridge for hybridization with other wild grass species. Therefore, the use of herbicide resistant wheat transgenics for combating the weed menace looks prospective however, testing these transgenic crops prior to commercialization is mandatory.

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Herbicide Residues and Environmental Concerns-Indian Perspectives

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In the process of sustainable food production chemical herbicides will remain a keystone component of crop protection for several decades to come. Even though the statement is frequently disputed by those who believe that more recently introduced technologies such as genetic manipulation will totally dominate the future, at present there are no real alternatives on the horizon to herbicides for weed control.

If we look at the surface of the herbicide research today we would conclude that it is healthy, highly productive and innovative. We would see that across the industry, new herbicides are frequently being discovered and moving into development to replace, or to complement, older less effective herbicides.

When, take a closer look and detailed inspection on herbicide scenario in India over the last decade the picture is somewhat different from the view on the surface. In fact, from the closer study we are seriously concerned about some aspects of our current herbicide research. Herbicides are likely to drift to non-target areas during application or move with water or sediment running off the field or leaching through the soil closer to the areas of use. At the same time, herbicides are subjected to a number of degradation processes, in soil, air, water, and biota that result in the production of usually less toxic or less environmentally relevant substances. Apart from this the smaller quantity of herbicide residues causes phytotoxicity to succeeding sensitive crop. Further the environmental concerns for herbicides are focused very critically outside the agro ecosystem due their potential effects. Thus the presence of residues in food and environment in relating to public health has become a great subject for debate between scientific community, government and public.

Environmental concerns associated with herbicide residues

The effect of prolonged and over use of herbicides on soil results in human health hazards and pollutes the environment. Apart from this herbicide application also alters the ecosystem, the essential bacteria which fix nitrogen in soil and fungi facilitating the nutrient uptake by plants are inhibited by most herbicides. If we look at the reports on herbicide residues majority of the reports are pertaining to;

- Contamination of drinking water
- Contamination of soil and terrestrial systems
- Contamination of food and agricultural produces
- Contamination of aquatic and marine products
- Phytotoxicity to succeeding crops
- Influence on human health and environment

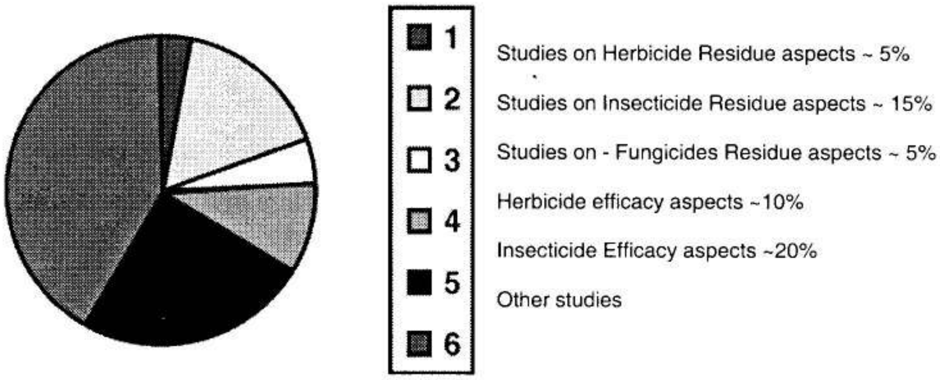
Majority of the toxicological studies reported for several agrochemicals on animal models ends with an indication towards the dreaded diseases like cancer.

In reality, the agrochemicals are amongst the most highly regulated products in India. The regulations covering exposure to crop protection chemicals and their residues are stringent and large safety margins are employed. Early stage screenings are incorporated as indicative tests for favorable environmental properties (eg. soil persistence, phytotoxicity, leach ability).

If the process of ecological risk assessment for pesticides works accurately as we predicted, why is there such a concern for the environmental risks? There are a number of reasons for this. Perhaps the most important is that there are still a number of older compounds being used, some of which (Ex: atrazine) are of environmental concern if we looking at their presence as residues. To highlight, the presence of residues is becoming so severe that the organic agricultural form products are also getting affected. Thus there exists a dire need to review the potential effects of herbicides in the environment consistently , which is the responsibility of the environmental core assessment group.

Herbicide Residue analysis in India - Questions to be addressed

It is surprising to know the quantum of research work published in rated international journals on herbicide residue aspects is ~20 papers during the past five years. Similarly in Indian journals, out of 400 publications made on different aspects, only around 5% is pertaining to the herbicide residue analysis.



From the data we need to address several questions:

- Do we have adequate data on herbicide residues in soil, ground water, agricultural produces?
- Do we have adequate data on herbicide residues in fish and other marine products?
- Do we have adequate data on herbicide residues in food and composite dietary intakes?
- The data what we are generating is it adequate for feature demands?
- Do we have a national database on herbicide residues in different aspects?
- Do we have any advanced technology for implementation at gross root level to minimize the risk of herbicide residues?

With the restriction on quantities of herbicide residues present in different strata estimation of residues is becoming harder and harder. Residue scientists need to focus on the aspects that the absence of residues in a given strata is due to lack of sensitivity of the method used or really due to their absence. In this process it will become essential to adopt new inventions and techniques of residue chemistry

Analytical Issues

Analytical methods have changed and developed over time. Old data are often treated with suspicion where methods of validation are uncertain. The information available on the metabolites is scarce. Internationally majority of the data is generated with lower limits of detection than what we are using. To make the data generated acceptable to international community, it is necessary to use harmonized protocols and method. Apart from this the data what we report needs confirmation. As per USEPA any data reported on residues requires confirmation by another suitable technique. Without which the data is not valid.

Future perspective

Although the common man's first interest in connection with herbicides is the safety of food that they eat, they are increasingly becoming aware of, and concerned about, the effect of herbicide residues may have on human health and environment. This may likely to force the monitoring agencies to concentrate on surveillance programs. In this process, the generation accurate data on quantities of herbicide residues present in different strata will become harder and harder. Residue scientists need to focus on the aspects that the absence of residues in a given strata is due to lack of sensitivity of the method used or really due to their absence this will further lead to adopt new inventions and techniques of residue chemistry. With the consumer awareness the likely changes

- New chemical weed controllers will get introduced with new sites of action
- Natural products and combinatorial chemistry will be major focus for lead discovery in chemical weed control
- Biological weed control will become an important tool
- Use of transgenic herbicide resistant crops will increase
- Registration requirements will continue to become even more stringent weed control
- Public conception on herbicide residues will become a major problem in future for agricultural scientists and for policy makers

What we need to focus on

The report on occurrence of herbicide residues is clearly an indicative of the extent of contamination in any given substrate. The residues have such a potential to get distributed to extremely remote habitats in nature. This has greater impact on domestic and export market. For a sustainable food production within the country and to assure the national and international consumers that the food produced within the country is safe for consumption it is necessary to focus on:

- Nation-wide monitoring and surveillance program on herbicide residues in soil, water, food and feed samples connecting different laboratories in India, whilst using harmonized protocols.
- e-CAD – Electronic capturing of analytical data and harmonization of the results between the labs in a net work program
- Assessment of residue levels in biota with special attention to aquatic species and animal tissue as indicatives of environmental contamination.
- Identifying and testing potential methods as an alternative to ameliorating problems associated with the use of herbicides
- Introduction of new Biotechnology based developments and concepts to minimize the use of herbicides
- Designing and development of Allelochemicals
- Organic Agriculture

Now the Science is very clear and the public are becoming more and more concerned about their food contamination by the residues of pesticides including herbicides featuring high in their list of worries. In most of the cases they believe the whistle blowers complicating the issues. In this contest it is the responsibility of the every individual scientist to put before them the correct technology and findings of research in such a way to safeguard human health and environment, alleviating the public perceptions.

Making Allelopathy Acceptable: An Ecological Perspective

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Allelopathy is defined as the effect of one plant (including microorganisms) on another plant through the release of chemical compounds into the environment (Rice, 1984). Because the definition includes both positive and negative effects and also includes microorganisms, it is considered too broad in its scope. Allelopathy as the suppression of seed germination and growth of one species by another through the release of chemical compounds, however, is more acceptable to most ecologists (Inderjit and Callaway, 2003). The allelopathic effects of compounds could be due to: (a) direct release of allelochemicals from the donor plant; (b) degraded or transformed products of released allelochemicals resulting from abiotic and biotic soil influences; (c) effects of released allelochemicals on physical, chemical and biological soil characteristics, or (d) induction of release of biologically active compounds by a third species (Inderjit and Keating, 1999). Few studies are acknowledged to have demonstrated probable allelopathy in nature, most appeared limited to *in vitro* circumstances. This difficulty reflects the complexity of allelopathic interactions. Allelopathic effects are often modified by additional biotic and abiotic stress factors, uncertain climatic events or, physical, chemical and biological edaphic factors all of which can influence the residence time, persistence, concentration and fate of allelopathic compounds in the environment (Inderjit, 2001; Inderjit and Bhowmik, 2004). One of the major concerns about allelopathy research is inadequate methodology, which includes (i) use of artificially sensitive species and unnatural growth medium in laboratory bioassays, (ii) less attention to ecological factors, (iii) lack of correspondence between laboratory bioassays and field pattern, and (iv) the absence of well replicated and repeated long-term field studies (Inderjit and Dakshini, 1995; Inderjit and Nilsen, 2003). In general, broad criteria to demonstrate allelopathy include: (i) identification of an allelopathic donor plant with reduced growth of other plants in its vicinity, (ii) the capacity of a donor plant to produce bioactive chemical compounds, and to release them into the environment, (iii) isolation, identification, and characterization of biologically active chemical compounds, and (iv) observation of the effects of isolated chemical compounds and their mixtures on seed germination and, or, growth of certain plant species. However, there are many other aspects of this phenomenon, which need to be considered. For example, during phytochemical analysis, attention is often paid only to biologically active compounds with "appropriate" concentrations, and compounds with low concentration remain neglected. Bioassays are often performed only with individual compounds, and insufficient attention is paid to the roles of compounds in mixtures of allelopathic chemicals. Furthermore, bioassay-guided fractionation is not necessarily the best approach for studies of allelopathy, given that the allelochemicals in the plant may be converted into more active compounds once they reach the soil. It is important to study at what concentration, and in what form, a chemical is available to the target species, and to consider how the qualitative effects and quantitative concentration of a given compound are influenced by habitat, by physical, chemical and biological soil factors, by climatic factors, and by many other characteristics of the habitat. Although there has been significant progress in the understanding of physiological aspects of allelopathy, molecular target sites of allelochemicals can be better understood with recent molecular tools (Inderjit and Duke, 2003; Yang et al., 2004). A better knowledge of the biochemical pathways (enzymes and genes) involved in production of putative allelochemicals, the methods of allelochemical storage and transport to the soil, the molecular target sites of allelochemicals, their detoxification, and the potential *in vivo* interactions of these compounds will provide the physiological basis for improved understanding of the role of allelopathy in ecosystems, both agricultural and natural. However, there are some good examples of work providing a solid basis for inferring the significance of allelochemicals in explaining plant dominance in certain natural situations. These include the work of Muller and Gliessman work on bracken fern (Gliessman and Muller, 1978), Nilsson and her colleagues on crowberry (Nilsson, 1998), Weston, Duke and co-workers on sorgoleone (Nimbal et al., 1996; Rimando et al., 1998), Blum on phenolic acids in soil environment (Blum et al., 1999), Weidenhamer and others on the Florida scrub (Weidenhamer and Romeo, 1989; Weidenhamer et al., 1989), Callaway on invasive success (Callaway and Ashehoug, 2000; Callaway and Ridenour, 2004; Hierro and Callaway, 2003) and my on work on *Pluchea lanceolata* (Inderjit, 1998; Inderjit and Dakshini, 1992, 1994a, b,1996; Inderjit et al., 1996) . Is any of these work perfect? The answer probably is 'No.' Are there still questions to be answered? The answer is 'yes'. But allelopathy as a science has certainly progressed the way beyond the days of Harper's criticisms.

Allelopathy can be better conceptualized and investigated in terms of soil ecology (Inderjit and Weiner, 2001). Such an approach can further allelopathy research and reduce some of the less fruitful controversy surrounding this science. A series of experiments with large numbers of species should be designed to understand the general role of allelopathy in natural communities. Merely isolating chemicals from plants and conducting bioassays is not enough to invoke allelopathy. Biotic and abiotic variation in natural soils creates a great deal of conditionality in chemical effects, and can either lessen or enhance chemical effects. In order to understand the ecological role of allelochemicals, experimental studies must be carried out in the field or under conditions comparable to those in the field so that results provide an appropriate basis for drawing conclusions about the roles of these compounds in plant communities and ecosystems (Inderjit et al., 2004). Allelopathy is conditional and species-specific effect, and the term 'allelopathy' may be misleading unless the conditionality is addressed (Inderjit and Callaway, 2003). Allelopathy is only one of the potential mechanisms to explain plant dominance. It has previously suggested that several mechanisms (e.g., allelopathy, resource competition, microbial nutrient immobilization) may operate in parallel and largely control community structure and ecosystem processes (Inderjit and Del Moral, 1997). In addition to investigating the role(s) of allelochemicals at population level, there is a need to explore temporary versus long-term ecological changes due to allelochemicals, and to define changes at population and community level.

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Biotechnological Approaches for Aquatic Weed Control

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INTRODUCTION

A major challenge in the present millennium is the dramatic decline in water availability. This is projected as the single greatest threat to human health, the environment and global food production. It has been estimated that one third of world's population will experience severe water deficits by 2025 and with increasing population, food production will become more dependent on irrigation. At present, 70 per cent of all water withdrawals are towards agriculture and 40 per cent of world food production is from irrigated land with consequent progressive increases in salinity (Leaver, 2001). Several floating, submerged, emergent and shoreline aquatic plants are among the world's worst weeds. These aquatic weeds cause, greater economic damage through revenue losses and control costs, environmental damage through loss of recreational and tourist potential, loss in bio-diversity and impairment of human health. For managing aquatic weeds, classical bio-control using insect agents and bio-herbicides appear to be promising in temperate countries. However, such options are constrained with hurdles such as interrupted host range, lack of host specificity, shelf life and knowledge on spray techniques. Hence a comprehensive biotechnological programme comprising several tools need to be developed as site specific options. Such a strategy will serve as a vital approach in improving the existing bio-control agents and increasing their virulence for managing problem weeds as suggested by Joel (2004). Linking similar biotechnological approaches to IWM and IPM helps to address the bio-diversity concerns with a simultaneous reduction in agrochemical use.

Weed bio-control

Julien (1997) reports that out of 174 projects using deliberate introduction of bio-control agents, 39 per cent were successful and 101 species of weeds were targeted of which 48 per cent were controlled. The use of bio-control agents involve two different approaches (i) Classical, which is the most commonly used technique that involves the introduction of natural enemies from their native range in to an exotic range where their host plants has become a weed (ii) non-classical approach that include augmentative or inundative release of large numbers of a control agent to combat the weed menace.

Classical bio-control of aquatic weeds

The most widely used classical bio-control agents with appreciable success rates are fish and insects (Charudattan, 2001). Exotic bio-control agents that are to be introduced for weed control need to be thoroughly tested for their host – specificity and safety to non-target organisms. Further, they need to have an aggressive feeding habit, multiple mode of damage on the weed, high reproductive capacity and above all better adaptability to the differing environments. The popular examples of aquatic weeds fully or partially managed by insect agents are furnished below.

1. *Alternanthera philoxeroides* (Mart.) Griseb - *Agasicles hygrophila* Selman and Vogt (beetle) & *Vogtia malloi* Pastrana
2. *Eichhornia crassipes* - *Neochetina eichhorniae* & *N.bruchi* (weevils) *Orthogalumna terrebrantis* Wallwork (mite)
3. *Pistia stratiotes* L. - *Neohydronomous affinis* Hustache (weevil) *Spodoptera pectinicornis* Hampson (moth)

4.	*Salvinia molesta* D.S.Mitchell	-	*Cyrtobagous salviniae* Calder and Sands (weevil)
5.	Several submerged weeds	-	*Ctenopharyngodon idella* Valenciennes (fish, grass carp)

Bio-control of aquatic weeds using pathogens and bio-herbicides

Pathogens have also been used as classical bio-control agents for aquatic weeds. Rust fungus *Puccinia chondrillina* Bubak & Sydenham on Australian rush skeleton weed (*Chondrilla juncea* L.), *Nimbya alternantherae* (Holocomb & Antonopoules) Simmons & Alcorn on *A. philoxeroides, Colletotrichum typhae* HC Greene on *Typha* sp, *Fusarium graminearum* Schwabe on *Egeria densa* Planch and *Cercospora piaropi* Tharp on *Eichhornia crassipes* (Baretto *et al.* 2000).

The approach of bio-herbicides involve application of inundative doses of spores as a liquid suspension like a conventional herbicide to create an artificial and localized epidemic (Auld, 1997). The process of launching of a commercial bio-herbicide includes several steps. Initially a range of isolates of potential pathogens are tested for their bio-efficacy. A host-range test is carried out with a small group of selected isolates on a range of cultivars and afterwards defining optimal environmental conditions for infection and diseases development is essential. There after the possibility of mass production of fungus could be examined before preliminary field tests. The hurdles that arise in a bio-herbicide research are the difficulty in mass production of fungal spores, provision of a conducive environment for the spores to multiply and establish, precise application techniques ensuring optimum number of spores in spray droplets and appropriate formulation technology ensuring reasonable shelf life.

Integrated bio-technological approach for managing water hyacinth

Biotechnology assumes significance in managing aquatic systems. Use of herbicides are constrained with drastic reduction in water quality and ultimate ill effect or associated non target organisms. In countries like India, herbicides are yet to get registered for use in aquatic systems. Under such circumstances managing infestations of water hyacinth, water fern and water lettuce is alarming in true sense. In one of the recreational lakes with tourist attraction in a hill resort Ooty in the State of Tamilnadu, the public authority has spent heavily with rupees 1.25 crores (nearly tow hundred thousand and odd us dollars) for manual clearing of water hyacinth once. Similarly thousands of army men were used for clearing water hyacinth in a lake in Bangalore, the capital city of Karnataka State. Biological control is the only option available and that too is difficult in situations where the water body dries off in the hot summer, leaving the released insects to starvation and death due to interrupted host range. In such conditions an augmentative approach using the similar bio-control agents is construed as a possibility. The same was tested at watershed environs of Cauvery Delta region of Tamilnadu using the insect agents *N.eichhorniae* and *N. bruchi*. Before taking up the study, the weed *E. crassipes* was categorized in to small, medium and large, using discriminant analysis tool based on leaf area, fresh weight and plant height. Three different inoculation loads of the insects viz. 3, 6 and 12 were tried for each of the small, medium and large plants of *E. crassipes*. It was observed that large plants of *E. crassipes* could not be controlled or even partially damaged inspite of using the highest inoculation load of insects viz. 12 per plant (Kannan and Kathiresan, 1998). The study indicates that integration of short term control measures reinforcing classical bio-control might offer excellent results. In another study at Annamalai University, Tamilnadu allelopathic inhibition of water hyacinth by an Indian medicinal herb *Coleus amboinicus / aromaticus* was observed. The dried leaf powder of the *C. amboinicus* was taken up through roots, when applied to water body @ 25 g l^{-1}, causing death of the weed with in 24 hr and near cent per cent reduction of biomass with in 9 days. The plant product proved effective on *P. stratiotes* and *S. molesta* However, the requirement of plant product for treating larger water sheds might pose practical difficulties. Previous results also indicated that if driven in to the weeds system through foliage, the plant product could bear striking results even under very low doses such as 0.1 g l^{-1} of water or 100 ppm concentration (Table - 1). The only hurdle faced for application of the plant product on the weed's foliage is the resistance and repulsion offered by the cuticle of the weed's leaf (Kathiresan, 2000). It was speculated that if by any means, the cuticular barrier is to be opened up, then the plant product could get absorbed easily through the weed's foliage and cause lethality rapidly with lesser quantity requirement of plant product. Accordingly, the well established insect bio-control agents in India *Neochetina bruchi / eichhorniae* were chosen for the study, to serve as a component of IWM and to serve as vehicles to transport the plant product in to the weed. These weevils normally scrape on the leaves of *E. crassipes,* removing the cuticle.

Table 1 Percentage reduction in the biomass of water hyacinth due to *C. amboinicus*

Treatments	*Total fresh weight*	*Total dry weight*
Coleus amboinicus (40 g l^{-1})	80.72	75.63
Coleus amboinicus (20 g l^{-1})	71.18	62.18
Coleus amboinicus (10 g l^{-1})	69.13	52.43
Sodium chloride (40 g l^{-1})	2.51	10.90

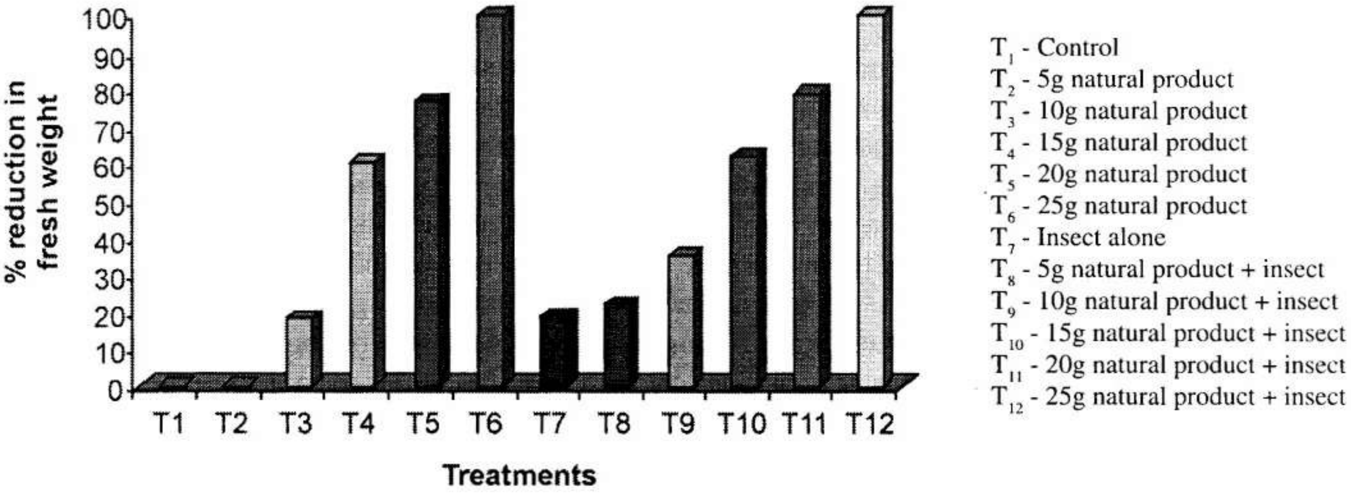


Fig. 1 Impact of the integrated approach of treating water first with the natural product followed by the release of insect agents on percentage reduction in fresh weight of *E. crassipes* on 10 DAT

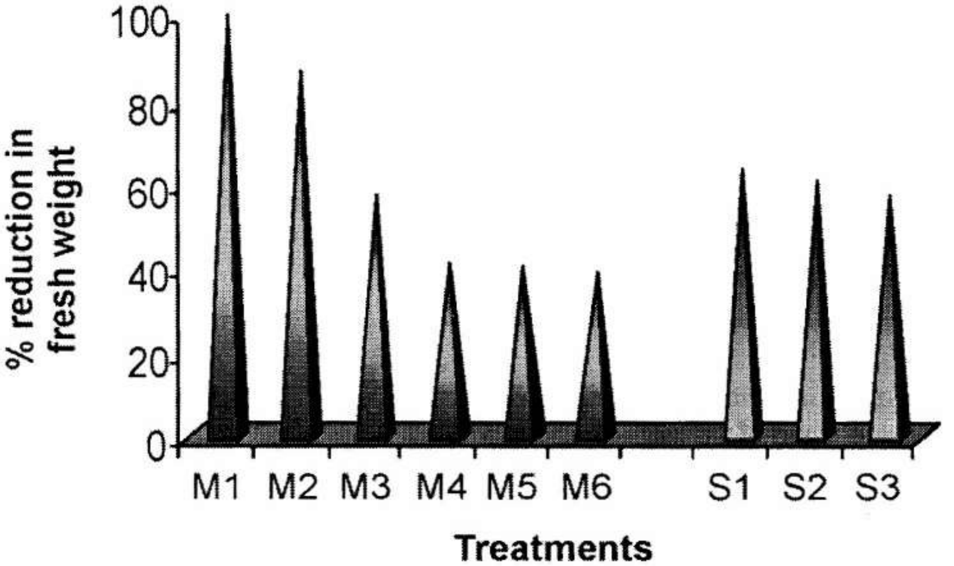
In this attempt to integrate both the bio-control tools viz. classical bio-control using *N. bruchi / eichhorniae* and application of the plant product *C. amboinicus,* integration is possible with two different sequences. Treating the water body first with plant product at a lesser dose with the expectation that it will reduce the vigour of the weed, predisposing it for faster and rapid destruction by the insect agents that are to be released later is one possibility where as releasing the insect agents first on the weed host, allowing them to make leaf scrapings that might help foliar uptake of plant product to be sprayed later is another.

Both these sequences were compared in the study. It was observed that treating the water body first with plant product followed by the release of insect agents on the weed showed only antagonistic interaction (Fig.1), as the insects migrated from treated partially killed plants to healthy plants (Table - 2). But the

Table 2 Impact of the integrated approach of treating water with the natural product followed by the release of insect agents on insect migration rate (%)

Treatments	*1 DAT*	*2 DAT*	*3 DAT*	*4 DAT*	*7 DAT*	*14 DAT*
T_1 - Control	-	-	-	-	-	-
T_2 - 5 g natural product	-	-	-	-	-	-
T_3 - 10 g natural product	-	-	-	-	-	-
T_4 - 15 g natural product	-	-	-	-	-	-
T_5 - 20 g natural product	-	-	-	-	-	-
T_6 - 25 g natural product	-	-	-	-	-	-
T_7 - Insect alone	0.01 (0.00)	21.41 (13.33)	21.41 (13.33)	25.56 (20.00)	26.56 (20.00)	31.09 (26.66)
T_8 - 5 g natural product + Insect	21.41 (13.33)	25.56 (20.00)	25.56 (20.00)	31.09 (26.66)	35.26 (33.33)	46.90 (53.33)
T_9 - 10 g natural product + Insect	25.56 (20.00)	25.56 (20.00)	31.09 (26.66)	31.09 (26.66)	35.26 (33.33)	50.77 (60.00)
T_{10} - 15 g natural product + Insect	46.90 (53.33)	54.53 (66.66)	58.91 (73.33)	58.91 (73.33)	75.03 (93.33)	90.00 (100.00)
T_{11} - 20 g natural product + Insect	58.91 (73.33)	63.43 (80.00)	75.03 (93.33)	90.00 (100.00)	90.00 (100.00)	90.00 (100.00)
T_{12} - 25 g natural product + Insect	68.38 (86.66)	75.03 (93.33)	90.00 (100.00)	90.00 (100.00)	90.00 (100.00)	90.00 (100.00)
CD at 5%	7.45	5.41	4.77	3.48	4.40	4.08

Figures in parenthesis are original values before arc-sine transformation



M_1 - 25 % natural product spray
M_2 - 20 % natural product spray
M_3 - 15 % natural product spray
M_4 - 10 % natural product spray
M_5 - 5 % natural product spray
M_6 - Insect alone

S_1 - 10 DAIR
S_2 - 20 DAIR
S_3 - 30 DAIR

Fig. 2 Impact of releasing the insect agents first followed by natural product spray on percentage reduction in fresh weight of *E. crassipes* on 60 DAIR second sequence of releasing the insect agents first followed by spraying of the plant product on the weed foliage showed additive or synergistic response with rapid and complete weed control with in a single season (Fig.2). The optimum inoculation loads of insect agents, concentration of the spray fluid of plant product required, length of interlude between the release of insect agents and spraying of plant product were standardized for different growth stages of the weed and success of this technology of integrated approach was demonstrated at three different watershed environs in the state of Tamilnadu. The plant product was also shown to be safe for the insect agents with out inducing migratory behaviour and without causing any histopathological injury on different tissues of the insects agents like salivary gland, gut, cutin, testis, and brain. Further, the integrated approach also proved safe for non-target organisms and water quality (Kathiresan, 2004).

CONCLUSION

Managing aquatic weeds need varying combinations of tools and options as an integrated package according to the habitat requirements. Among such options, use of biological agents whether insects or pathogens or plant products appear to be safe in terms of water quality, non target flora and fauna and bio-diversity concerns. Medicinal herbs of Indian origin offer good leads in this direction as a biotechnological tool, though not independently at the initial stages but as integral components of an integrated package. Such a complex but comprehensive biotechnological approach for managing persistent aquatic weeds proves superior among all other options in terms of efficient, eco-friendly and economic management of aquatic weeds.

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Farmers' Participatory Approach for Herbicide Resistance and Tillage Reforms

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The research agenda in the past has been prioritized on the basis of commodity approach with focused attention on individual crop. However, with emergence of second-generation problems and for improving the sustainability of agriculture, a holistic approach is needed. In this type of approach cropping system may be used as one commodity and the overall sustainability should be based on farming system approach. With the increase in population and increased market competition the agriculture has to be viewed with a specific limit for natural resources. The key to success in testing and promoting agricultural technologies now depends on how we conduct the research. A paradigm shift is needed to employ farmers' participatory research. Scientists need to work jointly with farmers to find ways to manage the resources to improve their profitability, food security and sustainability of the environment.

Monitoring of crops as part of a local neighborhood farm group activity allows farmers to compare the performance of their crops with others in their group, village and district. This process is called comparative analysis. Crop monitoring is done at different stages of crop growth. At each stage, a wide range of factors are monitored. Measurement of these factors and comparing then to standards of the district help determine whether the crop is performing at an optimum level.

Farmers' participatory approach is the process of collaboration that optimizes greater technology extension and then adding value to it gives an extra-ordinary access to modify technologies. It relies on farmers' experimentation and farmers' interaction with important market opinion, backstopping and follow up research. Even long-term trials may be monitored to anticipate and deal with any kind of undesirable consequences that may arise out of recommendations. Based on implementation of ACIAR and NATP project with success story of the zero-tillage following advantages have been experienced:

1. The research at farmers' field allows creating data to adapt to rapidly change in field conditions.
2. It involves farmers in the process of evolving this technology in the least possible time and avoids potential problems. This approach collects more information about farmers' preferences.
3. It creates bundle of services in real time. For researchers it saves lot of time and for farmers it allowed regular access to expert advice.
4. The approach serves as a guard against factors that might be deterrent for acceptance of technology.
5. It is easy to notice small problems, which are less complicated.
6. The system works well because near neighbors tend to know better and have more legitimacy when they inquire from their neighbors about the advantages of the technology.
7. Frequent interactions of all partners including farmers and state officials help catalyzing larger adoption of technology in different regions.
8. The multi-disciplinary and multi-institutional approach help to employ much better management strategies for marketing the technology.
9. Less costly.
10. Attracts farmers' primary interest.

11. Consolidates research and extension.
12. More innovative.
13. Create data to adapt to rapidly changing field conditions.
14. Farmers keep too much weight to recent experience.
15. Have vision to the future.
16. Determination to make changes for the better.
17. It is cheaper to implement because once convinced it is easy to justify investment.
18. Involve farmers in the process of designing new technology in least possible time.
19. It avoids potential problems.
20. Collects more information on farmers' preferences and create bundles of services in real time.
21. Less investment which is even less if extension activities are included.
22. Gain more information and deepens relation with farmers.
23. It is easy and efficient to take away guesswork out of technology development.
24. Multi-institutional approach facilitates the use of outside expedite.
25. Help endorsing research priorities.
26. Promote and strengthens linkages between agricultural programs of SAUs, ICAR, NARS and IARS.

Table 1 Activities and requirements in the diagnostic stage of a farming system research (FSR) project .

Person with unique skill and vision to initiate and drive the process
- Based on dynamics of funding sources assignments/ availability of personnel

Identifying target groups/partnerships
- Social mobilization – entering community, identifying local organizations and key informants
- Feedback to stakeholders/ community – raising awareness
- Increase local ownership

Inventory
- Undertake a systematic evaluation of system characteristics
- Record and classify – local database
- Develop ways of interpreting database
- Create a hypothesis

Ideas being disseminated – attractive package
- Availability of technical solutions
- Easily communicated through indigenous routes
- Credibility

Structures
- Farmer groups (focal points)
- Support groups for information sharing
- Local institutional commitment (capacity) to project

Response to an identified need: problem focus
- Understanding the problems of farmers from the perspective of farmers
- Understanding of farmer objectives and their environments (biophysical and socio-economic)
- Understanding of the farmer base core knowledge
- Availability of technical solutions

Situational analysis
- Constraining factors
- What are the references, priorities, diversity of farmers
- Methods of analysis
- Prioritizing needs and problems
- Identify intervention points

Table 2 Levels of activity and decisions in the scaling-out stage of a farming system research (FSR) project

Technical options testing phase • Farmers involved throughout • Links to farmer livelihoods • Wide stakeholder representation • Support studies: adaptive research (experimentation, quantitative on-farm trials, on-farm demonstrations)	**Scale** • Scale of analysis • Scale of intervention • Scale of community empowerment • Scale of regional coverage
Learning culture • Support groups for information sharing • Knowledge and information sharing among partners • Feedback into research process	**Technology promotion** • How is knowledge managed • What partners are trying to achieve • Dissemination materials and approach
Implementation phase • State of practice; how will adoption be done • Define groups facing similar conditions	**Community organizations** • Capacity building and networking • Policy dialogue
Monitoring and evaluation • Testing perceptions and expectations against reality • Impact indicators • Feedback loop to adjust research	**Reach a conclusion** • Empowerment and social change • Vertical scaling up – expansion to other sectors

Non-chemical approaches for the control of *P. minor* Retz. in wheat

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Phalaris minor (little seed canary grass) is the most troublesome weed of wheat especially in rice-wheat cropping sequence which is the dominating cropping system adopted by the Punjab farmers. Depending upon the management practices, there can be 30 to 80% reduction in wheat grain yield (Brar & Singh, 1997) due to the presence of this weed. So, in order to achieve economical yields, all the weeds of wheat particularly *P. minor* (little seed canary grass Gullidanda) should be controlled very effectively with the use of one or the other method of weed control. *Phalaris minor* has become increasingly alarming in the recent years because of development of resistance in it to isoproturon herbicide (Malik & Singh 1993, Walia *et al.,* 1997). Alternate herbicides, namely clodinafop, sulfosulfuron, fenoxaprop-p-ethyl and mesosulfuron are available but due to their high costs they are out of range of a poor/average farmer.

The chemical method of weed control became very popular amongst farmers as it is very effective, economical and quick method. In Punjab, about 90 to 95 per cent of net sown area under paddy and 80 – 85 per cent of wheat area is treated with herbicides. However, the continuous and indiscriminate use of herbicides may lead to pollution as well as other problems such as development of resistance and shift in weed flora. So, need based use of herbicides should be done and in order to achieve this target, exploitation of some non-chemical methods which are mostly cultural practices must be done. Gullidanda (*P. minor*) can be controlled completely or partially with the adoption of few cultural practices (agronomic manipulations). This method is free from pollution as well as other hazards of chemicals. Certain cultural practices or non-chemical methods such as crop rotations, adjusting dates of sowing, planting pattern, crop density, methods of fertilizer application, zero till sowing, selection of quick growing wheat varieties, management of soil moisture, stale seed bed preparation/ Dab system, etc. can be adopted by the farmers in order to eliminate or reduce the population of *P. minor* and other weeds from wheat crop. The role of these non-chemical approaches is being discussed under the following sub-heads, with the support of data.

CROP ROTATION

Crop rotation is the best cultural practice for breaking association of crop and weeds. With the adoption of this practice cent percent control of a problematic weed can be achieved which may be due to elimination of their life time association. The infestation of *P. minor* can be eliminated or lowered by rotating wheat with other Rabi crops such as berseem, potato based rotations, raya or gobhi sarson, winter maize, oats (fodder), sugarcane, etc. Data pertaining to dry matter accumulation by *P. minor* (average of three years) recorded after the completion of a particular rotation(except for berseem when data was recorded at the time of first cutting) indicated that adoption of rice-potato-wheat, rice-potato-sunflower and rice-berseem resulted in significant reduction in dry matter accumulation by *P. minor* as compared to all other adopted crop rotations i.e. rice-wheat and rice-gobhi sarson (Walia and Brar, 2004) (Table 1). However, all non wheat rotations were found to be significantly superior to rice-wheat rotation.

Data pertaining to seed bank studies, also indicated that by rotating rice-wheat with rice-berseem, rice-potato-wheat or rice-potato-sunflower, there was significant reduction in seed bank of *P. minor*. (no. of seeds per kg of dry soil) even during first year (1998-99) as compared to rice-wheat treated with herbicide. It was observed that within a period of three years there was complete elimination of *P. minor* seeds (infestation) under these rotations (Table 1). Also rice-gobhi sarson rotation was found to be significantly superior to rice-wheat for reducing seed bank of this weed. Due to initial slow growth of gobhi sarson, it was not able to suppress *P. minor* effectively and later on these weed plants were smothered by the crop but they produced seeds. In berseem, due to repeated cuttings *P. minor* plants were not able to produce seeds. Similarly, in potato-based rotations uprooting of germinated plants of *P. minor* took place with earthing up or digging operations. Similarly, Bhan (1987) reported that *P. minor* populations can be reduced /eliminated by replacing wheat with berseem, potato, raya / gobhi-sarson, sugarcane etc.

Table 1 Seed bank (0-7.5 cm soil depth) of P. minor as influenced by different crop rotations

Crop rotations	**Dry matter of P minor (q ha^{-1})*	*Seeds of P. minor per kg of dry soil*			
		1998-99	*1999-00*	*2000-01*	*Mean*
Rice-Wheat (herbicide)	2.95	26.1	22.5	17.5	22.03
Rice-Wheat (control)	41.60	75.3	92.5	102.5	90.10
Rice-Potato-Wheat	0.93	6.5	15.0	0.0	3.83
Rice-Potato-sunflower	0.93	4.7	2.5	0.0	2.40
Rice-berseem	1.20	5.6	2.5	0.0	2.70
Rice-gobhi sarson	3.60	12.7	7.5	5.0	3.40
LSD (p= 0.05)	1.25	2.8	3.53	3.91	7.4

*Average of three years
(Walia and Brar, 2004)

DATE OF SOWING

Efforts must be made to plan sowing of wheat crop during the period which is unfavourable / less favourable for germination of problematic weed seeds but emergence of crop may not be harmed. This agronomic manipulation can be practically implemented for reducing/controlling *P. minor* from wheat crop.

Data present in Table 2 revealed that crop sown on Oct. 25 (early) during both the years resulted in significant reduction in dry matter accumulation by *P. minor* as compared to crop sown on Nov 15. Less growth and development of *P. minor* in early sown wheat crop may be due to prevailing unfavourable climatic conditions for germination of *P. minor* particularly temperature. So, speed of germination of *P. minor* was very low in early sown crops. However, late sown crop (Dec. 5) also resulted in significant less dry matter accumulation by *P. minor* even from early date of sowing. This may be due to the reason that up to Dec. 5 majority of seeds of *P. minor* showed germination and these emerged seedlings were uprooted at the time of sowing. As a result of this significantly higher wheat grain yields were recorded in early sown crop (Oct. 25) as compared to crop sown on Nov. 15 and Dec. 5 during both the years. Higher yields in early sown crop may be due to less growth and development of *P. minor* and availability of more time with the crop to complete its life cycle. Crop sown on Dec. 5 produce significantly less grain yield as compared to other two dates of sowing which may be due to enhanced physiological maturity of the late sown crop. Mahajan and Brar (2001) reported 26.9% reduction in dry matter accumulation by *P minor* and 21.6% higher grain yield of 25th Oct. sown crop over 10th Nov. sown crop.

Table 2 Dry matter of *P. minor* and grain yield of wheat as influenced by dates of sowing

Date of sowing	*Dry matter of P. minor (q ha^{-1})*		*Grain yield (q ha^{-1})*	
	2000-01	*2001-02*	*2000-01*	*2001-02*
Oct. 25	2.1 (4.5)	1.6 (2.9)	42.9	51.9
Nov. 15	2.5 (6.1)	1.8 (3.2)	38.8	46.4
Dec. 5	1.2 (0.8)	1.3 (2.6)	32.3	40.5
LSD (p=0.05)	0.31	0.16	3.61	4.2

(Walia and Brar, 2004)

PLANTING PATTERN

Planting pattern should be adopted in such a manner that minimum space should be left at the disposal of weeds so that they can not grow in a normal phase. This objective can be achieved with the adoption of either cross sowing or closer sowing techniques in order to encourage maximum occupation of land by the crop plants.

Closely spaced crop (15 cm row to row) provided good smothering potential on growth and development of *P. minor* as is indicated by significant less dry matter accumulation by *P. minor* as compared to the crop sown at 22.5 cm spacing (Table 3). These findings were reported by Walia and Brar (2004) on the basis of experiments conducted from 1999-2000 to 2002-2003. Less dry matter in closer sown crop may be due to less availability of space for the growth and development of *P. minor* and secondly due to well distribution of wheat seedlings per unit areas, it exhibited more smothering effect. During all the years of study significantly higher grain yield was recorded by the crop sown at 15 cm spacings as compared to the crop sown at 22.5 cm spacings. Similar findings were also reported by Brar and Singh (1997) and Mahajan *et al* (2001).

Table 3 Effect of row to row spacings on dry matter accumulation by *P. minor* and grain yield of wheat

Treatments (spacings)	*Dry matter accumulation by P. minor (q/ha)*				*Mean*
	1999-2K	*2K-01*	*01-02*	*02-03*	
22.5 cm	15.6	6.66	3.5	30.4	13.99
15.0 cm	10.6	4.53	3.3	25.6	11.1
LSD (P=0.05)	1.55	0.66	0.13	4.1	2.0
		Grain yield (q/ha)			
22.5 cm	32.9	43.6	50.9	39.2	41.03
15.0 cm	37.5	47.0	48.4	46.2	45.40
LSD (p=0.05)	2.9	2.80	1.7	5.34	3.1

(Walia and Brar, 2004)

Singh and Singh (1996) reported a significant reduction in weed intensity in cross sowing technique as compared to all other adopted techniques and grain yield was found to be significantly higher in this treatment (Table 4). Second best treatment was sowing wheat at 15.0 cm row to row spacing. Broadcasting method was found significantly inferior to line and cross sowing techniques.

Table 4 Weed intensity and wheat grain yield as influenced by different planting techniques

Treatments	*Weed population /m²90 DAS*	*Weed dryweight g/m² 90 DAS*	*Grain yield (q/ha)*	*Net profit (Rs/ha)*
Broadcasting	172	106	24.90	4656
Cross sowing(22.5x22.5cm)	86	56	31.31	6664
Closer sowing (15 cm)	104	66	28.51	5685
Normal sowing (22.5 cm)	123	77	26.55	5160
LSD (p=0.05)	8.0	6.3	0.87	119

(Singh and Singh, 1996)

Similarly, Jena and Behera (1998) also reported significant reduction in weed population and weed dry matter as well as significant improvement in yield and yield attributes of wheat in closer sowing (15.0 cm) treatment as compared to 23 cm row to row spaced crop (Table 5).

Table 5 Weed intensity, yield and yield attributes of wheat as influenced by planting patterns.

Treatments	*Weed population at harvest (plants/m²)*	*Weed dry weight at harvest (g/ m²)*	*No.of spikes /m row length*	*1000 grain weight (g)*	*Grain yield (q/ha)*
Closer sowing (15.0 cm)	15.25	42.33	86.50	39.81	3.45
Normal sowing (23.0 cm)	17.58	53.00	58.70	41.28	3.04
LSD (p=0.05)	1.84	2.16	3.40	0.49	0.07

(Jena and Behera, 1998)

SEED RATE/CROP DENSITY

The objective of increasing seed rate particularly of wheat is to attain more number of crop plants/unit area in order to boost initial smothering potential of wheat plants on weeds. However, wheat yield is not directly correlated with seed rate beyond a particular level, but yield tends to increase at higher seed rates which may be due to production of less dry matter by *P. minor* in densely planted crop. Walia & Brar (2004) reported significant reduction in final dry matter accumulation by *P. minor* by the crop sown with 150 kg/ha seed rate as compared to 100 kg/ha (recommended) (Table 6). Consequently there was significant improvement in grain yield by increasing seed rate to 150 per cent. These findings holds good from 1999-2000 to 2002-2003 crop season.

Table 6Dry matter of *P. minor* and grain yield of wheat as influenced by plant density

Treatment	*Dry matter of P. minor (q/ha)*				
	1999-2000	*2000-2001*	*2001-2002*	*2002-2003*	*Mean*
Seed rates					
100 kg/ha	15.1	7.21	4.1	31.1	14.4
125 kg/ha	13.4	5.53	3.3	28.5	12.7
150 kg/ha	10.8	4.04	2.9	24.3	10.5
LSD (p=0.05)	1.89	0.81	1.06	4.6	2.1
Grain yield (q/ha)					
100 kg/ha	32.8	42.7	46.1	40.6	40.55
125 kg/ha	35.0	46.1	49.5	42.5	43.30
150 kg/ha	37.8	47.0	53.4	44.9	45.80
LSD (p=0.05)	3.5	3.43	4.82	2.6	2.54

(Walia and Brar, 2004)

Jena and Behera (1998) reported significant reduction in weed population and weed dry matter with successive increase in seed rate from 100 to 125 to 150 kg/ha (Table 7). A significant increase in grain yield was also observed with successive increment in seed rates from 100 to 150 kg/ha.

Table 7 Influence of seed rates on weed intensity, yield and yield attributes of wheat.

Treatments	*Weed density at harvest (plants/m²)*	*Weed dry wt at harvest (g/m²)*	*No. of spikes /m row length*	*1000 grain weight (g)*	*Grain yield (t/ha)*
Seed rate (kg/ha)					
100	22.20	53.94	62.40	41.84	2.81
125	17.15	46.00	72.30	40.62	3.24
150	9.89	43.06	83.10	39.17	3.68
CD (p=0.05)	2.42	2.64	4.20	0.61	0.09

(Jena and Behera, 1998)

METHOD OF FERTILIZER APPLICATION

To improve competitive ability of wheat for applied fertilizers particularly nitrogen, the placement should be close (not very near) to the seed or crop plants so that maximum quantity of applied fertilizers should be at the disposal of the crop plants and minimum for weed plants. So, initial growth of crop plants will be more and crop will smother weed plants.

Experimental results of the trial conducted by Walia & Kaur (2004) regarding method of nitrogen application to wheat indicated that placement of nitrogen (near the crop row) either ½ dose or full dose helped to reduce intensity of *P. minor* and consequently grain yields were improved (Table 8). There was significant improvement in grain yield by the crop receiving ½ dose of nitrogen with side placement method and remaining ½ with broadcast which may be due to significant reduction in dry matter production by weeds due to its chances of more availability to crop plants as compared to weeds.

Table 8 Effect of methods of nitrogen application on dry matter of *P. minor* and grain yield of wheat

Treatments (methods of application)	*Dry matter of weeds (q/ha)*		*Grain yield(q/ha)*		
	1999-2000	*2000-01*	*1999-2000*	*2000-01*	*Mean*
Full placement	27.4	26.2	49.5	38.0	43.8
Full broadcast	29.6	27.1	47.2	37.2	42.2
½ side placement + ½ broadcast	26.2	20.8	54.3	41.8	48.1
½ broadcast + ½ broadcast	26.2	22.3	51.2	39.8	45.5
LSD (p=0.05)	1.27	1.6	2.1	1.8	

(Walia and Kaur, 2004)

TILLAGE SYSTEMS

The interactive effect of tillage systems on the growth and development of *P. minor* have divergent views. Many scientists have reported decrease in intensity of *P. minor* in zero till technology, however, few have reported the reverse findings. Dixit *et al* (2003) reported 18.8 per cent decrease in weed count in zero till system which may be due to better growth of crop as indicated by 3.19 per cent increase in effective tillers in this technology (Table 9). On an average there was 14.76 per cent increase in grain yield of wheat in zero till wheat as compared to conventional tillage sown crop.

Table 9 Effect of tillage operation on wheat crop production.

Treatment	*No-till method*	*Conventional method*	*Increase (+) Decrease (-)*
*Germination count	39.76	38.50	+ 3.27
*Effective tiller count	85.39	82.75	+ 3.19
Weed count (plant/sq m)	7.51	9.25	- 18.81
Grain yield (q/ha)	43.75	38.12	+14.76
Straw yield (q/ha)	70.06	61.49	+ 13.93

* Plants/m row length
(Dixit *et al*, 2003)

Similarly, Yaduraju and Mishra (2002) reported significantly less population of *P. minor* in zero till wheat as compared to conventional tillage wheat crop (Table 10). Consequently higher yields as well as net returns were reported in zero till wheat.

Table 10. Grain yield and population of *P. minor* as influenced by tillage systems

Tillage systems	*P. minor population no/m²*		*Grain yield (kg/ha)*	*Net income (Rs/ha)*
	25 DAS	*90 DAS*		
Zero	9.82	6.61	5000	13660
Conventional	15.16	12.48	4300	11350
LSD (p=0.05)	5.30	3.62	-	-

(Yaduraju and Mishra, 2002)

The population of *P. minor* have also been reported to decrease under inverted tillage operation done with mould board plough before wheat sowing as indicated by Chahal *et al* 2003 (Table 11). They reported significant reduction in dry matter accumulation by *P. minor* in inverted tillage plots as compared to conventional till sown wheat. Also crop sown after giving inverted (deep) tillage resulted in significant increase in grain yield of wheat along with leaf area index and light interception (%) as compared to conventional till sown wheat crop.

Table 11A Influence of tillage systems on dry matter accumulation by *P. minor* and grain yield of wheat

Treatments (Tillage methods)	*Dry matter of P.minor(q ha⁻¹)*		*Grain yield(q ha⁻¹)*	
	1999-00	*2000-01*	*1999-00*	*2000-01*
Zero	30.3	20.5	31.9	38.4
Conventional	22.4	18.2	37.0	40.0
Inverted	16.6	14.0	39.5	43.6
LSD (p=0.05)	4.3	3.13	3.7	2.1

Table 11B Influence of tillage systems on LAI and Light interception (%) of wheat

Treatments (Tillage methods)	*LAI120 DAS*		*Light interception (%)120 DAS*	
	1999-00	*2000-01*	*1999-00*	*2000-01*
Zero	2.88	3.10	92.0	92.1
Conventional	3.09	3.30	91.4	91.0
Inverted	3.51	3.68	94.1	94.0
LSD (p=0.05)	0.38	0.34	0.82	1.07

(Chahal et al, 2003)

WHEAT VARIETIES

Due to differential growing habits of different wheat cultivars, their smothering potential on weeds particularly *P. minor* would be variable and these will decide the fate of *P. minor* growth. Different wheat varieties were raised under weedy and weed free conditions in order to find out their smothering potential on the weeds (Walia and Brar, 2004). From the grain yield values of an individual variety grown under weedy and weed free conditions, the percent reduction in grain yield due to competition by *P. minor* over the weed free situations was worked out. Among the different wheat varieties, on an average of 3 years minimum dry matter of *P. minor (6.4 q ha⁻¹)* was recorded in PBW-343 and highest of 13.9 q ha⁻¹ in WH 846 indicating thereby more smothering potential of PBW-343 variety of wheat. Minimum percent reduction in grain yield due to *P. minor* was observed in PBW 343 (7.8%) and PBW 373 (7.5%) varieties of wheat. These varieties were followed by WH 283 and HD 2687. Other wheat varieties namely WH 896 and WL 711 were found to be poor competitor which is indicated by more dry matter accumulation and highest per cent reduction in grain yield due to competition by *P. minor*. Similarly, Brar and Singh (1997) reported that the bread wheat cultivars i.e. WH 542 and HD 2329 gave more suppression of *P. minor* than durum wheat cultivar i.e. PBW 34 resulting in 23.4 and 19.1 per cent higher grain yields.

Table 12 Competitive ability of wheat varieties with *Phalaris minor*

Wheat varieties	*Dry matter of P.minor in untreated crop (q ha⁻¹)*				*% reduction in yield over weed free*
	2001-02	*2002-03*	*2003-04*	*Mean*	
PBW 343	9.3	4.0	5.9	6.4	7.8
PBW 373	14.7	5.2	5.7	8.5	7.5
WH 283	10.5	3.8	5.7	6.6	11.4
HD 2687	16.5	6.9	9.8	11.1	11.5
C 306	19.7	6.6	6.6	10.9	14.8
WL 711	18.1	6.1	7.3	10.5	20.2
WH 896	18.8	12.8	10.3	13.9	21.0
LSD (p=0.05)	3.71	2.94	2.3	3.01	-

(Walia and Brar, 2004)

SOIL MOISTURE

In general growth and development of *P. minor* is directly related with soil moisture content or moisture holding capacity of the field. Data pertaining to number of panicle and dry matter accumulation by *P. minor* with respect to variable depth of first and second irrigation are presented in Table 13 (Kumar, 1998). Four combination of 2 depth of irrigation (7.0 and 10.5 cm) of 1st and 2nd irrigation were kept in main plots. Minimum number of panicles and dry matter of *P. minor* were recorded in the crop receiving both i.e. 1st and 2nd light irrigations (7.0 cm) and these values were significantly less as compared to all other irrigation treatments. Crop receiving both heavy irrigations recorded significantly higher panicle number as well as dry matter of *P. minor* as compared to other treatments indicating thereby that growth and development of *P. minor* is directly related with soil moisture.

Table 13 Influence of depth of irrigation on intensity of *P. minor* in wheat

Treatments (irrigation)	*Depth of irrigation (cm)*		*Panicles of P. minor (No. m⁻²)*		*Final dry matterAccumulation of P. minor (q ha⁻¹)*	
	Ist	*IInd*	*1995-96*	*1996-97*	*1995-96*	*1997-97*
$I_{7.0+7.0}$	7.0	7.0	6.21(61)	6.40(62)	2.12(7.25)	2.13(7.49)
$I_{7.0+10.5}$	7.0	10.5	7.43(75)	7.49(76)	2.55(9.13)	2.54(9.28)
$I_{10.5+7.0}$	10.5	7.0	7.31(74)	7.38(75)	2.50(8.97)	2.52(9.16)
$I_{10.5+10.5}$	10.5	10.5	8.04(83)	8.34(88)	2.95(11.39)	2.97(11.42)
LSD (p=0.05)			0.51	0.48	0.31	0.29

(Kumar, 1998)

On the other hand weeds are very hardy in nature and can survive even with low moisture as compared to crop plants. Naik *et al* (1997) reported significantly more biomass of weeds in what crop given two irrigations as compared to crop given six irrigations (Table 14). Due to better growth and development of wheat with 4 or 6 irrigations, grain yields were found to be significantly higher as compared to two irrigations only.

Table 14. Weed biomass and grain yield of wheat as influenced by different irrigation levels

Treatments	*Weed biomass (kg/ha)*		*Pooled Grain yield (q/ha)*
	1989-90	*1990-91*	
Moisture regime			
M_1-2 irrigations	10.85(11.72)	7.62(57.56)	33.24
M_2-4 irrigations	9.91(97.71)	6.05(36.10)	38.37
M_3-6 irrigations	6.40(40.64)	5.43(28.98)	37.11
LSD (p = 0.05)	3.01	0.13	2.09

(Naik *et al*, 1997)

STALE SEED BED / DAB SYSTEM

This method is very effective for reducing weed population in wheat but the only drawback is that wheat sowing gets delayed. Under this method double pre-sowing irrigation is given so that the weed seeds gets optimum time and conditions for their emergence. The emerged weeds are either uprooted or killed with the spray of any contact herbicide before wheat sowing. Second option is that after seed bed preparation, sowing is delayed by 10-12 days and during this period plankings may be given to uproot emerging seedlings and to create soil mulch on the top soil surface. Then place the wheat seed in the moist zone. The objective of this technique is to reduce seed bank status of the field.

CONCLUSIONS

Crop rotation was found to be best cultural technique to control weed infestations particularly *P. minor* from wheat crop. Among the variable crop rotations, adoption of rice-berseem or rice-potato based rotations helped to eliminate seed bank of *P. minor* completely within a period of three years. Early sowing of wheat (Oct. 25) resulted in significant reduction in dry matter accumulation by *P. minor* as compared to the crop sown on Nov. 15 (normal) and consequently early sown crop yielded significantly higher than normal sown crop. Among the planting patterns, crop sown at 15 cm row to row spacings resulted in significant reduction in dry matter accumulation by *P. minor* and consequently there was significant increase (7.4 to 13.5 per cent) in grain yield of wheat as compared to the crop sown at 22.5 cm spacings (seed rate constant). Also with the increase in seed rate by 50% of the recommended (100 kg ha^{-1}) there was significant reduction in dry matter production by *P. minor*. Placement of fertilizers helped to decrease growth and development of *P. minor* and grain yields ere improved. Among the tried tillage practices, wheat sown after giving deep tillage with disc plough resulted in significant reduction in dry matter accumulation by *P. minor*. Among wheat cultivars, PBW 343 was found to be the more suppressing cultivars for *P. minor*. It was also observed that growth and development of *P. minor* was directly related with soil moisture.

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Sustainability Issues Related to Weed Management in Direct Seeded Rice – Wheat System in the Indo – Gangetic Plains

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Indo–Gangetic plains (IGP) are considered as most fertile plains and livelihood of millions of people depend on the agricultural richness of these lands. In past western part of IGP (Punjab and Western U.P.) was an important wheat producing area and the eastern part (East U.P., Bihar, West Bengal) was basically a rice producing area. The increasing food grains demand and developments in irrigation infrastructure, availability of fertilizers and high yielding crop varieties lead to extension of rice cultivation in western and wheat in the eastern IGP making the whole IGP an important rice–wheat area. In irrigated areas the double cropping is a common practice and the rice – wheat area is estimated to be around 10 m ha (Paroda *et al*, 1994; Gupta *et al*, 2003). Increased area of the cropping system and its productivity made the country self sufficient and surplus in food grain production. The food security of the country is highly dependent on the efficiency of these two crops in the system. The intensive cultivation has resulted into negative nutrient balance, continuous decrease in the input use efficiency, a decline in the water table, production and productivity of the rice and wheat and the total food grains production particularly in high productivity areas are pleateauing. Therefore, newer technological interventions that may enhance over all system productivity are the requirements of the day.

One major cause of low productivity of rice is delayed planting due to various constraints like labour, water and power source for transplanting of rice. Alternate technologies of rice establishment have been developed and the sustainability issues related to improvement in water use efficiency, soil structure and weed management against a background of increasing labour scarcity for agriculture may be answered through the alternate rice establishment methods. As in many part of South East Asia where there are water and labour shortage for agriculture, in India there is increased interest in direct seeding.

The wheat yields have been oscillating around 2.7 t ha^{-1}. The area has nearly stabilized and the production has been also become stagnant which is of major concern. Delayed wheat sowing is a major problem in most rice–wheat areas, except Punjab (Fusisaka *et al*, 1994). In Punjab rice is transplanted in late May and June and wheat sown in November, the best time for higher productivity. In eastern part of IGP planting gets delayed and most of the rice in U.P., plains of Uttaranchal and Bihar is transplanted in July and it continues till mid or even late August, which in turn results into delayed wheat sowing and nearly more than half of wheat area is sown in December (Hobbs *et al.*, 1991).

Rice

Rice in the Indo-Gangetic plains are managed by two principal culture methods – Transplanting and Direct seeding. Transplanting rice seedlings on puddled soils is wide spread in the irrigated ecosystems. Puddling, a process of wet tillage of soil in excessive water, requires high amount of water, breaks the soil aggregates, reduces water percolation rate and suppresses weeds. Puddled soil becomes hard after drying leading to development of cracks and thereafter water requirement increases many folds due to deep percolation through cracks. Puddling also results into poor soil physical conditions for establishing and raising succeeding crops (Tripahti *et al.*, 2003). Shortage and rising cost of labour and excess water use in puddling are the constraints to look for alternatives to transplanting. Possibilities of establishing rice without puddling have been explored and direct seeding is an alternative, which has already largely replaced transplanted irrigated rice in South East Asia particularly Philippines, Malaysia and Thailand (Pandey and Velasco, 2002). In direct seeded rice culture weeds are the biggest constraints as all type of weeds like grasses, non-grasses and sedges emerge simultaneously at high density with rice seedlings because of absence of flooding during early stages.

The farmers growing direct seeded rice are however likely to encounter greater problems related to weed management. The transition to direct seeding of rice can therefore only be successful if accompanied by effective weed management practice.

Weed species association

Weed flora in direct seeded rice consists of various kind of grasses, non-grasses (broad leaf) and sedges. The community composition of these weeds varies according to crop establishment methods, cultural methods, crop rotation, water and soil management, location, weed control measures, climatic conditions and the inherent weed flora in the area.

Echinochloa colona and *Echinochloa crus-galli* are the most serious weeds affecting direct seeded rice. *E. colona* requires less moisture than *E. crus-galli*. The density of these weeds in direct seeded rice will depend upon moisture conditions in the field. *Cyperus rotundus* and *Cynodon dactylon* may be major problem in upland conditions particularly in poorly managed fields. The other weeds of major concern in direct seeded rice are *Paspalum* spp., *Ischaemum rugosum, Leptochloa chinensis, Digitaria sanguinalis, Dactyloctenium aegyptium, Commelina* spp., *Caesulia axillaris, Cyperus iria, Fimbristylis miliacea* and *Cyperus difformis.*

Losses and critical duration of weed-crop competition

Weeds in direct seeded rice adversely affect yield, quality and cost of production as a result of competition for various growth factors. The extent of loss varies depending upon cultural methods, rice cultivars, weed species associated, their density and duration of competition. The yield loss may vary from 10 % to complete failure of the crop depending upon situation. In general, the potential yield loss due to weeds is less in wet seeded rice than in dry seeded rice (Fig. 1). In a survey of upland rice producing countries covering 80% of the total production area weeds were the most widely reported biological constraint to yields (Johnson, 1996). In West Africa, yields of upland rice with farmers' weed control were 44% lower than on weeded researcher plots. Losses due to uncontrolled weeds in India were up to 90% and in both lowland and upland systems in Africa losses were within the range 28-100%. Losses can be sever in direct seeded rice as the rice and weed seedlings are at similar growth stages. The competitive advantage of transplanted rice is due to the size difference between 4-5 week old seedlings (20-30 cm tall) and the weeds that emerge later and immediate flooding after transplanting limit the weed establishment. This results into less yield losses due to weed competition in transplanted rice than in direct seeded rice. In Asia yield losses due to uncontrolled weeds in direct seeded lowland rice was reported to be between 45-75% and for transplanted lowland rice approximately 50%. Every farmer adopts some weed control measure and therefore losses on farmers' fields are likely to be considerably less. In order to formulate an effective and economical weed management system for direct seeded rice, it is essential to establish critical duration of weed- crop competition and a limit for an acceptable presence of weeds.

The yield decrease in direct seeded rice increases with the increase in competition duration during initial period. But at later stages or after a certain stage the rate of decrease may not change due to the maximum damage already occurred. Infestation of *Echinochloa colona, Dactyloctenium aegyptium, Cyperus iria, Cyperus rotundus* and *Trianthema monogyna* with a total density of 381 m^{-2} and dry matter production

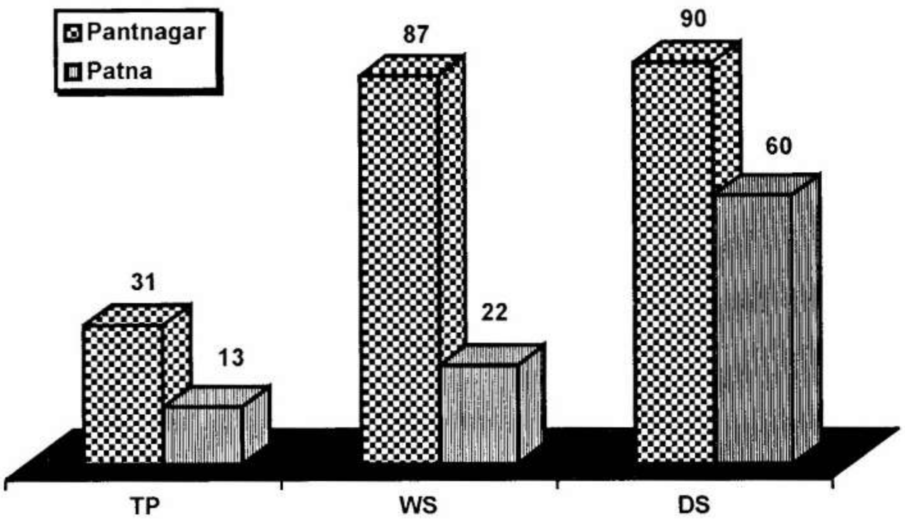

Fig.1 : Potential yield loss (%) due to weeds in rice cultures

of 531.2 g m^{-2} resulted into a grain yield loss of direct seeded rice by more than 96 % (Singh *et al* 1987). The higher rate of dry matter production by the weeds was during 15-30 days after seeding. The rate of dry matter production by the weeds varies according to their emergence and life cycle. *Trianthema monogyna* was found to grow faster than other weed species during early stages due to shorter life cycle and contributed much more to the competition with rice crop as compared to other weed species such as *Echinochloa colona* during first 4-5 weeks. The effective period of competition occurred in two phases; i.e. between 15 and 30 days, and 45 and 60 days after seeding. The competition in direct seeded rice beyond 15 days after seeding may cause significant reduction in the grain yield. However, competition for the first 15 days only may not have much adverse effect on the crop.

Weed management in direct seeded rice may be accomplished by various practices including cultural, mechanical and herbicide use.Cultivation of rice fields prior to seeding, especially during summer months, help in reducing the perennial weeds like *Cyperus rotundus* and *Cynodon dactylon*. A properly prepared field with good levelling provides a favourable medium for optimum crop establishment and plant growth. It also helps in uniform emergence of weeds and if majority of weeds emerge at one time, the efficacy of herbicides used in such fields is increased.

It may be possible to limit weeds in direct seeded rice by adopting stale seed bed technique where seed bed may be prepared at least 7-10 days in advance of seeding with ensured moisture either by irrigation or rain to stimulate germination and emergence of weeds and destroying them either by shallow cultivation or use of herbicides such as paraquat or glyphosate. Use of herbicides may have advantage of destroying weeds without disturbing the soil reducing possibilities of bringing new seeds to the upper soil surface. The rice should be sown with a minimum soil disturbance after destroying the emerged weeds. The use of zero-till-ferti-seed drills may be very useful to serve this purpose. A reduction of 59% in the density of *Echinochloa colona* and 78% reduction in the fresh weed weight was recorded due to stale seed bed technique in Philippines (Moody, 1982). The research work on this aspect is limited.

The competition offered by a crop can affect the degree of weed control achieved by herbicides. Crop density changes the quantum and quality of environment available for the growth of weeds in association with the corp. In low crop plant populations resulting from either low seed rate, faulty germination, uneven seeding, or damage to crop seedlings, weed growth is profuse leading to intense weed-crop competition. Increasing seed rates for direct seeded rice has little influence on weed suppression probably because of the intense weed pressures (Moody, 1982). The rice varieties with weed suppressing characters is an important aspect in managing weeds in direct seeded rice. The tall fast growing traditional rice varieties were more competitive with weeds than the dwarf high yielding varieties (Kawano *et al.*, 1974).

The effect of soil moisture and water depth in rice on weed emergence and suppression has long been recognized (De Datta, 1988). Weed density due to standing water in early stages may be reduced but once the weeds are established their stand is not affected. The response of weed species to soil moisture levels and depth of standing water is variable (Johnson *et al.,* 2004). In deep water *Manochoria vaginalis* was pre-dominant where as in saturated soil (with standing water) *Echinochloa* spp. and *Fimbristylis miliacea* have been found to be dominant. Herbicide efficacy is also affected by soil moisture. Pendimethain when applied as pre-emergence in dry seeded rice performs effectively when enough soil moisture is available in upper surface.

Manual weedings

Manual weeding is the most prevalent practice of weed control in direct seeded rice in India. It has been described as slow and laborious, less effective in some occasions because of escape or regeneration of perennial weeds, many flushes of weeds and impractical during adverse weather conditions. Repeated weeding is generally required. Labour for timely weeding is expensive and often unavailable. Delayed weeding results into loss of crop and increase in cost. The frequency of manual weeding will depend upon the weed species, their density and emergence pattern. Depending on these factors normally 2-3 manual weedings at appropriate stages have been found to be effective in providing desired level of weed control in direct seeded rice. The first weeding should be done at 20-25 days stage in dry seeded rice and at 25-30 days stage in wet weeded rice followed by second weeding at 45-50 days stage. The further weedings will depend upon the actual field condition. Under high rain fall situations three weedings at 15, 30 and 60 days after seeding produced grain yields at par with the crop kept free from weeds through out the season.

Herbicides

The herbicides tested and available for direct seeded rice have narrow weed control spectrum and low efficacy when used alone and do not provide season long weed control. A list of herbicides widely tested in India are given in Table 1.

Table 1. Herbicides evaluated for direct seeded rice

Anilofos	Fenoxaprop
Butachlor	Imazosulfuron
Bentazon	Oxadiazon
Cinmethylin	Oxyfluorfen
Clefoxydim	Pendimethalin
Cinosulfuron	Pretilachlor
Cyhalofop	Propanil
Dithiopyr	Quinclorac
Ethoxy sulfuron	Thiobencarb
Almix	2, 4 –D

Pendimethalin, thiobencarb and anilofos have been found more effective and safe for direct seeded rice. Pendemithalin at 1.0 kg ha^{-1} as pre-emergence has been quite effective and economical for dry seeded rice (Jayadeva and Bhairappanavar, 2002 and Singh *et al.*, 2002). But good surface moisture is essential for its better efficacy. Anilofos at 400 g ha^{-1} and thiobencarb at 1.0 kg ha^{-1} as early post-emergence have proved better with more safety in wet seeded rice as compared to others (Bindra *et al.*, 2002). Butachlor though provides good control of grasses in wet seeded rice but its has been phytotoxic to rice seedlings without safener (Bindra *et al.*, 2002). Its efficacy is quite low under dry seeded rice culture. Cyhalofop-butyl at 100 g ha^{-1} as post-emergence has also been found very effective against most of the annual grasses in wet seeded rice (Angiras and Attri, 2002). Use of 2, 4-D at 500 g ha^{-1} at 30-35 days stage provides effective control of non-grasses and sedges in wet as well as dry seeded rice. Ethoxy-sulfuron has been found to provide effective control of broadleaf weeds and some of the sedges and found to be compatible with anilofos which widens weed control spectrum (Bindra *et al.*, 2002). Using these herbicides and manual weeding in direct seeded crop, integrated weed management systems have been developed (Johnson *et al*, 2003).

Integrated management

Integrated weed management (IWM) is an approach in which principles, practices, methods, materials and strategies are choosen to control weeds while minimizing undesirable results. It includes use of multiple pest-resistant, high yielding, well adapted varieties that resist weed competition, precision placement of fertilizers to given the crop a differential advantage in competiting with weeds, timing the fertilizer application for maximum stimulation of the crop and minimum stimulation of the weed population, pre-planting seed bed tillage, effective seed bed preparation, seeding methods that enhance crop growth and minimize weed growth, optimum plant populations per hectare, including close spacing in the rows and close spacing between the rows to optimize crop growth and minimize weed growth, use of crops that form a canopy for shading as early in the growth season as possible to discourage weed growth, use of judicious irrigation practices, timely and appropriate cultivations, sound crop rotations, crop diversifications, field sanitations, use of clean crop seeds, harvesting methods that do not spread weed seeds, use of biological agents-insects and pathogens and effective chemical methods.

The weed management components described above, each has its own merits and disadvantages. Therefore, a combination of two or more weeding methods must be evaluated for widening weed control spectrum and efficacy in order to achieve an effective and economical weed management in direct seeded rice. The sequential application of pre-emergence herbicides like pendimethalin in dry seeded rice or early post-emergence application of anilofos/thiobencarb for the control of annual grasses in wet seeded rice and post-emergence application of 2, 4-D against sedges and non-grassy weeds in wet as well as dry seeded rice may be a better option than the use of one herbicide. The post-mergence herbicides may be substituted with manual weeding which may have added advantage of controlling escapes and reducing herbicide load. This will also help in managing herbicide resistant biotypes.

Wheat

With the introduction of herbicides for control of weeds the effect of tillage as an agricultural practice for weed control is being re-evaluated. Reduced tillage has numerous advantages as it protects soil moisture, prevents soil erosion by the mulch created by crop residues and maintains soil structure. Similarly, no tillage is an extreme form of reduced tillage or conservation tillage where the crop is planted in unprepared seed bed by opening a narrow slit of only sufficient width and depth to obtain proper seed coverage. It is well documented that the density of *Phalaris minor* in zero tilled wheat after transplanted rice is reduced to a great extent when compared with conventionally tilled wheat (Table 2). The population of *Coronopus didymus* was high in zerotilled wheat while it was absent in conventionally tilled wheat.

Table 2 Weed density in crop establishment methods of wheat after rice

Weeds	*Density (No. m⁻²) 30 DAS*	
	Zero tillage wheat	*Conventional tillage wheat*
Phalaris minor	24	113
Chenopodium album	2	17
Melilotus spp.	9	26
Coronopus didymus	37	0
Others	1	3

Rice establishment methods have been found to affect the weed flora in the following wheat crop under various establishment methods in rice-wheat system. The density of *Phalaris minor, Chenopodium album, Polypogon monspeliensis* and other weed species was observed to be higher in wheat grown by conventional tillage or zero tillage after direct seeded rice than that of transplanted rice (Table 3).

Table 3 Effect of crop establishment methods on weeds in Rice-wheat system at 30 DAS

Crop establishment	*Phalaris minor*			*Chenopodium album*			*Polypogon monspeliensis*			*Other species*		
method	*CTW*	*ZTW*	*Mean*	*CTW*	*ZTW*	*Mean*	*CTW*	*ZTW*	*Mean*	*CTW*	*ZTW*	*Mean*
DSR	143	22	82.5	69	21	45.0	30	10	20.0	27	16	21.5
TPR	89	14	51.5	46	6	26.0	9	2	5.5	13	7	10.0
Mean	116.0	18.0		57.5	13.5		19.5	6.0		20.0	11.5	

DSR= direct seeded rice, TPR= transplanted rice, CTW= conventionally tilled wheat
ZTW= zero tilled wheat

In another field study more population of *Rumex acetosella* was recorded in wheat after direct seeded rice, irrespective of wheat establishment methods (Table 4). Similar observations are also made at the farmers' field (Plate 1). *R. acetosella* is considered to be more competitive with wheat crop than other weed species.

Table 4 Effect of crop establishment methods on density of *Phalaris minor* and *Rumex acetosella* in wheat after rice at 30 days stage

Establishment method	*Phalaris minor (No. m⁻²)*			*Rumex acetosella (No. m⁻²)*		
	CTW	*ZTW*	*Mean*	*CTW*	*ZTW*	*Mean*
Direct seeded rice	117	16	66.5	0.0	13.0	6.5
Transplanted rice	76	7	41.5	0.0	8.0	4.0

The above observations are indicative that in long run there may be shift in weed flora in direct seeded rice-wheat system and it needs intensive research to monitor the changes and find solutions for the new emerging weed species.

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Weed Management and its Role in Production Technology

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Meeting the challenge in crop protection today is more demanding than any other time in the history of production technology. On the one hand, there is a continuing need for weed control technology to ensure a reliable, affordable and adequate food supply to feed the increasing world population. On the other hand, herbicides are relatively cost effective weed control technology available; there is a public resistance to their use. This dilemma has brought society to a crossroads requiring decisions that could seriously affect the ability of farmers to meet worldwide food demands. The solution will require both short and long term strategies. In the short term, it is imperative that the Government, Universities and agrochemicals industry work together to educate farmers, regulators, the food industry and the farmers about the positive steps being taken to ensure responsible pesticide use. Open dialogue and interaction with public and environmental groups are needed to better understand their issues and demonstrate a sincere effort in responding to legitimate concerns. In addition, better management systems must be developed which allow the farmer to use the right weed control systems at the right time and at the right place. We must learn to recognize the value of all weed management technologies – chemical, cultural, genetic, biological, etc. in an integrated systems approach.

In longer term, new approaches are needed to find better, safer crops protection chemicals, ideal microbial products and improved varieties to resist weeds. Also, the promise of biotechnology must be realized to yield novel weed competitive crop varieties and microbial products to complement herbicides and allow for the development of more balanced weed management programmes.

In considering each of these strategies, it is important to recognize that about 20 per cent of all pesticides are sold in developing countries. The requirements in these countries needs special consideration since applicator training and protective equipment are often not readily available and the new technology cannot be adopted or afforded on the same time frame as in the developed countries. Nevertheless, it would be a serious mistake to assume that the requirements for product safety or the desire to protect the environment and ensure a safe food supply are different.

Herbicides

With the discovery of 2,4-D made available after the World War – II, the agrochemicals were quickly adopted by the farmers. The embryonic agrochemical industry responded vigorously to this demand with a more diverse type of herbicides. The convergence of chemical crop protection technology with other emerging new technologies such as introduction of high yielding varieties, synthetic fertilizers, irrigation and mechanization resulted in a powerful new agricultural production system unprecedented in the history of mankind. Pesticides in general and herbicides in particular made a very significant contribution to agriculture and revolutionized farming practices by increasing labour use efficiency, crop yields and improving the food quality.

Risk involved with the benefits of agrochemicals

Early herbicide research primarily focused on biological efficacy and little was known about the potential long term adverse effects on the environment. Rachel Carson's book, "Silent Spring", published in 1962, brought these issues sharply into focus. While these concerns have waxed and waned over the ensuing two decades, the 1980s saw a renewed intensity about the concerns over the use of pesticides. The general fear of chemicals by the public combined with the environmental movement that is sweeping many part of the world has led to accusations by various anti-pesticide groups that pesticides are a major threat to public health and the environment. This has led to the recent banning of some pesticides. Several developed countries are planning to have more stringent and costly regulations. Denmark, Sweden and Netherlands are planning to reduce the pesticide by 35 to 50 per cent during this decade.

Future Requirements

By the year 2050, the total world population is projected to increase to 11 billion, more than twice today's population, indicating that we will have to produce more than twice as much food as is currently being produced. This is going to increase the pressure on land used for food production. As the agriculture intensifies, so will man's battle with crop pests. Effective pest control and to be specific, weed management technology will become more important than it is today. Cultural, chemical, genetic and biological control methods will all contribute in this battle.

It is believed that just as the herbicides of the past have brought us to where we are today, only those of the future can take us where we want to go. Although, there are many ways we can improve the safety and effectiveness of existing products, concerns such as persistence, leach-ability or adverse toxicology can only be overcome through product replacement. New product discovery research by industry is going to be the most important keys in meeting our challenge to crop protection. In future, the new products should have following qualities :

1. Cost-effective, flexible, reliable and convenient to use.
2. Safe to the crop, environment, user and consumer.
3. Low use rate to minimize the amount introduced into the environment.
4. Leaves no harmful residues.
5. Persistence in the crop and soil tailored to desired effects.
6. High specificity to target organisms.
7. No off-target effects.
8. Easily integrated with best management practices.
9. Does not lead to weed resistance?

To have all these factors in a molecule would be an unrealistic goal. For example, in the area of weed control, there are already examples of what the future can hold. Low use rate, broad spectrum products, such as the sulfonylureas, now exist. Their manufacturing process frequently generates as little as 5 per cent of the by-products as compared to many conventional herbicides and farmers often need to apply only 1 per cent as much herbicide to their fields; and these new products are safe to people and the environment and meet many of the other ideal product criteria listed above. There is still a lot of space for improvement and the work is to continue in this direction.

Status of weed research in India

The weeds are emerging as the most important cause of damage to the crops. This is primarily due to exhaustive amount of uptake of nutrients removed by the weeds.

All crops without exception are exposed to severe competition from weeds. Most of these weeds are self sown and the competition is caused by fast rate of growth of weeds in the initial stages of crop growth. In some crops, the yield is reduced by more than 50 per cent due to weed infestation. The new agricultural production strategy involves use of high yielding varieties of crops grown under heavy and costly inputs like fertilizers, irrigation and repeated measures of plant protection. These conditions stimulate the growth of crop and weed alike. If weeds are not controlled, then the very purpose behind adoption of improved technology gets defeated. Paradoxically, only 15 per cent of the total pesticides consumed in this country account for herbicides (weed killers), while 70 per cent are insecticides and 15 per cent fungicides.

CROPS AND ASSOCIATED WEEDS

Rice

The major crops of India, namely rice and wheat are heavily infested with the weeds. Rice crop is having a tremendous problems of *Echinochloa crusgalli, Cyperus iria,* etc. (Naidu and Bhan, 1979). Lot of work has been done to control these weeds in the transplanted rice using mechanical methods. Transplanted paddy growers in the conventional rice growing areas of Eastern and Southern states of the country have found the paddy roto-weeder useful. In the states of Punjab, Haryana and newly developed areas of rice in Tarai belt of Uttar Pradesh, where the water availability and its retention is not up to the desired level, weeds have threatened the cultivation of transplanted rice and this has lead farmers to use chemical on large scale. Higher use of fertilizers especially nitrogen increases weed biomass. Some of the recommended herbicides are butachlor, fluchloralin, nitrofen, benthiocarb, oxadiazon and pendimethalin, which have been found to control weeds successfully (Mishra and Tosh, 1980). Due to the continuous use of the grass kill herbicides, the problem of sedges and broad leaf weeds is on the increase which needs future investigation.

Wheat

Phalaris minor and wild oats have been threatening wheat cultivation in Punjab, Haryana, Western Uttar Pradesh, North Madhya Pradesh and Rajasthan. All the districts of Punjab and Haryana states are infested with these weeds. Reports of its infestations are coming from Bihar, west Bengal, Assam, Maharashtra and Gujarat. The mechanical and cultural methods used to control these weeds could not find much place among the farmers due to their morphological similarity with crop. The farmers have now resorted to the use of herbicides in large amounts to control these weeds. Besides, *Lolium temulentum, Poa annua and Polypogon monspeliensis* (grass weeds) are coming up as a threat to the existing list of grassy weeds in the wheat fields. Work done at various Agricultural Universities, ICAR Institutes and also in the All India Coordinated wheat Improvement Programme helped to identify the herbicides like methabenzthiazuron, metaxuron and isoproturon which have considerably helped the farmers in suppressing these weeds (Katyal, Singh and Bhan, 1980). It was observed that these herbicides have no doubt killed the grass weeds but were not effective against legume weeds, which are coming up as the escape or in the succession of weeds in the wheat fields. Suitable research programmes need to be developed to study the appropriate herbicide mixtures which can give broad spectrum control of these species in wheat. Moreover, due to the continuous use of isoproturon, *Phalaris minor* developed resistant to this herbicide which was managed by recommending the new molecules including sulfosulfuron, clodinafop and fenoxaprop-p-ethyl. The sole dependence on these herbicides may lead to cross resistance in *Phalaris minor* hence, there is need to develop sound management system which may include all possible non-chemical and chemical combinations.

In the Hills of Northern India, spreading from Jammu and Kashmir and Himachal Pradesh to Uttar Pradesh, there is a severe problem of *Oxalis latifolia and Oxalis corniculata* which have infested wheat and other crops such as potatoes and pulses. Very little information is available on control of these weeds, which mainly spread through bulbils which remain dormancy in the soil during the winter and become active soon after the summer sets in (Mishra *et al* 1979). The work of this problem should be taken up on scientific basis to alleviate the farmers of hilly region from the ill effects of this serious weeds which affects adversely the production potential of the various crops.

Maize, sorghum and millets

In the *kharif* season, *Trianthema monogyna and Cyperus rotundus* aare creating problems in various crops in Punjab and Haryana. Successful techniques of controlling *T. monogyna* have been developed in cotton and leguminous crops with the use of fluchloralin and in sorghum, maize and bajra using atrazine as pre-emergence spray. However, more work is needed on the biology of this weed so that the spread which is extremely fast should be checked at the source of infestation and new areas already infested by this weed could be kept in control.

Sugarcane

Apart from annual grass and Broad leaf weeds, sugarcane crop is facing a major problem of *Sorghum halepense and Cynodon dactylon* and can be controlled by giving interculture. Use of atrazine and simazine in sugarcane, though found very effective, has not yet found favour with the farmers. It may be worthwhile to mention that the crop-weed competing ability of sugarcane has not been worked out in detail particularly with reference to weed species.

Vegetable crops

The intensity and the growth of weed is much higher in vegetable crops due to large scale use of farmyard manure, compost and irrigation water. Potato, onions and chillies are the major vegetable crops in this connection, apart from tomato, brinjal, cole crops, where the farmer takes extra initiative for controlling weeds. Conventional weeds in potato are removed during the earthing operations. With the mechanical planting of potatoes in North Indian, generally, the farmers do not go for complete earthing operations. With the mechanical planting of potatoes in North India plains, generally, the farmers do not go for complete earthing of ridges and therefore, face a stiff problem of weeds. Controlling these weeds, using herbicides namely paraquat, atrazine, alachlor and pendimethalin is easy, effective and therefore, successful. Use of mechanical methods for controlling weeds in potatoes grown on small holdings is effective except in areas having problem of *Trianthema monogyna*. Onion are planted at the narrow spacing where the manual weeding operations are extremely costly. However, some herbicides namely fluchloralin, pendimethalin, oxadiazon etc. are coming up which may find some use.

Orchard Crops

Orchards are the one area where the herbicides have been used sparingly. Mechanical methods are found quite effective and used on large scale. Tea plantations have been using herbicides on a large scale and various herbicides like glyphosate and paraquat have been found effective.

AQUATIC WEEDS

Aquatic weeds like *Typha* are creating menace in the irrigation canals, banks of the reservoirs and drainage ditches. On the other hand, water hyacinth, Salvinia are still the problem among the floating weeds. Potamogeton, Hydrilla, Utricularia, Chara, etc. are the major submerged weeds. Control of immersed weeds has been worked out to a greater extent using cultural practices like submergence with water alongwith the use of herbicides. Emphasis is needed to develop the economic and efficient herbicides which would have a lasting effect to control these weeds. Use of mechanical methods for controlling submerged and flatting weeds mainly constitute the physical removal of weeds by manual labour. Though some research work has been undertaken to develop suitable measures to cut these weeds and collect mechanically but the use of such machinery is extremely limited due to either higher cost or relatively less utilization in the problem areas. Herbicides have also been worked out to control floating and submerged weeds but their practical use is extremely restricted because of lack of availability of information about the degradation of applied herbicides with reference to mammalian toxicity and crop safety. A systematic project needs to be developed to control aquatic weeds in large water bodies, ponds, canal systems and drainage channels effectively, so that our irrigation projects work to their maximum efficiency.

WEED ECOLOGY

Ecological shift in weed species is being observed with the use of herbicides. Most of the chemical methods have always controlled the weeds effectively for which they have been utilized but always leaving one or the other species of weeds unattended. These unattended species later on take a serious turn. In other words, succession of weeds is being observed. Practically negligible research has been done in following the succession of weeds in disturbed plant communities, especially with reference to weeds. Such change in the weed species due to herbicide use has been observed in wheat fields. Emphasis should be laid to do the work on dynamics of ecological succession which will decide the long term use of herbicide in different cropping systems.

PHYSIOLOGY OF WEEDS

Studies on the physiology of weeds with reference to its germination growth, reproduction and dispersal are very little. Physiology studies are almost on the influence of moisture and temperature influencing weed germination. Systematic work is needed on the influence of fertility levels on weed germination, behaviour of weed seed germination in associated crops with reference to emergence in flushes. If majority of the weeds would have come in one flush, the control of weeds would become easier tasks either by chemical or mechanical methods.

It is important that to work out the reproduction behaviour of different weeds in different plant communities. This should be associated with the amount of seeds produced and also the mode of dispersal that helps in enhancing the infestation by a weed in a particular area. The weed seed bank is an important aspect which influence the weed pressure on a crop and hence requires attention.

HERBICIDE RESIDUES

Very little information is available on herbicides residues in India. The reports are available on the residual effect of herbicides applied in the preceding season on the crops as a bio-efficacy test. This is of practical importance and helps to understand the residual effect of herbicides with reference to germination and growth of the succeeding crops in double crop system. Experiments have been started on the response of crop varieties to herbicides application, the relative selectivity of herbicides to crop, etc. However, researches are needed to go into the details of herbicide residue with reference to absorption, translocation and metabolism of herbicides in plant and soil system.

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Weed Science Research – Challenges and Opportunities

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To produce more with decreasing resource base is challenging enough. To achieve the same with less external inputs such as fertilizers, pesticides and irrigation is indeed daunting. With reference to management of weeds with less herbicides, less labour and decreasing population of draught animals is going to be difficult to come to terms with. Further, agriculture under WTO regime is not so much on *how much to produce* but is on *how it is being produced.* In order to make our products globally competitive, it is important to give utmost importance to input efficiency and quality of the produce. Every scientist has to incorporate these challenges in his research agenda.

Cheap labour – a great myth!

Despite great progress made in agriculture in the country, much of weed control is still being done through manual and mechanical means in vast majority of the crops. While to some extent it is due to the lack of awareness amongst the farmers, to a great extent it is dependent on the socio-economic factors of the farmers. However, due to unavailability of labour, most farmers do not accord high priority to weed management. By a conservative estimate of 20 man-days for one manual weeding, a whopping 2 billion man-days of labour force is required annually for weeding operation in food crops alone. The figures would be much higher if we were to consider vegetable and horticultural crops. It is a great myth amongst many policy makers and administrators that India is a country with plenty of cheap labour. The ground reality is that labour is not in plenty and certainly not at affordable cost even in backward areas.

Growing urbanization, diversification of agriculture and various welfare measures introduced by the Government aimed at improving the rural mass are seriously affecting the availability of labour for crop production. It is estimated that about 50% of the people would be living in urban areas by the year 2020. Growing mechanization has made maintenance and use of animal power in agriculture uneconomical.

Is human comfort – no consideration?

It is well known that manual weeding is back-breaking and involves human drudgery. The discovery and use of herbicides for weed management has revolutionized agriculture in much of the developed countries. Herbicides have come as a boon in saving labour , reducing cost and increasing profits. Despite this some section of people in India strongly believe that *use of herbicides would displace labour* and therefore not to be encouraged. We believe in pushing hapless women (more than 80% weeding is done by women) to this arduous task rather than liberating them to undertake more productive work. We need to be pragmatic in our approach and thinking rather than sounding rhetoric.

Due to these reasons, the herbicides are slowly but surely becoming popular with farmers. It has already made a big impact in north-western part of India (Punjab and Haryana, Uttranchal, western Uttar Pradesh) where 55% of the wheat area is currently treated with herbicides. About 8% of soybean area in Madhya Pradesh is under herbicide application. From a meager 1400 MT in 1985-86, the herbicide consumption has increased to about 11,000 MT in 2001-02. Today the herbicide industry is worth Rs. 1000 crores with wheat herbicides having the major share (57%) followed by rice (17%), plantation crops (6%) and soybean (4%). The benefit of this technology must reach more crops and more areas.

Are herbicides harmful?

Herbicides are of course poisonous substances hence would be harmful to the user and the environment if used recklessly. With the growing awareness about the quality of food and water we consume and the environment we live in, the pesticide use in agriculture in general has come under close scrutiny. Insecticides, which presently constitutes about 75% of the total pesticide use in the country, are by and large more toxic than herbicides. Out of 52 insecticides registered in India, about 40 (70%) of them come under highly hazardous to extremely hazardous category (LD50 less than 500 mg/kg body weight) compared to 3 (9%) of the total 32 herbicides falling under this category. Further, herbicides, unlike insecticides are applied during early part of the crop growth and due to long waiting period is rarely detected in edible parts when used at recommended doses. Through permanent herbicide trials carried out under AICRP-Weed Control, it has been established beyond doubt that continuous use of herbicides neither affect productivity, pollute soil or water nor upset soil biology. We need to demonstrate this with data for diverse agro-climatic conditions to allay fears in the minds of public and policy makers. It is also our duty and responsibility to identify adverse impact, if any, of a particular chemical, so that remedial measures could be taken if needed with registration and regulatory authorities.

Is Biological control a panacea?

A strong wave of organic farming is currently sweeping the country. Unlike insect pests and diseases, the control of weeds through non-chemical methods is not difficult but they may not be efficient or cost effective. In arable agriculture, weed management through biological control agents has limited scope. Identification of a weed-specific bio-control agent (insect, pathogen, etc.) is hard. Further, successful agent would only control a specific weed thus encouraging other weeds to dominate the flora. However, it has a great scope in management of weeds in non-crop areas and in aquatic ecosystem. In fact, it is the only practical method for management of invasive weeds which are seriously threatening the biodiversity of our country.

Sustainability concerns

Lessons have been learnt that over reliance on a particular method of weed management particularly herbicides will impact negatively by way of development of resistance to herbicides, shifts in weed flora, etc. More and more farmers would start using herbicides as a chief method of weed control in the future for a variety of reasons. We must ensure that herbicides are used judiciously. Integrated management weeds (IWM) involving different methods be followed in the true sense. It is time we went beyond integrating herbicides with manual/mechanical weeding and included other non-chemical methods such as tillage, competitive crop cultivars, cover crops, mulching, irrigation and fertilizer management, etc.also.

Agriculture is the main user of fresh water and rice cultivation in the present form is highly water demanding. IRRI-sponsored research at GBPUAT, Pantanagar has shown that the productivity of direct seeded rice is comparable to puddle transplanted crop and it uses less water, energy and labour. Weeds of course are the chief constraints in direct seeded crop and it is a challenge for weed scientists to demonstrate that they could be managed successfully. Zero tillage and conservation tillage, though are old concepts have found new meaning in the country in the recent past. Large-scale adoption of zero tillage in rice-wheat system in the Indo-Gangetic Plains is truly a success story worth emulating in other cropping systems and in other regions.

Basic research ignored

Basic research concerning weed biology, ecology, systematic, etc. is not given due emphasis. We need to draw a blue print for basic research in weed science or the success of IWM depends largely on it. Weed science should not be treated as a domain of agronomists. Scientists from related disciplines must be encouraged to undertake collaborative research. There is excellent talent available from outside the SAUs and ICAR System which should be tapped.

Alien Invasive Weeds

The alien invasive weeds are a great problem in the country. They have invaded vast areas of grasslands, forest, orchards and plantation crops etc. and rendering them unproductive. We need to educate the public and the stakeholders about the dangers of such invasive weeds and seek their help in management. Weed scientists have a great role in doing this. Awareness raising activities such as publications, articles in newspapers, workshops, lectures, rallies involving NGOs, school children, residents, local administration, etc. will go a long way. The key factors in management of invasive weeds is early detection and control which can only achieved if all stakeholders are sensitized on this issue. The NRCWS-sponsored **Parthenium Awareness Day** observed through out the country on 4 September 2004 is a case in point. We need to do similar activities on an annual basis.

Is weed-resistant crop a possibilty?

Host resistance plays a chief role in management of insect pests and diseases. Although excellent research work has been done on allelopathy for over several years, unfortunately it has not succeeded in providing practical solution to any weed problem. However, concerted efforts may lead to identifying crop cultivars, cover crops and intercrops with excellent weed suppressing ability. It is theoretically possible to develop weed-resistant crops by identifying genes responsible for allelopathy and their incorporation in to crops through genetic engineering. But it is a challenge of very high order.

Herbicide-resistant crops (HRCs)

HRCs occupy over 75% of the total acreage of over 80 million hectares under genetically modified crops (GMCs) in the world. Perhaps no other technology had found such a large scale adoption in such short time in the history of agriculture development in the world. Development of herbicide resistance in crops such as soybean, corn, cotton and rapeseed have helped farmers in better management of weeds with greater profits and lesser use of herbicides in countries like USA, Canada, Argentina and Brazil. This technology, however, has found stiff opposition from environmentalists in many countries including India. We need to discuss this critically taking in to account the relative benefits and risks associated with the technology. It appears very promising in our country particularly in soybean and maize crops, where there is little risk of transgression of herbicide- resistant genes in to wild types.

CONCLUSION

Weed Science research in India is at a critical juncture. There is greater recognition now than before about the importance of weeds and their management in agriculture and environment. But we need to raise our competence and do business differently than before to address the new challenges comprehensively. There is greater need for collaboration and cooperation with a cross section of scientists belonging to different disciplines.

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