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Weed Management Practices in Wheat (*Triticum aestivum* L.): A Review

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ABSTRACT

Wheat is India's second-largest staple food crop grown in different agro climatic zones within different crop sequences, as a result of which a diversity of weeds infests to this crop. Diversity of weeds including grassy, broadleaf weeds and sedges are mainly infested to the crop. *Phalaris minor* (grassy) and *Rumex dentatus* (broadleaf) are the most dominant weeds in northern region of country. For receiving fast results, use of herbicides is most popular method of weed control and used all over the world. But over reliance on herbicides has created several complications such as environmental quality deterioration, shifting in weed flora and development of herbicide resistant weeds. These problems can be abridged to a great extent by decreasing reliance on chemical method which can be done by integration of various cultural and mechanical methods to the weed management program. Various cultural practices such as nutrient management, seeding rate, spacing, cropping sequence, water management, sowing methods, sowing time and competitive varieties should be followed in such a way that crop plants utilize much more resources in comparison to weed plants. As a mechanical measure, Furrow Irrigated Raised Bed (FIRB) method and stale seed bed technique are recommended for effective weed management. Timely application of herbicides with recommended doses with the help of efficient spray technology improves the efficacy of herbicides. So with the help of Integrated Weed Management (IWM) *i.e* integration of various cultural, mechanical and chemical methods, we can efficiently managed the diverse weed flora in wheat crop.

Key words: Herbicide resistance, Herbicide, IWM, Weed flora, Wheat.

Wheat is king of cereal crops as it is the world's most valuable cereal crop and India's second most important food-grain crop. It constitutes a major portion of total food grain production of our country. It occupies an area of 214.3 m ha worldwide, with production and productivity of 734.1 mt and 3425.5 kg/ha, respectively (FAO STAT, 2018). In India, it is grown an area of 30.59 m ha with an annual production of 99.78 mt and an average productivity of 3220 kg ha^{-1} (Anonymous, 2018). As population density of India is continuously increasing day by day, so to fullfill the food requirement of growing population, the present productivity of wheat has to be raised to the level of 4.29 t/ha, as the possibility of expansion in horizontal direction is remote. Although there are several obstacles in achieving full potential of this crop but poor weed management is one of the key barrier that lowers down the yielding ability of wheat crop to a great extent (Bisen and Singh, 2008a). The susceptible nature of high yielding dwarf varieties along with high requirements of water and nutrients provided a favorable environment for more weed infestation and created a serious problem in successful crop production. The dwarf cultivars of wheat along with erectile leaf orientation cause more penetration of light through weed canopy and make them more competitive (Bisen and Singh, 2008b). The reduction in yield depends upon various factors such as species and type of weed flora, number of weed plants, varieties and spacing of wheat and various soil and environmental factors (Malik and Singh, 1995). Although wheat crop is cultivated in many cropping systems including sequence with rice, maize, bajra, moongbean *etc*., but among these, cropping system including rice has occupied maximum area throughout the country and world (Timsina and Connor, 2001). Weed infestation has more disastrous effects on rice-wheat cropping system as compare to other systems (Harrington *et al*., 1992; Singh *et al*., 2017) because puddling practiced in rice causes nearly 8 per cent losses in succeeding wheat crop (Kumar *et al.,* 2008). Wheat production also gets reduced due to late sowing of wheat by delayed harvesting of preceding rice crop (Singh *et al*., 2014). So, for getting higher grain yield, weed control is key task, which should be performed during early growth period of wheat *i.e* 30-45 days period after sowing because wheat plants are very sensitive during this period. Weed management in wheat can be performed by cultural, mechanical and chemical methods. Due to laboriousness, energy intensiveness and time consuming nature of hand weeding it is only applicable for control of annual weeds at small scale. Mechanical methods are also effective but

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limited to control of weeds occurring between crop rows. Under such conditions, herbicides plays as most ideal, effective and economic method in lowering down the weed population and grain yield losses (Chhokar *et al.,* 2012). However, inappropriate use of many effective herbicides has contributed to the creation of resistance to herbicides in weeds which is a chief region for serious infestation of weeds. Under such circumstances, integrated weed management (IWM) have a crucial role in economical weed management in sustainable manner. IWM includes combining multiple methods of weed prevention and weed control with the target weeds in the correct proportion and at the required time (Gupta *et al*, 2008). This review paper focuses on various components (cultural, mechanical and chemical means) and approaches of integrated weed management and explains them in a precise manner.

Weed competition

Weed infestation creates competitive environment for wheat by competing with it for water, nutrients, light and space (Jeet *et al*., 2010). Weeds account approximately third portion of total losses caused by all pests. Under severe cases they may cause total failure of crop. Weeds cause increase in cost of production by influencing costs associated with chemical, labour, equipment and other management practices (Singh *et al.,* 2011a). Weeds also affect crop production indirectly. Indirect effects of weeds on crop production mainly include harboring various insect-pests, lowering down the grain quality and increasing the processing cost (Zimdahl *et al*., 2013). Extent of wheat yield loss caused by weed infestation is described in Table 1.

Diversity and shifting of weed flora in wheat

A number of weeds infests wheat crop throughout the world. Some of the important weeds of wheat crop are discussed in Table 2. Weed flora varies with respect to field and areas depending upon various environmental conditions, soil characteristics, fertilization, irrigation, cropping systems and various weed management practices. Performance of wheat cultivars on the basis of dry weight of weed flora is represented in Table 3. Weed flora of wheat crop has represented a significant variation over last many years. During 1960's, *Carthamus oxycantha* was major problem in wheat crop but this weed disappeared from wheat fields due to increased irrigated area during green revolution. During green revolution, cultivation of various semi dwarf high yielding cultivars along with increased rate of fertilizer application and more assured irrigation resulted in replacement of broadleaf weeds by various grassy weeds such as canary grass and wild oat (Yadav and Malik, 2005). But several weeds such as jungali palak and alfaalfa still associated with rice-wheat cropping system as major weeds of irrigated weed (Pal *et al*., 2016). Repeated use of single herbicide for a longer period of time results into development of resistance and shifting of weed flora (Qasem, 2013). After isoproturon resistance in *P. minor* (Chhokar and Sharma, 2008), some new chemicals such as fenoxaprop, clodinafop and sulfosulfuron were tested against *P. minor* and these herbicides provided excellent results against this weed. These herbicides were effective against only grassy weeds and their repeated use for long time resulted in shifting of weed diversity towards broadleaf weeds (Chhokar *et al*., 2008b). In recent years, *Rumex dentatus* has also emerged as a big problem in irrigated wheat (Singh *et al.,* 2011b). This weed has developed resistance against various ALS inhibitor herbicides particularly metsulfuron (Heap, 2014). Per cent occurrence of major weeds in rice-wheat cropping system and other cropping system is represented in Table 4. *P. minor* still remains a dominant weed in rice *fb* wheat cropping system whereas *A. ludoviciana* became a serious issue in well aerated light textured soil (Pal *et al*., 2015). With respect to present time, *P. minor* is still causing drastic yield losses in wheat crop particularly in north-west part of India comprising Haryana, Punjab, Delhi and U.P. Nearby areas to North West region such as Uttaranchal, Himachal Pradesh, Bihar and Madhya Pradesh are also at higher risk of developing herbicide resistance in *P. minor.* In Haryana, *P. minor* infestation varies with one district to other district. Table 5 represents the contamination of *P. minor* in wheat crop in several districts of Haryana.

Different approaches of integrated weed management

Cultural methods of weed management

There is a significant impact of various cultural practices on growth of weed plants (Barberi *et al*., 2002). Several major cultural methods are discussed below:

Zero tillage

Table 6 represents the effect of different tillage practices on weed population and their dry weight. It is observed that population of various weeds particularly *P. minor* is reduced to a great extent by practicing zero tillage as it lower down its germination. Zero tillage also gives effective results against weeds even in the absence of residues on soil surface (Kumar *et al*., 2013). Yadav *et al.* (2002a) also reported less severity of *P. minor* under zero tillage. Rice straw burning results into more emergence of *P. minor* and lower down the efficacy of various grassy herbicides (Chhokar *et al*., 2009). Zero tillage with residue retention also helpful in management of broad leaf weeds such as *R. dentatus* and *Mellilotus indica* (Kumar *et al*., 2015) but continuous practice of zero tillage for a year after year may result into shifting of weed diversity in the favor of broadleaf weeds like *R. dentatus and M. parviflora.*

Mechanical method of weed control

This method has great role in suppression of population of weed and enhancement in crop yield (Kolb *et al*., 2010). It

Table 1: Extent of yield losses in wheat due to weed infestation.

Examples	Wheat grain yield losses (%)	Examples	Wheat grain yield losses
Gharde *et al*, 2018	10-20	Oad *et al*., 2007	35
Malik and singh, 1995	Upto 100	Jat *et al*., 2003	15-40

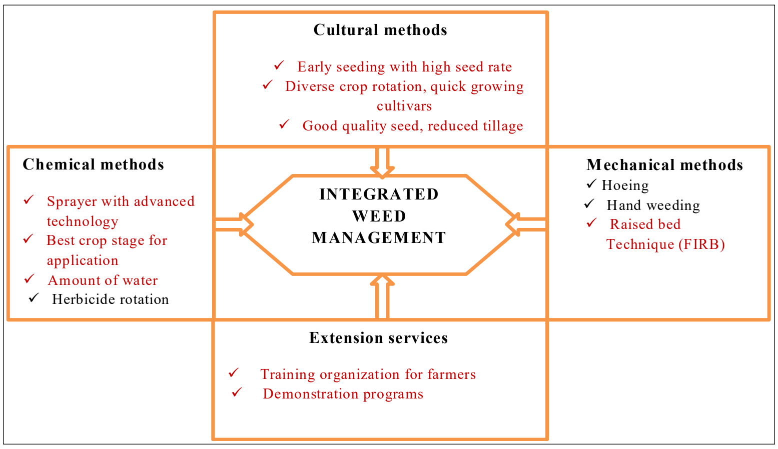

Table 2: Major wheat flora of wheat crop.

Weed species	Common name	Family	Habitat
A-Grasses			
Phalaris minor	Canary grass	Poaceae	Annual
Avena fatua	Wild oat	Poaceae	Annual
Cynodon dactylon	Bermuda grass	Poaceae	Annual
B-Sedges			
Cyperusrotundus	Nut sedge	Cyperaceae	Perennial
C-Broad leaf weeds			
Chenopodium album L.	Lamb's quarter	Chenopodiaceae	Annual
Anagallis arvensis L.	Blue pimpernal	Primulaceae	Annual
Convonvulus arvensis L.	Field binder	Convonvulaceae	Annual
Melilotus alba	Sweet clover	Leguminaceae	Annual
Coronopus spp.	Lesser swine-cress	Brassicaceae	Annual
Rumex spp.	Dock	Polygonaceae	Perennial

Table 3: Performance of wheat cultivars on dry weight of weed flora.

Varieties	Weed Population (no. per m^2)	Weed dry matter (g/m^2)	Economical yield (t/ha)
WH283	3.1	175.1	36.6
WH542	3.7	211.6	35.7
HD2329	3.8	201.9	32.6
CD at 5%	0.13	14.29	1.82

(Source: Walia and Singh, 2005).

Table 4: Per cent occurrence of major weeds of wheat in rice fb wheat and other major cropping system.

Rice-wheat cropping system		Other cropping system	
Weeds	% occurance	Weeds	% occurance
Phalaris minor	86	*Anagallis arvensis*	33
Rumex marimatus	45	*Trigonella polycerata*	26
Anagallis arvensis	42	*Chenopodium album*	93
Chenopodium album	58	*Avenaludoviciana*	48
Melilotusindica	56	*Phalaris minor*	48
Convolvulus arvensis	24	*Fumaria parviflora*	21
Polypogon monspeliensis	18	*Vicia sativa*	19

Source: Malik and Malik (1994).

Table 5: *P. minor* competition in wheat seeds in several districts of Haryana.

Districts	Sample (no.)	*P. minor* seed count/125 kg wheat seed		
		Mean	Minimum	Maximum
Kurukshetra	16	379896	98738	940847
Karnal	39	330687	48350	1700003
Fatehbaad	15	302818	32213	1537347
Kaithal	33	189017	17784	679172
Barwala	11	128437	46578	214891

(*Source*: Yadav *et al.,* 2002).

Table 6: Weed population and dry weight as influenced by various methods of tillage.

Tillage	Weed (no./m^2)		Weed dry matter (g/m^2)		Grain yield (Kg/ha)	
	P. minor	*C. album*	*A.arvensis*	Other weeds		
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).

involves practicing of various equipment for hand weeding and uprooting of weeds. This method reduces the dependency on herbicides and this quality makes this method more popular among researchers (Chikowo *et al.*, 2009; Jabran *et al.,* 2010).

Planting with FIRBS technique that is furrow irrigated raised bed system, is one of the best practices of mechanical weed management. In this method, several raised beds are prepared which causes failure in the germination of weeds due to fast drying of topmost surface of bed (Mishra *et al.,* 2005). Kumar *et al.* (2014) also observed a significant reduction in weed population and weed control efficiency under FIRBS technique (Table 7). Generally bed planter is used for practicing this technique. Some other effective practices of mechanical weed control such as planting with Turbo Happy Seeder and raised bed sowing are also found effective against various weeds of wheat crop. Mechanical hoeing practiced for raised bed preparations is mainly done by tractor and it causes large extent reduction in the population and dry matter of weeds (Dhillon *et al.*, 2005). Mechanical weeding practiced twice over 15 and 30 days stage was observed to be most effective in reducing the accumulation of weed dry matter (Sharma and Singh, 2011).

Seed rate and spacing

Babu *et al.* (2017) reported that maximum weed population was observed in wheat sown under 25 cm spacing between two rows with 100 kg of seed rate per hectare and minimum weed population was reported in wheat sown under inter row spacing of 20 cm with seed rate of 150 kg per hectare (Table 8). Similarly higher the seed rate, lesser will be the population density of weed (Marvat *et al.*, 2011). Narrow spacing and higher seed rate causes lower uptake of nutrients by weeds which results into decrease in the dry matter of various weeds more particularly *P. minor* to a great extent (Mahajan and Brar, 2002).

Row direction

It is generally assumed that ground surface is more efficiently covered by North-South rows as compare to East-West rows and thus reduces the weed infestation (Widderick *et al.,* 2018).

Crop sequences

There is a great impact of crop sequences on severity of weed population (Kagode *et al.*, 1999). Methods of various herbicidal applications can be easily dictated by choice of crops and crop sequence (Stevenson and Johnston, 1999). By getting proper knowledge of suitable crop sequence, farmers can easily reduce the current weed infestations and also can predict the weed severity of upcoming future.

Planting time

It is generally observed that less infestations of *P. minor* occurs in early sown wheat as compare to late sown wheat. This is due to higher temperature faced by weeds during early sowing which is not favorable for weeds of wheat crop. Under early seeding, wheat plants give a tough competition to *P. minor* plants germinated during first irrigation. Table 9 presents the effect of sowing time on *P. minor* dry weight and wheat grain yield.

Prevention of weed seed entry into field

Weed seed may also enter into cultivated area through various contaminated inputs such as crop seeds, FYM, vermicompost and irrigation water. Among these, contamination of crop seeds with weed seeds is the main cradle responsible for heavy weed infestation. This type of contamination can be removed by using clean and certified seeds. Various kinds of manures and vermicompost used in field should be well decomposed and free from contamination of weed seeds.

Crop rotation

Crop rotation is supposed to be an excellent practice for controlling various noxious and mimicry weeds such as

Table 7: Effect of sowing methods on several weed characterstics and wheat grain yield.

Treatments	Weed population at 60 DAS	Weed dry weight at 120 DAS	Weed control efficiency (%)	Grain yield (q/ha)
Strip till-drill (STD)	467.30	198.10	61.38	31.28
	16.61	11.83		
Zero tillage (ZT)	524.43	213.63	61.44	29.59
	16.97	13.07		
Surface seeding (SS)	569.87	238.93	61.09	29.93
	18.04	12.27		
Reduced tillage (RT)	505.03	247.17	62.09	30.42
	17.06	13.00		
Conv. line sowing (CLS)	346.27	199.40	62.16	33.31
	14.17	11.66		
FIRBS	261.40	180.07	62.17	37.43
	12.35	11.08		
SEm ±	0.41	0.175	1.25	0.62
CD (P = 0.05)	1.30	0.565	NS	1.96

(Kumar *et al.,* 2014).

Table 8: Weed density as influenced by planting geometry and seed rate.

Treatments	Weed density (m^{-2})								
	Chenopodiumalbum		*Anagallisarvensis*		*Convolvulusarvensis*		*Phalris minor*		*Cyperus*
	45 DAS	90 DAS	45DAS	90DAS	45DAS	90 DAS	45DAS	90DAS	*rotundus*
Plant geometry									
Broadcasting	6.14	4.48	6.76	4.66	5.06	3.54	6.9	4.54	13.94
25 cm	6.18	4.24	6.3	4.4	5.2	3.82	6.34	3.66	10.44
22.5 cm	5.86	4	5.94	4.3	5.5	3.42	6.34	4.02	13.76
20 cm	7.34	5.16	6.12	4.14	6.06	4.24	5.78	4.08	10.18
SEm±	0.54	0.62	0.94	0.8	0.64	0.32	0.6	0.36	0.73
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	2.18
Seed rate									
100 kg ha^{-1}	6.3	4.66	6.46	4.48	5.66	3.9	6.32	4.12	12.82
125 kg ha^{-1}	6.38	4.46	6.3	4.32	5.42	3.68	6.32	4.04	12.12
150 kg ha^{-1}	6.4	4.6	6.08	4.32	5.24	3.7	6.38	4.06	11.3
SEm ±	0.92	0.68	0.68	0.48	0.92	0.62	0.92	0.64	1.34
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

(Babu *et al.*, 2017).

Table 9: *P. minor* dry weight and wheat grain yield as influenced by sowing time.

Date of sowing	Dry weight *P. minor* (q/ha)	No. of effective tillers per m^2	Grain yield (q/ha)
25^{th} Oct	4.7	381	47.2
10^{th} Nov	5.7	284	37.3
25^{th} Nov	4.3	258	30.0
CD (0.05)	0.27	27.5	2.15

(Source: Mahajan *et al.,* 2000).

P. minor. It adversely affects weed seed bank because of change in weed management practices with respect to successive crops. Wozniak (2019) reported that number and air-dry weight of weeds were higher in the CM than in the CR system by 57.1% and 75%, respectively. Integration of various vegetables with short life cycle in rice *fb* wheat system may also enhance weed control without any application of herbicides, As discussed earlier, rice-wheat cropping system is more severely affected by the problem of isoproturon resistance compared to other systems like cotton-pigeonpea-wheat, sugarcane-vegetable-wheat, rice-berseem-sunflower-wheat *etc.* So this system should be least followed in farming systems. Dry matter of *P. minor* as influenced by crop rotation is represented in Table 10.

Competitive cultivars

The two components that characterize the weed competitiveness of crops are weed suppression ability (WSA) and weed tolerance (WT). WSA is defined as a variety's inherent ability to lower down competition-based weed growth and WT is defined as a variety's inherent ability to produce good yield despite tough competition from weeds (Jannick *et al.*, 2000). Some of tall and fast growing varieties

Table 10: Dry matter of *P. minor* as influenced by crop rotation.

Treatments	Dry matter of *P. minor* (g/m^{-2})
Rice *fb* wheat (weedicide)	20.9
Rice *fb* wheat (control)	455.3
Rice *fb* potato *fb* wheat	0.0
Rice *fb* berseem	0.0
CD at 5%	4.0

(*Source*: Om *et al.*, 2004).

Table 11: Weed competitiveness as affected height of crop plants.

Wheat genotypes	Dry weight of *P. minor* (q/ha)	Height of *P. minor* biotypes (cm)
Tall (115 cm)	5.3	57
Medium (85 cm)	12.5	92
Dwarf (60 cm)	17.0	90

(*Source*: Paul and Gill, 1979).

with spreading habits forms canopy much earlier as compare to other varieties and smoothers the weed plants (Balyan and Malik, 1989). Wheat varieties like 'WH-147' and 'HD-2285' are more competitive with weeds particularly wild oat as compare to other cultivars. It was reported that under late sown conditions, PBW-343 was found superior against *P. minor* as compare to other varieties (Kaur *et al.*, 2003). Effect of height of wheat cultivars is represented in Table 11.

Stale seed bed/dab system

In this method; two irrigations are applied before seed bed preparation to stimulate the germination of weed seeds present in fields. As a result of this, weeds are germinated which are then destroyed by hand weeding or by using heavy planker. Several non-selective weedicides like glyphosate and paraquat can be also sprayed for getting quick results (Singh *et al.,* 2017). Table 12 and 13 shows the effect of stale seed bed technique on weed density and yield parameters of wheat crop.

Soil mulch

After the preparation of seed bed with the help of various plough, harrow and plankers, the topmost layer of soil is dried and then used as a soil or dust just before sowing of wheat. Generally wheat seeds are sown at a depth of 4-5 cm and weed seeds present in the topmost surface of soil will not germinate until first irrigation is applied and thus shifting of crop weed competition occurs in the favoritisms of crop plants (Ranaivoson *et al.*, 2018).

Straw management and residue mulching

Straw mulch is very helpful in maintaining adequate soil moisture and temperature, conserving soil and controlling various weeds in wheat. Mulch application raises the height of crop plants which results into suppression of weeds (Ullah *et al.*, 1998). Several implements like turbo happy seeder and rotary disc drill have a great role in weed control in wheat sowing with 8 to 10 t ha^{-1} residue mulch on surface. This practice also does not have any adverse effect on wheat plants (Sharma *et al.,* 2008).

Straw burning affects germination of weeds as well as efficiency of herbicides. Therefore burning of straw should be prohibited and it should be retained on field surface as it helps in suppressing weed plants.

Water management

Generally presence of high moisture causes luxury growth of various moisture loving weeds. So level of water should be managed in such a way that it enhances crop growth not weed growth. Weeds like *R. dentatus* and *P. minor* cannot grow in light dry soil whereas wheat crop can easily germinate in marginally drier region.

Nutrient management

Adequate amount of various nutrients particularly nitrogen helps in increasing the competitive ability of crop plants (Blackshaw *et al.*, 2008). Band placement of fertilizers also reduces weed growth (Blackshaw *et al.*, 2004) by making nutrients availability only for crop plants not for weed plants. Fertilizers have also stimulatory effects on the efficiency of various herbicides. Various plant and animal derived nutrient sources such as FYM, vermicompost *etc.* should be applied after their complete decomposition because these are the sources of weed infestation.

Soil solarization

Soil solarization is characterised as a special weed management technique where a polyethylene sheet covers moist soil and heats it for several weeks with solar radiation. As a result of this polyethylene sheet coating, a high temperature of 50-60°C develops in the soil of the northern area during the summer season. In solarized soil, there is significant reduction in the number of total weed flora (grasses, broadleaf weeds and sedges) when compared to non-solarized soil (Arora and Tomar, 2012).

Intercropping

It is one of the most promising approaches for suppressing various weeds in wheat crop. Intercrop helps in whole coverage of cultivated area so that no space remains available for growth of weeds which causes reduction in weed infestation to a great extent in intercropped areas (Elsalahy *et al.*, 2019).

Allelopathy

Allelopathy is defined as key tool of weed management in which various plants discharges several allelochemicals or secondary metabolites which acts as natural weed inhibitors. Various allelochemicals extracted from mulberry, sunflower, winter cherry and barnyard grass have great potential for control of most problematic weeds of wheat such as *Phlarais minor* and *Avena fatua* (Jabran *et al.*, 2010). Liquid extract of *Lantana camara* has also a great role in suppression of germination and vegetative growth of *P. minor* (El-Kenany and El-Darier, 2013). Abbas *et al.* (2018) reported that

Table 12: Weed population (no./m^2) as affected by stale seed bed and other tillage practices.

Treatments	*Chenopodiumalbum*		*Rumex dentatus*		*Cyperus rotundus*		*Cynadon dactylon*
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS
SSB using shallow tillage	3.21(10.9)	1.65(3.1)	2.76 1.63	(8.0) (2.9)	1.99 1.80	(3.8) (3.7)	2.01(3.8)
SSB using glyphosate at 2.0 kg/ha	2.91(8.9)	1.54(2.5)	2.54 1.54	(6.5) (2.5)	1.67 1.50	(2.5) (2.3)	1.42(1.6)
Deep tillage	3.79(15.5)	1.87(4.3)	3.21 1.76	(11.0) (3.5)	2.99 1.85	(9.5) (4.1)	2.38(5.7)
Conventional tillage	4.00(17.4)	1.94(4.7)	4.00 1.88	(17.4) (4.3)	3.19 1.96	(10.9) (4.7)	2.57(6.7)
LSD (p=0.05)	0.10	0.04	0.11	0.06	0.08	0.04	0.08

SSB, stale seedbed technique; DAS, days after sowing (Shivran *et al.*, 2020).

Table 13: Yield parameters as affected by stale seed bed and tillage practices.

Tillage method	Plant height (cm)	Tillers per hill (no.)	Effective tillers per hill (no.)	Non effective tillers per hill (no.)	Spike length (cm)	Spikelet per spike (no.)	1000 grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	Harvest index (%)
CT	78.80a	4.92b	3.90b	1.03	10.40	19.30	41.01b	3.13b	4.95	8.08	38.73b
SS	75.57b	5.46a	4.37a	1.09	10.24	21.05	46.12a	3.54a	4.42	7.96	44.47a
$LSD_{(0.05)}$	2.19	0.39	0.41	3.12	4.34	3.85	2.93	0.058	4.09	3.27	4.44
LS	**	**	**	NS	NS	NS	**	*	NS	NS	**
CV (%)	6.34	4.17	3.06	4.09	4.21	3.72	11.69	12.69	13.69	14.69	15.69

CT: Conventional tillage; CV: Coefficient of variance (significance at 5% or at 1% level of probability); LS: Level of significance; LSD: least significance difference; NS: Non significant; ST: Stale seed bed (Khatun *et al.*, 2016).

application of sunflower, rice, maize and sorghum residues significantly reduced the population of *Phalaris minor* due to allelopathic effects of these crop residues. Use of these residues also caused a significant decay in the seed bank of various weeds in soil.

Chemical method for weed management

Worldwide chemical method of weed management is most popular due to its higher efficacy and quick results. For getting good results, herbicides should be timely applied by knapsack sprayer at recommended dose. Herbicides when smeared in small droplets, causes less toxicity compared to larger droplets due to their superior numerical exposure and translocation (Prasad and Cadogan, 1992).

As we know that wheat crop is affected with a number of various grasses, sedges and broadleaf weeds, so different herbicides are applied in wheat on the basis of their selectivity to weed flora. For isoproturon resistant *P. minor,* several herbicides are fenoxaprop, clodinafop, pinoxaden, pendimethalin, Atlantis and sulfosulfuron are widely used due to their higher efficacy. Among these, clodinafop, pinoxaden and fenoxaprop are specifically used for the control of grasses such as *P. minor* and *A. ludoviciana*. For the management of dicotyledonous weeds (broadleaf weeds), metsulfuron, 2,4-D and carfentrazone are mostly used weedicides. But these weedicides have very little effect on various noxious weeds such as *R. spinosus* and *M. parviflora*. Application of herbicidal mixtures effectively controls such kinds of weeds. Effect of different herbicides and their mixtures on density and biomass of diverse weed flora of wheat is represented in Table 14.

Important guidelines for application of herbicides

Spray technology

Pre emergence spray of herbicides such as pendimethalin and trifluralin can be efficiently done by using tractor mounted sprayer. Because of better coverage in less time, the use of self-propelled sprayers fitted with multiple nozzles should be encouraged for herbicide application compared to other sprayers.

Surfactant and adjuvents

Surfectants improves the efficacy of herbicides by providing better penetration and uniform spreading of herbicide. Herbicides can be easily penetrated into cuticle of leaves with the help of adjuvents which make changes in cuticular waxes of leaves (Malik *et al.*, 1993).

Integrated weed management (IWM)

It means integration of all feasible method of weed control in harmonious manner so that weed density is reduced to a level at they are not harmful for crop growth. Currently we are solely dependent on chemicals for weed management due to their quick and effective results but this over dependence on herbicides has resulted to several serious issues such as development of herbicide resistant weeds, weed flora shift, adverse impacts on soil and environment. For prevention of these detrimental effects of chemicals, it is necessary to integrate other weed control measures such as cultural and mechanical methods along with herbicide application to a weed management program so that weeds can be successfully controlled without any harmful effects

Table 14: Efficacy of different herbicides and their mixtures against density and biomass of diverse weed flora in wheat.

Treatments	Density (no./m^2)		Biomass (g/m^2)	
	P. minor	*R. dentatus*	Grasses weeds	Broadleaf weeds
Pendimethalin (PE) 1.0 kg/ha	2.8 (7)	1.1 (0)	3.6 (12)	2.6 (6)
Metribuzin (PE) 0.21 kg/ha	2.8 (7)	3.0 (9)	3.7 (13)	3.0 (8)
Pendimethalin+metribuzin (tank-mix as PE) 1.0 + 0.175 kg/ha	2.6 (6)	1.1 (0)	3.0 (8)	2.2 (4)
Pendimethalin (PE) *fb* sulfosulfuron (PoE) 1.0 *fb*0.018 kg/ha	2.1 (4)	1.0 (0)	1.9 (3)	1.1 (0)
Sulfosulfuron+metsulfuron (pre-mix as PoE) 0.03 + 0.002 kg/ha	4.2 (17)	1.0 (0)	5.3 (28)	1.0 (0)
Pinoxaden+metsulfuron (pre-mix as PoE) 0.06 + 0.004 kg/ha	2.7 (8)	1.0 (0)	3.3 (13)	1.0 (0)
Mesosulfuron+iodosulfuron (pre-mix as PoE) 0.012 + 0.0024 kg/ha	3.6 (13)	1.0 (0)	4.2 (18)	1.2 (1)
2 Hand weeding (20 and 40 DAS)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Unweeded control	4.3 (18)	5.2 (27)	5.9 (34)	5.7 (34)
LSD (p=0.05)	0.4	0.2	0.6	0.3

(*Kaur et al., 2017*).

Table 15: Most successful IWM approaches for weed control in wheat.

IWM	References
Isoproturon @ 0.75 kg/ha + 2,4-D @ 0.5 kg/ha with one interculture at 30 DAS	Rathi *et al.*,2008
Isoproturon @ 2.0 kg *a.i.* ha/ha+one hand hoeing at 50 DAS	Khaliq *et al.,* 2003
Higher seed rate (125 kg/ha) in zero tillage with mulch of 8 t/ha straw of rice+Mixture of pre-emergence herbicides (pendimethalin @ 1.5+metribuzin @ 0.210 kg/ha	Sindhu *et al.,* 2017
Pre emergence application of pendimethalin @ 1.0 kg/ha+hand weeding	Patil and Dhonde, 2009
Intercultivation+hand weeding	Sudha *et al.,* 2016

on our environment. Various mechanical measures such as soil, different kinds of mulches and stale seed bed also helpful in weed control. Some of the important IWM practices are listed in Table 15.

CONCLUSION

Wheat crop is severely affected with multifarious weed flora comprising several grassy and broadleaf weeds along with sedges. For the management of such a diverse weed flora, application of herbicides is the most efficient method as it gives fast results with greater efficacy. But excess use of the chemicals has resulted into several impediments such as deterioration in environment quality, swing in weed flora and development of herbicide resistant weeds. These complications can be effectively controlled by practicing the INM (Integrated Weed Management) approach. The integration of various cultural methods such as tillage, planting time, row spacing, competitive cultivars, soil solarization and mechanical methods like stale seed bed and Furrow Irrigated Raised Bed Technique (FIRBS) can reduce the over dependency on herbicides. Proper crop rotations should be followed to control some perennial weeds. Farmers should adopt these agronomic practices very efficiently so that they can reduce the infestation of weed with the application of minimum dose of chemicals. Various extension activities should also be conducted in rural areas to educate farmers about the importance of these non-chemical methods so that they can reduce their dependency on herbicides. Thus integration of these cultural and mechanical methods along with the use of chemical can provide excellent control of weed flora if they are efficiently used with proper guidance of experts.

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Conflict of interest

The authors of this paper declare that they do not have any conflict of interest.

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