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INTEGRATED WEED MANAGEMENT-A STRATEGY FOR SUSTAINABLE WHEAT PRODUCTION - A REVIEW

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ABSTRACT

Wheat is one of the important cereals contributing approximately 30-35 % to total food grain basket of the country. Wheat infested by multifarious weed flora comprising both grassy as well as broad leaf weeds causing yield reduction of 15- 40 % depending upon type and intensity of their infestation. Herbicides continue to be the most powerful, economically effective and reliable way to control weeds in wheat. Over the years, the efficacy of herbicides has started declining and there is possibility of development of cross resistance. An integrated approach, where herbicide plays a pivotal role is the only way ahead for effective weed management. Use of weed free seed, use of well rotten farm yard manure, method of sowing, seed rate, sowing time, varietal selection, amount of fertilizer application, proper herbicide selection, proper dose, time and method of herbicide application, herbicide rotation and mixture, use of adjuvant, mechanical weeding and crop rotation are the major constituents of integrated weed management. Thus, integrated weed management practices should be location and time specific by considering the weeds in a broader ecological and management context.

Key words- Herbicide, Integrated weed management, Phalaris minor, Weed, Wheat

In India, wheat is one of the important cereals contributing approximately 30-35 % to total food grain basket of the country. Weeds compete with wheat for soil moisture, nutrients, light, carbon dioxide and space, thus reducing the yield and quality of produce. The major problem under high input wheat production system is interference of weeds which alone cause drastic reduction in yield. The reduction in productivity depends upon the type of weed flora and weed density. Wheat infested by multifarious weed flora comprising both grassy as well as broad leaf weeds causing yield reduction of 15- 40 % depending upon type and intensity of their infestation (Jat *et al.*, 2003). Uncontrolled weeds in wheat remove 30-40 kg N, 10-20 kg P and 20-40 kg K/ha from soil (Mishra and Gautam, 1995). *Phalaris minor* is the dominant weed in the rice wheat cropping system of the north- western India including Haryana. Wheat and *Phalaris minor* (Littleseed canary grass/ wild canary grass) have deep associations from germination till maturity. The morphology and other growing conditions resemble with each other. More than 90 percent seeds of *Phalaris minor* plants shed on the ground before the harvest of wheat crop, hence increasing seed bank status of the field for infestation during the coming years. Even in the sprayed field, the left over *Phalaris minor* plants produce seeds before their death or maturity. So, continuous cultivation of wheat in the same field will not eliminate the infestation of *Phalaris minor* even with the adoption of best herbicide application methods. Most farmers rely on herbicide with the same mode of action and show reluctance to change their weed control programmes. Farmers use lower than the recommended dose of herbicides (under dose), faulty spray techniques and improper time of spray *etc.* also help in development of resistance. Alternate herbicides like clodinafop, sulfosulfuron, fenoxaprop, tralkoxydim, sulfosulfuron+ metsulfuron and mesosulfuron+ iodosulfuron have been recommended during the last decade for the control of the isoproturon-resistant *Phalaris minor*. Over the years, the efficacy of these herbicides has started declining and there

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is possibility of development of cross resistance, as increase in GR_{50} values of sulfosulfuron, fenoxaprop and clodinafop under continuous use of herbicides has been observed (Dhawan *et al.*, 2009). As the resistance in *Phalaris minor* is metabolic in nature, there are chances of cross resistance development against new herbicides as well. The continuous reliance on some specific control techniques and crops resulted in development of herbicide – resistant weeds and weed population shifts towards a difficult to control species which creates new challenges for agricultural scientists and farmers.

Now, to meet out this challenge, the reliance on one or two specific weed control practices is to be reduced. The best solution may be the integration of cropping system design and weed control strategies combining preventive, physical, mechanical, agronomic, cultural, biological and chemical weed management in to a comprehensive system which is environmentally viable and maintain weed densities below their economic thresholds along with simultaneously maximize wheat yield and profits. Thus, integrated weed management practices should be decided on site and time specific basis and should design the weed control management strategy on long term basis by considering the weeds in a broader ecological and management context. In an Integrated approach the best options and tools are combined in such a way that the cropping system becomes unfavorable for weeds.

The principal strategies which can considered under an integrated weed management approach are preventive, agronomic and cultural and chemical strategies.

Preventive strategies: Prevention is least cost strategy but often least used management strategy. So, to prevent the introduction of weeds to fields, the easiest and cheapest ways may be adopted are use certified, clean and weed free crop seeds only. Wheat seed contaminated with little seed canary grass has been a major source of its short and long distance spread (Singh, 2007). Use clean farm equipment and machines, pull out weeds before seed setting. Control the weeds in animal feed and fodder and bedding ground because some weeds seeds remain viable and active even after passing through animal digestive tract. Use only well rotted manure (minimum of 4-5 months old material) because through unrotted or half rotted manures viable weed seeds enter the fields and subsequently spread to new areas. Some organic manure like FYM and vermi-compost are important source of crop nutrition, however these organic sources may carry weed seeds which increase weed infestation and introduction of new weeds to fields (Singh and Singh, 2005b; Badiyala *et al.*, 1991).

Mechanical and manual weeding: Removal of weeds by various means of tools and implements, hand weeding and pulling comes under mechanical and physical practices of weed control, respectively. These methods can be practiced effectively with best method of sowing, zero tillage and bed planting of wheat. Dhiman *et al.* (1985) reported that inter row culture by long tine hand hoe (*Kasola*) or wheel hoe increased wheat yields by 26-29% over unweeded checks. Generally manual weeding is less effective under heavy soil and grassy weeds infestation, while most efficient in light soils.

Hand weeding and hand hoeing at 4-5 weeks after sowing reduced the dry weight of *Phalaris minor* by 38 and 69% respectively, compared with unweeded control plots (Sharma *et al.*, 1985). Mechanical weeding done twice at 15 and 30 days stage was found most effective in reducing weed dry matter accumulation (Sharma and Singh, 2011). Hand weeding is ineffective particularly with grassy weeds. Mechanical weeding has now replaced the manual weeding at most of the places due to increased labour cost and non-availability of labour during peak periods of weeding.

Agronomic and cultural strategies: Some Agronomic practices which favor the crop competition to weed plants by encouraging healthy and vigorous wheat crop thus reducing losses from weeds are:

Sound knowledge about identification of weeds, its growth habit and life cycle, so that best control method may be adopted. The entire field should be examined and visited to identify the kind of weed and take a visual idea about population especially at the crop growth stage of 2-3 leaf. Balyan and Malik (1989) reported that a population of 20 plants/m^2 of *Phalaris minor* had no significant effect on wheat yield, whereas a population of 50-500 plants /m^2 of *Phalaris minor* reduced wheat yield by 8-50 % (Singh and Malik, 1994a) and a higher of

2000 plants/m^2 of *Phalaris minor* resulted in complete failure of crop (Malik and Singh, 1993 and 1995).

Seeding methods: Tillage is used to eliminate existing weeds and enables the farms to attack many weed survival mechanisms by burial of entire plants and weed seed, exposure of root system to drying and depleting food reserves of weed plant etc. Tillage also incorporate residues and fertilizer, reduce compaction and prepare seed bed. Ploughing of 30-35 cm upper layer reduce the risk of herbicide carry over from the previous crop. It should be ensured that crop seed must be placed in an ideal growing environment and any practice which enables the crop to emerge as early as possible ahead of weeds will favour crop yield and will suppress weed seed production.

Zero tillage practice reduced the level of crop weed competition due to reduced emergence of little seed canary grass weed because of minimum soil disturbance and also early planting gives an advantage to wheat over little seed canary grass weed in rice wheat cropping system in heavy soils (Singh, 2007). Among different planting techniques, zero till sowing in standing stubbles, partial burning and bed planting techniques significantly reduced the growth and development of *Phalaris minor* as well as broadleaf weeds than conventional tillage and zero tillage treatments and recorded significantly higher growth parameters, yield attributes and grain yield of wheat in zero till sowing in standing stubbles and partial burning as compared to conventional tillage and zero tillage techniques (Brar and Walia, 2009). Bisen *et al.* (2006) reported lowest density and dry weight of *Phalaris minor* and other broad leaf weeds in zero till wheat as compared to conventional till crop. This might be due to the fact that *Phalaris minor* seeds remained buried in deeper soil layer and could not come to top layer favourable for seed germination (Table 1).

In zero tillage, the seeds present in the top soil layer germinate with pre sowing irrigation which can be killed with the use of any contact herbicide. However, the weed seeds present in lower layer do not get chance to germinate. Intensive summer fallow in often the only cultural alternative to suppress weed growth, prevent weed seed production, deplete seed reserves in the soil and starve weed roots. The total population of narrow leaf weeds was higher in conventional tillage than minimum tillage at 4 and 8 weeks after sowing (Ranjit and Suwanketnikom, 2003).

Bed planting proved advantageous method over flat conventional sowing of wheat as bed planting reduced the population of *Phalaris minor* by 12.5% over flat sowing (Walia *et al.*, 2003). Raised bed planting of wheat provides an opportunity for mechanical weeding and offers irrigation water saving over flooding method in wheat (Singh, 2007). Bed planting also reduces the weed infestation by burial the weed seeds deep at the time of bed preparation. The weed seeds lying on the top of bed will show poor germination and their growth will be comparatively less due to less availability of irrigation water on the top of bed. Also the inter row bed space is used to control weeds by mechanically during the early vegetative growth of weeds. Reshaping the bed before planting of wheat can kill the first flush of *Phalaris minor* seedlings.

Phalaris minor seed germinate largely from shallow depth, deep ploughing after wheat harvest can bury the seed and have profound effect on its germination in the following season. Deep tillage with Mould board plough gave 13.7% and 8.5% reduction in *Phalaris minor* population compared to zero and conventional tillage system. The inversion of the soil with mould board plough resulted in deep placement of weed seed and could not emerge out and hence reduction in population of *Phalaris minor* was

TABLE 1: Effect of tillage methods and weed control treatments on weed density, total weed dry matter at 60 DAS and grain yield of wheat.

Treatment	Dose (g ha^{-1})	Weed (No./m^2) *Phalaris minor*	*Chenopodium album*	*Anagallis arvensis*	Other weeds	Weed dry matter (g/m^2)	Grain yield (Kg/ha)
Tillage							
Conventional	-	5.0	5.8	8.4	16.3	35.9	4620
Zero	-	2.4	4.6	3.7	14.3	30.2	4323
Reduced	-	3.9	6.4	5.8	15.3	32.9	4457
LSD (P= 0.05)		-	-	-	-	1.7	150

(Source: Bisen *et al.* 2006)

recorded (Chahal *et al.*, 2003). Due to burial of large number of weed seeds present on soil surface into deeper layer in soil, which later failed to germinate and gave the minimum weed population and weed dry mass in wheat sown with rotavator twice as compared to farmer's practice and zero tillage (Pandey *et al.*, 2001).

Sowing methods: The main aim of sowing method is to uniformly distribute the crop plants per unit area to provide better crop architect. It also provides minimum space to weeds and maximum space for the growth and development of crop, so that it can provide good smoother on weeds. Due to more number of wheat tillers at the narrow row spacing resulted in less weed competition. Closer row spacing of 15 cm resulted in 18% lower dry weight of little seed canary grass compared to normal spacing of 22.5 cm (Mahajan *et al.*, 2004 and Walia *et al.*, 2003). The reduction in weed density and dry weight was due to smothering effect of crop on weeds in cross sowing as limited space was available for growth and development of weeds due to more uniform distribution of crop plants in this method. Under late sowing conditions cross sowing of wheat (22.5 cm spacing row) reduced 59, 23 and 38% dry weight of *Phalaris minor* as compared to broadcast, closer and normal rows, respectively (Singh and Singh, 1996). Closer row spacing of 15 cm reduced the dry matter of *Phalaris minor* by 32.3 per cent and gave 8 -10 per cent higher grain yield of wheat as compared to normal spacing of 22.5 cm because of better canopy coverage over weeds (Chahal *et al.*, 2003 and Bhullar and Walia, 2004). Mahajan and Brar (2001) reported that closer spacing of 15 cm registered 15.5 per cent reduction in dry matter by *Phalaris minor* over crop sown at 22.5 cm row to row spacing and thus gave 13.2 per cent higher grain yield over normal spacing (22.5 cm). In narrow spacing due to limited availability of space to weeds and smothering effect by crop plants on weeds reduced the weed dry weight and favorable effects on crop yields were obtained (Mishra and Tiwari, 1999).

Higher weed density and weed biomass under broadcast method of sowing may be due to lesser and uneven distribution of crop plants and hence greater availability of space and light for weeds to grow as compared to cross sowing (20 x 20 cm) and normal sowing (20 cm). Normal line sowing and broad casting method recorded 7.29 and 19.93% lesser grain yield than criss cross sowing (Pandey and Dwivedi, 2007). Bi-directional sowing of wheat (22.5 x 22.5 cm) registered significantly less dry matter accumulation by *Phalaris minor* over unidirectional sowing (22.5 cm). However uni-directional sowing at closer rows (15 cm) proved to be equally effective as bi-directional sowing for suppressing the weeds at all the growth stages of the crop (Singh, 1996). Criss cross sowing significantly reduced the weed count and weed dry biomass as compared to broad casting because the competition created by canopy of more number of crop plants in an unit area having a suppressive effect on associated weeds (Pandey and Kumar, 2005 and Yadav *et al.*, 2001).

The maximum seedling emergence of *Phalaris minor* from 2.5 cm seed depth and only 9.9 % seedlings emergence from 10 cm depth. Increase in depth beyond 2.0 cm reduced emergence of *Phalaris minor* seedling because of increased mechanical impedence offered by soil column lying over the germinating seeds (Chhokar and Malik, 1999). Singh and Kundra (2003) also reported that highest seedling emergence (28.1%) was recorded under 2.0 cm depth of seed placement with significant reduction in emergence with increase in seeding depth and only 7.3 % seedlings emerged from seeding depths of 11 cm.

Seeding rate: Optimization of seeding rates is largely influenced by the multitude of environmental and economic factor. If the conditions are ideal, higher than normal seeding rate can increase crop competitiveness and yield thus give the crop an edge on weeds. Bhullar and Walia (2004) reported that the wheat sown with 150 kg/ ha reduced the dry matter accumulation of *Phalaris minor* by 35.4 per cent and resulting in increased grain yield of wheat by 12.3 per cent over recommended seed rate (100 kg/ha). It should be remembered that heavy seeding rates should be used together with other cultural and chemical control measures to be most effective. The competitive nature of wheat was found to be improved with increase in seed rate from 100 to 150 kg/ha even in light soils under optimum fertilizers and irrigation conditions. Sharma and Singh (2011) also reported that increased seed rates from 75 to

150 kg/ha significantly decreased dry weight of weeds in wheat. Increasing the seed rates from 100 to 175 kg/ha in wheat var. WH-423 decreased the dry weight of weeds from 135 to 96 g/m^2 under unweeded plots (Panwar *et al.*, 1995 and Yadav *et al.*, 2001). Therefore, increased seed rate helps in smothering weeds particularly *Phalaris minor* by providing early competition advantage due to more number of crop plants per unit area. As wheat density increased weed shoot biomass decreased significantly (Miralavi *et al.*, 2010).

Sowing time: The sowing of crop can be manipulated in such a way that ecological conditions for germination of weed seeds are not met due to escape mechanism. Temperature conditions during the last week of October are less conducive for the germination of *Phalaris minor* and its infestation is low in wheat crop sown during last week of October. The optimum temperature range for seed germination of *Phalaris minor* is 10 -20 ^{0}C (Chhokar and Malik, 1999). Singh and Kundra (2003) also study the effect of temperature on the germination of *Phalaris minor* biotypes and they reported that seed germination started at 10^{0}C, increased progressively with increase in temperature upto 19 ^{0}C and further increase in temperature caused decrease in germination percentage and no germination was recorded in *Phalaris minor* at 7 ^{0}C. Weeds vary in preference for germination, late seeding effectively control early germinated weeds, while early seeding results in crop competition with later germinating weed species but delayed seeding is not cost effective strategy as the cost in yield by waiting to control a weed flush exceeds the cost of applying herbicides as crop planted late are shorter, produce fewer tillers and are less competitive with weeds than crop planted at recommended time. Delayed sowing beyond November, however, resulted in reduced growth of some weeds like *Vicia sativa* and *Lathyrus aphaca* (Singh *et al.*, 1999). Mahajan and Brar (2001) reported that the crop sown on October 25 caused 26.9 per cent reduction in dry matter accumulation by *Phalaris minor* and 21.6 per cent higher grain yield over November 10 sown crop at Ludhiana. The highest dry matter of *Phalaris minor* was recorded in November 10 sown crop as compared to November 25 sown crop due to prevalence of congenial temperature for germination of *Phalaris minor* around this date. Whereas, Miralavi *et al.* (2010) observed less weed density and lower total weed biomass in early planting (October, 22) wheat crop as compared to November, 11 and November, 21 sown crop.

Crop cultivar: Crop variety play an important role in crop weed competition because of variations in morphological features, canopy size and relative growth rate which leads to weed suppression. Variety with quick initial growth and more leaf area must be preferred in order to reduce crop weed competitions. Crop vigour and competitiveness against weeds can differ among varieties. So, cultivar selection is an important component of integrated weed management. An ideal cultivar should have rapid seedling emergence and high seedling growth rate, rapid leaf area expansions, dense canopy maintained over time, rapid canopy closure, efficient in nutrient use with tall height and indeterminate growth habit (Davis *et al.*, 2005). Fast canopy forming and tall cultivars generally suffer less from the weed competition than the slow growing and short stature ones (Naylor, 2002). Travlos (2012) observed that some wheat cultivars with enhanced weed competitiveness can improve the efficacy of herbicides. Semi dwarf wheat varieties are generally less competitive than tall varieties, which spade out weeds. So, it is important to choose a variety of crop plant that is well adapted to agro climatic conditions of the region. Wheat variety WH 147 and HD 2285 were found to be most competitive with winter wild oat compared with HD 2009, WH 291 and S 308 (Balyan *et al.*, 1991). Mahajan *et al.* (2004) found that PBW 343 more competitive to weeds as compared to PDW 233 due to more number of tillers. Chauhan *et al.* (2001) reported that HD 2687 was more competitive variety followed by PBW 343 as compared to WH 542 and WH 157. Significantly less dry matter accumulation of *Phalaris minor* was recorded with HD 2687 and PBW 343 wheat varieties, which may be due to significantly higher effective tillers of these varieties as compared to others (Table 2).

TABLE 2: Performance of wheat cultivars on dry weight of *Phalaris minor* and grain yield of wheat.

Wheat cultivars	Dry weight of *Phalaris minor* at 90 DAS (g/m^2)	Effective tillers (per m row length)	Grain yield (q/ha)
WH 157	52.5	67.9	55.1
PBW 343	44.7	83.4	58.9
WH 542	51.0	71.4	56.0
HD 2687	39.3	86.1	67.1
LSD (P= 0.05)	5.0	4.8	2.9

(Source: Chauhan *et al.*, 2001)

Crop rotation: Crop rotation is one of the most important factors in an integrated weed management programme. Many weeds are strongly associated with specific crop because of ecologically similar requirements of both crop and weeds. So, by changing crop, ecological requirement of the associated weeds are not met resulting in niche disruption. Different crop also allow rotation of herbicides having a different mode of action. Reliance on a monoculture crop leads to weed population shifts to fewer weed species. So, crop rotation should be planned in such a way that maximum diversity in cropping pattern, tillage and herbicides use may be achieved to limit the weed adaptation. Inclusion of sugarcane, vegetable crops, beans, sunflower and clover in the crop rotation with wheat reduces the chances of resistance in weed plants (Malik and Singh, 1995).

There are several crops that can be rotated with wheat in the winter season such as potato (*Solanum tuberosum* L.), onion (*Alliums spp.*), winter maize (*Zea mays* L.), mustard (*Brassica spp.*) and sunflower (*Helianthus annus* L.). Rice- fallow- sugarcane- ratoon sugarcane- sunflower- rice- wheat- sugarcane is a long duration (4 year) rotation which is common in the northeast district of Haryana (India). This rotation offers little opportunity for *Phalaris minor* to proliferate. Other rotations include rice-potato-sunflower, rice-mustard-sugarcane and rice-potato-onion has been found best alternate (Singh, 2007). Resistance to Isoproturon in *Phalaris minor* was observed in 67% of fields under rice-wheat rotations compared to 8, 9 and 16% when rice-berseem-sunflower-wheat, sugarcane-vegetables- wheat and cotton-pigeonpea-wheat, respectively were rotated (Malik and Singh, 1995). Due to smothering effect during later growth stages and rotations of herbicides like atrazine and simazine the dominancy of *Phalaris minor* can be broken by the inclusion of sugarcane in crop rotation (Yaduraju and Ahuja, 1995 and Kirkwood *et al.*, 1997). Inclusion of berseem in the rice wheat cropping system helped to reduced seed bank of *Phalaris minor* within a lesser period of time because the emerged plants of *Phalaris minor* were cut with each cutting of berseem and these were not given any opportunity to set and shed seeds in field (Singh *et al.*, 1999). Similarly in potato based rotations uprooting of germinated *Phalaris minor* plants took place with earthing up or digging operations (Singh *et al.*, 1999). The left over *Phalaris minor* plants were uprooted during land preparation for succeeding crops and hence resulted in reduced soil seed bank status.

Fertilizer rate and application methods: The fertility of the soil affects both the vigour of crop plants and weeds. Weeds can utilize fertilizers as well as or better than crop plants. Placement of the fertilizers in the crop rows has an advantage over broadcast fertilization because most of the fertilizer is directly available to the crop. Due to early availability of band placed fertilizers to crop plants and that too in higher amounts, the crop will make early good growth and will take lead in competition. Proper amount of nitrogen and phosphorus and their banding in or near crop seed row will make them more available to the crop during the seedling stage than to weeds. Crop competition against weeds is increased when nitrogen is banded instead of broad cast. Banding places the fertilizer where the crop has greater access to it over surface germinating weeds. Weed densities, biomass and N uptake measured early in the growing season averaged 20-40% less and grain yield of wheat at maturity averaged 12% higher where fertilizer was side banded compared to broadcast in wheat (Kenneth *et al.*, 1998). The seed density of five of six weed species was reduced with subsurface placement of phosphorus compared with surface broadcast of phosphorus (Blackshaw and Molnar, 2009). Placement of fertilizers significantly reduce weed dry biomass from 8.5 to 7.9 g/m^2 than broadcast method of fertilizer application due to lesser availability of applied nutrient in inter row spaces and also due to weed smothering to crop plants (Pandey *et al.*, 2006; Blackshaw *et al.*, 2002). Therefore, placement of fertilizers near to the crop plants is also very beneficial in providing lead to the crop due to its quick and more availability to crop plants as compared to weed plants. Increased nitrogen application is known to increase the ability of cereals to suppress the weeds (Walia, 1983).

Higher dose of nitrogen (160 kg N/ha) significantly reduced the dry matter accumulation by weeds as compared to 120 kg N/ha (Kaur and Bajwa, 2001 and Ashrafi *et al.*, 2010). Prasad *et al.* (1993) reported that nitrogen application upto 150 kg/ha increased the dry weight of grassy weeds and resulted in significant decrease in dry weight of broad leaf weeds, similar results were also reported by Malik and Singh (1993). Thus, under conditions of dense weed infestation and high levels of nitrogen application, grassy weeds are highly competitive with wheat.

Mulching and crop residue management: The principle of mulching is to exclude light from the tops of the weeds until the reserve food supply in the roots is depleted and the weeds starve. Mulch include clean straw, hay or manure, tar paper, saw dust, crop stubbles and black plastic etc. Straw management is a major factor in weed management in wheat grown after rice. Sowing of wheat in standing rice stubbles after combine harvest with happy seeder is best option and this practice is becoming popular among the farmer. Burning of rice straw had many disadvantages and on the other hand its incorporation is labour consuming process involving high costs, so only last viable option is surface mulching of rice straw which is possible only by sowing wheat with happy seeder. Kaur (2009) reported slightly lower dry matter accumulation by *Phalaris minor* in wheat crop sown in standing rice stubbles with Happy seeder and improved grain yield and net returns over the conventional method of wheat sowing. The low population of *Phalaris minor* with happy seeder may be due to the reason that light penetration to the soil surface gets reduced resulting in less germination of weed seeds. Also few emerged seedlings are unable to develop as these face difficulty to come out of the thick layer of straw. Turbo seeder (Drill) utilize rice straw as mulch effectively by diverts straw in front of the tines and places it in between two rows (20 cm apart), wheat is seeded just like the zero tillage drill. Thus straw mulch placed between the two wheat rows checks the emergence of weeds and also adds organic matter in soil (Singh, 2007). Brar and Walia (2009) reported that zero till sowing in standing stubbles reduced the infestation of both grassy as well as broad leaf weeds as compared to conventional tillage as rice straw acted as mulch and due to less soil disturbance (Table 3). Rice straw mulching significantly reduced weed growth and improved grain yield of no-till wheat (Rahman *et al*., 2005).

Chemical strategies: Weed management in wheat is not accomplished by using agronomical and cultural practices exclusively. Herbicides continue to be the most powerful, economically effective and reliable way to control weeds in wheat. The very first step in the direction of chemical use for weed control is the determination of weed species and their densities present at the particular field. After the identification of weed species, their densities and consideration of their economic threshold levels, the next step is to choose the application technique for an herbicide *i.e*. optimum dose of herbicide should be chosen by keeping in mind the competitiveness of crop stand, environmental conditions, application technology and the stage of growth of weeds.

TABLE 3: Effect of planting techniques and weed control treatments on weed density, total weed dry matter at 120 DAS and grain yield of wheat.

Treatments	Weed density*/ m^2		Dry matter* (g/m^2)		Grain yield (kg/ha)
	Phalaris minor	Broad leaf weeds	*Phalaris minor*	Broad leaf weeds	
Planting techniques					
Conventional tillage	9.51	7.19	11.94	14.08	4156
Zero tillage (without tillage)	8.49	7.21	11.33	14.32	4238
Zero tillage (standing stubbles)	6.95	5.32	9.25	10.72	4637
Zero tillage (partial burning)	7.49	5.62	9.72	11.45	4586
Bed planting	7.20	5.44	9.42	10.94	4383
LSD (P= 0.05)	1.47	1.47	1.58	2.22	338
Weed control					
Clodinafop 60 g/ha	7.24	8.98	9.35	17.61	4331
Clodinafop 60g/ha fb 2,4-D 0.5 kg/ha	7.52	2.77	9.62	5.23	4738
Sulfosulfuron 25g/ha	5.05	3.19	6.5	5.67	5238
Mesosulfuron + iodosulfuron 12 g/ha	3.21	2.09	4.07	3.76	5023
Weedy	13.52	9.51	17.34	19.51	2664
LSD (P= 0.05)	2.46	2.11	2.49	3.26	236

* Data are transformed to " X+ 1.

(Source: Brar and Walia, 2009)

Integrated weed management approach creates an opportunity to reduce herbicide rates but never go below optimum or under dose of herbicides because the reduction of dose rate is accompanied by a risk of decreased herbicidal efficacy and development of further weed seed bank in field and acceleration in shift of a weed population to resistant biotypes. Thus, the herbicidal success rate will depend on given soil and environment factors, plant stage and growing conditions, time of application, application techniques and rate of the herbicides. There are several factors which govern the effectiveness of applied herbicides are as follows: -

Climatic conditions: Winds blowing with more speed will create the herbicide loss through drift and will effect non target plant thus causes wastage of herbicide. Rainfall during or after application of herbicides reduce the effectiveness of foliage applied herbicides. For best weed control results, the high nutrient levels of soil are desirable for well proliferation of weed growth thus provide well translocation of active poison to the target site in weedy plants. Good soil moisture is also essential for better efficiency of specially the soil applied herbicides. Always spraying early in the morning gives the best effective results of weed control as carbohydrate levels in the leaves is lowest in the morning and highest in late after noon.

Time of application: Weeds in the seedling stage are usually most susceptible to herbicides. In the actively growing plants, the movement of food and water material is fast throughout the plant. Thus once systemic herbicides enter the plant will reach the target point efficiently. Isoproturon applied at the 2 leaf stage showed the maximum reduction in dry weight of *Phalaris minor* and *A. fatua*, whereas application at the 6 leaf stage had no effect on *A. fatua* (Bhan *et al.* 1985a). Balyan *et al.* (1989) reported that *A. Ludoviciana, C. album* and *L. aphaca* were susceptible to Isoproturon (1.0 kg/ha) when applied at 20-30 DAS, while tolerance was observed with delayed application. Application of Isoproturon at 25 DAS not only resulted in saving of 25% in herbicide rates but also increased the efficacy of weed control (Singh and Malik, 1994a; Singh and Malik, 1993). Delayed herbicide applications after six leaf stage of *Phalaris minor* resulted in lower weed control efficacy with Isoproturon (Yaduraju, 1991). Efficacy of sulfosulfuron was lower on *Phalaris minor* when applied at 20 or 40 DAS compared to 30 DAS (Singh *et al.*, 2002).

Use of surfactants: To get good efficiency of foliar applied herbicides the chemical must be retained on and penetrate through the leaf surface. Wax cuticle, hairs on the leaf and the angle of the leaf, all determine retention and adsorption of chemical applied. Surfactants or surface active ingredients can be added to herbicide formulations to increase their wetting ability and penetration into the leaf. The various herbicides alone and with surfactants against a number of weeds were tested and the best results were obtained when the surfactant was tank mixed with herbicide for control of *Phalaris minor* (Malik *et al.*, 1988). Similarly increased control of *Phalaris minor* and other grassy weeds was achieved by the addition of mineral oil (Welsh, 1994). The activity of sulfosulfuron (Mon 37500) was greatly increased against resistant biotypes with the addition of surfactants (Malik and Yadav, 1997; Singh, 1998). Chhokar *et al.* (2008) also reported the beneficial effect of surfactant in enhancing the herbicide efficacy. They reported that the mean grassy weeds dry weight in pinoxaden at 40 g/ha with and without surfactant were 3.9 and 293.9 g/m^2, respectively. The grain yield with pinoxadan 40 g/ha without surfactant was significantly lower than its application with surfactant.

Selection of herbicides: Always select the proper kind of herbicide by considering environmental, socio-economic factors associated, crop factor and concerned site and situation basis in field scouting and regular weed monitoring of concerned field. Chemical should be selected on the basis of selectivity, mode of action (contact, systemic and soil sterilant) and it's time of application (pre plant incorporated soil applied, pre-emergence incorporated-soil applied and post emergence foliar applied).

Use of herbicide rotation and mixture: In the past few decades with the declining use of alternative weed control methods and complementary practices, the extensive use of herbicides with a single mode of action (often introduced at reduced dose rate) has resulted in weed shifts to resistant biotypes. To avoid this problem, mixing of herbicides of different mode of action has been advocated as a strategy to increase weed control efficacy and to avoid resistance evolution. The herbicide mixtures broaden the weed control spectrum and overcome resistance problem, are cost effective and result in biological activity higher than their individual application (Valverde, 2003). Herbicide mixtures may also be one of the options for management or delay of cross resistance development (Dhawan *et al.*, 2009). Yadav *et al.* (2010) also reported that intra- group combinations of herbicides viz., ACCase inhibitor (clodinafop/ fenoxaprop/ penoxaden) with ACCase inhibitor and ALS inhibitor (sulffosulfuron/ mesosulfuron + iodosulfuron) with ALS inhibitor were compatible and resulted in effective control of *Phalaris minor* and producing grain yield of wheat almost similar to weed free situations. While inter-group combinations were not found suitable and resulted in poor control of *Phalaris minor* with lower yields of wheat. Alternate herbicides with different mode of action also help in delaying the cross resistance. Brar and Walia (2009) also reported that mesosulfuron+ iodosulfuron, sulfosulfuron and clodinafop fb 2,4-D were quite effective against *Phalaris minor* and broad leaf weeds (Table 3).

Malik *et al.* (2008) reported that chlorsulfuron 30 g/ha, triasulfuron 40 g/ha and metsulfuron 4g/ha reduced the density and dry weight of total weed to the extent of 85-89 per cent and produced grain yield of wheat statistically similar to weed free check. The combination of Isoproturon + dicamba, Isoproturon + 2, 4-D and isoproturon + tralkoxydim were found to provide good control of grassy as well as broad leaf weeds (Bhan *et al.*, 1985b, Panwar *et al.*, 1988, Singh and Malik, 1994b, Singh and Singh, 1996). Metsulfuron provided good control of broad leaved weeds and was compatible with clodinafop in a tank mix application but an antagonistic effect was observed when it was mixed with fenoxaprop (Singh and Singh, 2005a). Carfentrazone-ethyl was compatible with sulfosulfuron as tank mixture and there was no adverse effect on the efficacy of both the herbicides against complex weed flora in wheat (Yadav *et al.*, 2009). Application of chlorosulfuron as a tank mix partner with pendimethalin or trifluralin provided good control of *Phalaris minor* and some broad leaf weeds (Singh *et al.*, 2005a). Tank mixed application of carfentrazone with clodinafop, fenoxaprop or sulfosulfuron was effective against grass and broad leaf weeds (Singh and Singh, 2005a). But some mixtures have antagonistic effect on weeds and grain yield. Singh and Singh (2005b) reported that the combinations of 2,4-D and metsulfuron with clodinafop, fenoxaprop and sulfosulfuron were found incompatible as tank mixture.

It may be inferred that tank mixture of herbicides although provided effective control of weed flora but provided some phytotoxic effect on effective tillers and grain yield of wheat (Singh *et al.*, 2005a). Fenoxaprop and clodinafop are very specific to *Phalaris minor* and *A. ludoviciana* control but are ineffective against broad leaf weeds of wheat. When fenoxaprop and clodinafop used as tank mixtures with 2,4-D and metsulfuron for the control of complex weed flora, show antagonistic effect and resulted in poor efficacy on grassy weeds (Yadav *et al.*, 2002).

Integrated weed management strategies: Integrated weed management practices is required for effective management of weeds in wheat crop. Such practices include field preparation, stale seed bed technique, residue management, planting time and method, increased seed rate, narrow row spacing, adoption of competitive cultivars, fertilizer application methods, crop rotation, time and method of herbicide application, herbicide rotation and mixture, mechanical weeding appears to be the key ingredients of a sustainable weed management in wheat. It is very clear that herbicide alone will not be the solution for weed problem in wheat. Therefore, perfect sowing techniques that allow integration of mechanical methods with herbicides or cultural methods require urgent attention. The integration of stale seed bed with isoproturon + surfactant and diclofop methyl + surfactant reduced the total weed dry weight and increased wheat grain yield by 113.8 and 117.4 %, respectively, over the unweeded normal seed bed. The superior performance of stale seed bed in integration with herbicides might be attributed to combined action of stale seed bed in uprooting the burial action of existing first flush of weeds and control of subsequent flushes with post emergence application of herbicides. Stale seed bed followed by herbicides also increase the grain yield of wheat compared to unweeded normal seed bed because of their efficacy in reducing crop weed competition (Kumar *et al.*, 2005) (Table 4).

TABLE 4: Interaction effect of seed bed manipulations and weed control methods on total weed dry weight and grain yield (q/ha) of wheat.

Weed control methods	Weeds dry weight (g/m^2)			Grain yield (q/ha)		
	Stale seed bed	Normal seed bed	Normal seed bed + triallate	Stale seed bed	Normal seed bed	Normal seed bed + triallate
Weedy check	209.1	345.0	237.6	35.61	25.59	32.51
Isoproturon + surfactant	85.9	132.8	101.1	54.71	44.52	51.79
Dichlofop-methyl	117.1	183.6	149.4	43.52	29.16	41.44
Dichlofop-methyl+ surfactant	104.1	161.4	114.1	55.63	39.37	49.03
Hand weeding	134.4	158.5	146.3	45.81	43.40	39.51
LSD (P= 0.05)		8.8			6.67	

(Source: Kumar *et al*., 2005)

Integration of herbicides with hand weeding attributed to efficient and prolonged weed control. Herbicide supplemented with hand weeding for the control of late emerging weeds. Weed intensity and dry matter of weeds at harvest were significantly lower in weed free followed by pendimethalin pre emergence @ 1.0 kg/ha + hand weeding and was maximum in weedy check (Patil and Dhonde, 2009). Integration of isoproturon @ 0.75 kg/ha + 2,4-D @0.5 kg/ha with one interculture at 30 DAS was the best treatment in terms of reducing weed population and dry weight at different stage of crop growth (Rathi *et al*., 2008).

An integrated approach, where herbicide plays a pivotal role is the only way ahead for effective weed management. Use of weed free seed, use of well rotten farm yard manure, method of sowing, seed rate, sowing time, varietal selection, amount of fertilizer application, proper herbicide selection, proper dose, time and method of herbicide application, herbicide rotation and mixture, use of adjuvant, mechanical weeding and crop rotation are the major constituents of integrated weed management. Thus, integrated weed management practices should be decided on site and time specific basis and it should be designed as a long term strategy by considering the weeds in a broader ecological and management context. The future demands that the farmer need to be more innovative to lower the menace of weeds by adopting new agronomic tools in an integrated manner for effective and efficient weed management in wheat crop.

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