Management of herbicide resistance

i) Farmers awareness, training and participatory approach

If a weed has developed resistance to a herbicide in any area/region, the farmer of that region in particular and other regions in general should be made aware of weeds resistance and adequately informed about the means at their reach/hands to tackle it. Farmers may be proven provided with adequate training on how to monitor and manage weed resistance. In this connection, some alternative cropping sequences, appropriate cultural and other management strategies proven enough beneficial since time immemorial should be recommended towards combating resistance menace. Extension personnel, private sector and the government policy/decision maker should be involved in this training to the farmers.

Farmer's participatory approach means farmers participation in problem solving activities planned and designed by the scientists and extension workers. Resistance monitoring and management would be a futile exercise if farmers remain isolated. In participatory approach, experiments towards management of resistance or demonstration of an improved control technique of the resistant flushes can be under taken in the farmer's field with his or their active participation. By doing so, they get exposed gradually and learn many things towards monitoring and management of resistance. This appropriate management practices for resistance affected areas within a short period and at lower cost.

ii) Abandonment of the herbicide to which weed showing resistance

First the herbicide on which weed has developed resistance should be abandoned/barred for use (e.g. isoproturon for resistant *Phalarisminor*). Using that herbicide is simply wastage of money, manpower and machinery. Even its use in very high dose than recommended in the belief that it may work, is merely a folly. It aggravates the problem in the following years and invites many other problems like soil and water population, crop phyto-toxicity and toxicity to non-target soil microorganisms.

iii) Stop sale/purchase, lending/borrowing or exchange of crop seed from area and resistance to other areas where resistance not reported;

The problem of herbicide resistance being a seed related one,is supposed to spread in newer areas through seeds, farm equipments and irrigation and run-off water. Prevention of dispersal of resistant of weed seeds through water, air or some other means is virtually impossible and time could be factor for its early or late evolution in other areas. However efforts should be made to check/modify the factor for dispersal of resistant weed seeds and to stop/slow dawn the spread in newer areas through wide publicity creating mass awareness among the farmers of both areas having and not having resistance. Seen/purchase lending/borrowing or exchanging of crop seed which had exposure to the resistant weeds in the field, should be prevented/discouraged from the area already under resistance to a not new area not having the problem. Otherwise, crop seeds should get cleaned to the tune 100 percent free from admixture of any weed seed and be sold, lent or exchanged.

vii) Prevention against its spread and seed bank enrichment in soil

a) Clean tillage and harvest equipment before moving them from field infested with resistant weeds to those that are not infested.

b) Rogueing for preventing seed production:

Even from adopting a sound control measure, some weeds particularly those emerge later escape to be controlled in the field. They grow unabatedly, come to maturity and set enough seeds to add to the soil seed bank and perpetuate/spread far and near in the coming years. Therefore, prevent seed production of the resistant population at any cost to reduce seed rain. In case of resistant weeds having considerable vegetative mimicry with crops, those along the rows of crops remained/ left uncontrolled may be identified during panicle/inflorescence emergence and hand pulled/ removed.

c) Rogueing for prevention of contamination of crop harvest: A sizable amount of inflorescence/seeds of those weeds is also harvested with crop produce and disperses with crop seeds. This applies as to resistant weeds so to usual weeds present in a field. Therefore, it is advisable that hand pulling/rouging may be adopted at the ear emergence stage of*Phalarisminor*or other weeds to prevent its seed production and dispersal. This prevents already existing resistant population to produce seeds in considerable amount and delays the development of resistance where resistance has not yet evolved.

v) Cultural/ecological approaches/options:

Cultural practices adopted to raise a crop do not have direct control of the resistant or other weeds. They however exert selective stimulation to crop towards vigorous/ greater growth compared to resistant weeds. Therefore, they need to be exercised mainly to exploit the differences in biological fitness (the ability to survive and reproduce in a mixed stand) if at all existing between the resistant weed populations and crop. Therefore, the more rational way of utilizing their merits/benefits is to integrate them with other methods of weed control (IWM) as applicable for usual weed control so as for the management of resistant weeds.

a) Competitive and high yielding variety: Competitive crop genotype play a vital role towards combating resistant weed seeds, which multiply and produce seeds for years. They usually exert some smothering effect. Several varieties of wheat such HD 2687,PBW 343 and WH 542 are enough competitive against grassy weeds.

b) Pure and certified crop seed: Pure and certified seeds of crop have no or negligible level of admixture of resistant weed seeds, which multiply and produce seeds for future years. Seed certification and quarantine rules permit 10 and 20 weeds seeds per kg of foundation and certified seeds, respectively in wheat. But, for an objectionable weed like *Phalarisminor*, only 2 and 5 seeds are permitted per kg of wheat seed. Using pure and certified wheat seeds can prevent even dissemination of many weeds such as *Avenaludoviciana*, *Convolvulus arvensis*, *Rumexretroflexus*,*Lathyrusindica* and *Viciasativa* apart from *Phalarisminor* from one field to

another by natural agents or from one place to another by farmers crop seed exchange or wheat seed movement.

c) Stale seed bed technique: Stale seed bed technique is highlyuseful during winter (*rabi*) season since the number of flushes of weed germination is reduced to one or two. Therefore, suitable combination of stale seed bed and time of sowing would be a good proposition towards combating *Phalaris* menace. Delaying wheat seeding after seed bed preparation, *Phalaris minor* and other weeds can be induced to sprout and later killed by ploughing or non-selective herbicides (e.g. gylphosate or paraquate each @ 0.4-0.5 kg/ha or glyphosate @ 0.5% (product basis) and paraquat @0.3% (product basis).

d) Closer row spacing: Closer row spacing and higher seed rate exert crop plant population effect which may reduce weed growth and enhance crops competing ability. Sowing wheat at lower than 22.5 cm row to row distance (say 18cm or even lower at 13cm in FIRBS) has significant bearing towards reduction of weed competition and enhancing wheat yield. Angiras and Sharma (1993) reported that increasing wheat plant density by way of reducing row spacing from 20 cm to 15 cm could reduce the dry weights of Lolium and phalaris by 11.9% and 18.3 % respectively.

e) Proper time, method and rate of sowing: Sowing of wheat earlier (last week of October to second week of November) than usually recommended (mid November) favours wheat's initial growth and competitiveness against *Phalarisminor* and other weeds (Malik *et al.*,1998) particularly under rice-wheat cropping system. In contrast Kolarand Mehra (1992) reported that weeds posed more competition in terms of their higher biomass accumulation when wheat was sown on October than on November or December. Similarly late planting of wheat in December instead of mid-November in North and North-Western India reduces overall weed competition in general and *Phalaris minor* problem in particular. However, late sowing of wheat on December reduces equally the growth of crop. Yaduraju and Ahuja (1992a) reported that competition in general and *Phalarisminor*(in terms of dry weight of weeds at harvest) was the highest with wheat planted on 15 November and it decreased with delay in wheat planting, Whereas, the growth of wild oats remained unaltered. Duary (1998) observed *Phalaris minor* more competitive in November sown than in December sown wheat.

Avoid sowing in moist soil as usually practiced under zero tillage in rice-wheat cropping system. Wheat should not be sown in soil with high moisture rather it should be sown when upper soil profile (1-2 cm) gets dried. It will reduce weed seed germination and thereby crop-weed competition at the initial stages of crop growth.

Similarly slightly higher seed rate, for example, 120-125 kg/ha (higher than recommended 100 kg/ha) is beneficial. Even 150 kg/ha seed rate proved useful in some experiments. Duary (1998) reported that increase in wheat seed rate from 100 to 150 kg/ha was beneficial in higher *Phalarisminor* density plots since they recorded yield increase greater (10.5-16.9%) than in weed free situation (4.8-4.9%). This implied that higher seed rate (150kg/ha) could render/equip wheat

plants more competitive in higher *Phalarisminor* density plots and result in greater yield increase. However, above all the benefit-cost economics should be encouraging.

f) Crop substitution/rotation: crop substation/rotation is called a panacea and should be followed as far as feasible and practicable. It maintains soil fertility and also helps to interrupt the life substitution is a better option provided the crop substitute is as remunerative as the substituted one. Rotating crops particularly those with different crops against the same weed species help to contain resistance in weeds if other effective weed control measures are not adopted. The crop substitute may differ in time of sowing, nutritional requirement and other cultural and management practices. All these have small but definite bearing on the germination and growth of resistant weed and may reduce or bypass the resistant weed problem. A change in weed flora is quite imminent in the new crop situation, but could be controlled satisfactorily by a selective herbicide or some other means. Crop rotation also facilitates the use of alternative herbicides and herbicide rotation and may be adopted as a component of the integrated weed management practice. Therefore, it could be used as an effective tool for delaying or avoiding herbicide resistance in weeds.

The resistant weed may be a crop bound, crop associated or season bound one. Phalaris minor is season bound weed and is mainly associated with wheat and other winter cereals although it could be found growing in many other winter crops. Singh and Singh (2006) reported that mustard/gobhisarson, vegetable pea, potato, Egyptianclover/berseem (*Trifoliumalexandrinum*) if adopted in sequence after rice during winter season, *phalaris minor* problem could be reduced to a great extent. Egyptian clover/berseem could be effective in reducing resistant *phalaris minor* population since it undergoes frequent cutting for fodder. Thus pea, mustard & rape seed, potato, Egyptian can be a good substitute wheat. However, net economic benefit and farmers' choice are the determining factor towards substitution of wheat and adoption of these crops. Farmers may hardly lose interest on wheat since it is a staple food and responds better to inputs and management and produces higher yield. Other crops for system-based substitution are sunflower, sugarcane etc.

g) Crop residue management: In rice-wheat cropping system of the North and North-western India enough crop residues particularly of rice accumulates in the field since rice straw is hardly fed to the cattle and livestock in this region. Farmers of Punjab and Haryana have inculcated a practice of *in situ* burning of that residue in the field. However, it has been established that rice straw burning stimulates *Phalaris minor*seeds to germinate in large population in wheat and it reduce the efficiency of post-emergence herbicides which get adsorbed to the ashes (burnt rice residues). Therefore, residue burning should be avoided and residue retention on soil surface (which act as mulch and reduces germination of*Phalaris minor* and other weeds) or tis incorporation should be encouraged to combat weed particularly *Phalaris minor*menace.

vi) Mechanical and manual approaches/options:

a) Tillage practices: Furrow irrigated raised bed system (FIRBS) is an effective method of non-chemical weed control particularly *Phalarisminor* and imposes no selection pressure if the same

degree of control of susceptible and resistance biotype is achieved. Zero tillage which requires increased use of herbicide may aggravate resistance problem. Increased use of herbicide in zero tillage kills susceptible population completely and the resistant population grows more luxuriantly in absence of competition and multiplies more profusely. Similarly minimal/reduced tillage favours quicker development of resistance. But, deep and inversion tillage reduces the requirement of herbicide and, therefore, the selection pressure and delays the build-up of resistance by bringing the buried susceptible weed seeds up continuously. In non-inversion tillage, since weed seeds obtained in the previous season/crop lie close to the soil surface, the proportion of weeds emerging from those seeds (dormancy may also be a factor) and the probability of back crossing with earlier unselected population/generations derived from older buried seeds get reduced.

b) soilsolarization: Soil solarization for a minimum period of 2 weeks during hot summer months (May and June in India) is sufficient to control weeds, but it may be continued to several weeks (4-6 weeks) together for achieving a prolonged effect. It controls wet-season (*kharif*) as well as winter (*rabi*) season weeds. Wild oat and *Phalarisminor* are effectively controlled by solarization, but not *Cyperussp*. and *Melilotussp*. However, if soil solarization is practiced, soil should be disturbed to the minimum possible. Even mechanical and manual weeding need to be withheld and herbicide is the only resort in that case. Otherwise, the very purpose of solarization is defeated.

c) Harrowing: Many farmers of Punjab and Haryana employ mechanical weeding by bar (tooth) harrow at the early stage of wheat preferably before first irrigation or a week after first irrigation. This followed by post-emergence herbicides ay 35-40 DAS gives an effective alternative option towards management of resistant *Phalarisminor* problem.

d) Manual weeding: Hand weeding/hoeing by experienced and trained labourers/farmers following first and second irrigation may be useful, but it has inherent limitations. It is difficult to operate with hand tools under broad-cast wheat which is a main practice by the farmers. Grassy weeds within rows or near crop plants are hardly pulled out because of their similarity with wheat. It is troublesome and usually costs higher. However, its integration with herbicides.*e.g.* first post-emergence herbicide after first irrigation and then hand weeding following second irrigation, would be a workable combination to reduce resistant *Phalarisminor* problem.

vii) Biological control of the resistant weeds: Many insects feed on weeds, fungi cause diseases and deleterious *Rhizobacteria* (DRB) colonize in the root rhizosphere of weeds. Identification and selective adoption of those bio-agents may provides significant weed control. Genetic manipulation through bio technological tools of these bio-agents towards improving their efficiency can help to manage the resistant weeds or other important weeds in the crop field. For example, *Trichodermaviridae* has been reported to control *Phalarisminor* selectively through colonization in roots. The mechanism is similar to how deleterious *rhizobacteria* and phytopathogenic bacteria work.

viii) Herbicide management: It areas where resistance had been confirmed, two important considerations of utmost priority in relation to herbicide management should be a) to search/evaluate and use of alternative herbicide to control the existing resistant flushes and b) to use rotation, mixture or sequence of the alternative herbicides evaluated to control the already resistant flushes and to avoid/delay the development of cross or multiple resistance in the resistant weeds. In addition crop protectants/safeners and synergists may also be adopted towards better management of herbicides. Alternative herbicides with different mode of action, but similar spectrum of weed control can be chosen/ identified from this table for field testing. Their recommendation, however, should always be made on the basis of their performance under actual field conditions. The risk for resistance development on the part of alternative herbicide should also be considered readily.

a) Evaluate alternative herbicide and use them at appropriate dose and time to control resistant weed flushes: screening for alternative herbicides having different mode of action, but same level of activity on the target weed group/resistant weeds and same level of selectivity to crop should be conducted immediately after confirmation of resistance. The effective alternative herbicide or herbicides evaluated if is/are already available in the market should be recommended provided they are cost-effective. Manu triazine resistant weeds have been controlled by using alternative herbicides in many countries. In India, several alternative herbicides such as clodinafop-propargyl (Topik 15 WP), sulfosulfuron (Leader 75WDG), fenoxaprop-p-ethyl (Puma Super), diclofop-methyl (Illoxan) have been used to control isoproturon-resistant *Phalaris minor* effectively. The chemical grouo/kind of herbicide and its dose and time of application and residual activity are also factors for development of resistance in the resistant flushes.

b) Herbicide mixture, sequence and rotation to avoid/delay the development of cross or multiple resistances in the already resistant weeds:

i**) Herbicide mixture and sequence**: Two or more herbicides having a) different mode of action, b) different degradation pathway, c) similar persistence and d) similar target weed-group specificity should be selected for mixture to reduce selection pressure for resistance development and to render efficient control of the target weed species.

ii) Herbicide rotation: The recommended alternative herbicide with different mode of action, but with same level of activity, selectivity and persistence and targeting similar spectrum/group of weeds should be rotated preferably once in every 3 year (i.e. after every 2 year) instead of using the same herbicide year after year. For example, *Xanthium strumarium* is effectively controlled by an ALS/AHAS inhibitor (imazaquin; Scepter) one year and by a photosynthetic inhibitor (atrazine, Atrataf) in the next year.

a) **Crop protectants/safeners and synergists:** The selectivity to a crop of certain potent non selective herbicide can be increased by using crop protectant/safener and hence that herbicide can be used to achieve good control of weeds in general and the resistant weed in particular.

Similarly synergists may be employed to augment herbicidal efficacy particularly where metabolic resistance has cropped up in weeds. However, accordingly crop selectivity may be a prime concern while using synergist.

b) **Spraying equipment and technique**: Use multi-nozzle booms in stead of single nozzle boom for uniform coverage of herbicide. Use flat fan nozzle for uniform spray droplets. Maintain suitable height nearly 50cm above the crop height or ground. Use less quantity of water 300-350 liters/ha for sticking and better penetration of herbicide.

ix) Integrated weed management (IWM)

Integrated weed management is mainly a concept which advocates the simultaneous or sequential use of a range of weed control technique embracing phycial(mechanical and manual), chemical and/or biological method and their effective combination in an integrated manner without much reliance on any single method to reduce weed population to economic threshold level. IWM is highlighted to be the panacea towards weed management in crops and cropping system. It is high time to reorient the weed control strategies and to develop IWM practices that include herbicide but not solely focused or fully dependent on herbicide technology. This could be a remedy to many problems related to weeds occurring off and on in the cropped and non-crop situations.