Indian Journal of Weed Science **47**(3): 233–239, 2015

Weed management in zero-till wheat

A.P. Singh*, Makhan S. Bhullar[1], Ramawatar Yadav[1] and T. Chowdhury
Department of Agronomy, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh 492 012

Received: 8 July 2015; Revised: 12 August 2015

ABSTRACT

In India, wheat covers an area of 30 Mha with 3.1 t/ha productivity. Rice–wheat system has started showing the signs of fatigue. Certain reports say that the wheat yield reduces by 8% when sown after puddled transplanted rice compared to wheat sown after direct-seeded rice. The conventional method of wheat sowing by repeated tillage delays the sowing by 10 to 15 days, which adversely affect yield. To curtail problems faced by intensive tillage in rice and delayed sowing of wheat, adoption of no or reduced tillage is a viable option. The high input requirement and less competitive nature of high yielding dwarf wheat varieties have provided conducive environment for weed infestation. The average yield losses caused by weeds in different wheat growing zones ranged from 20 to 32%. Uncontrolled weeds in wheat caused 60.5% reduction in wheat grain yield under CT and 70% in ZT conditions. Potential solutions include a shift from intensive tillage to no or reduced tillage and/or from transplanting to direct-seeding. Zero tillage ameliorates the problem of delayed sowing as well as reduces weeds like *Phalaris minor* in wheat. A shift from an intensive tillage to reduced/no tillage system cause major changes in weed dynamics, herbicide efficacy and weed seed recruitment. Therefore, an attempt has been made in this article to review works done on several aspects of weed management in zero-till wheat.

Key words: Conventional tillage, Weed management, Wheat, Zero tillage

Wheat is the king of the cereals and provides more nourishment (rich in carbohydrates). In India, wheat production has increased from 11.0 million Mt during 1960-61 to 93.9 million Mt during 2011-12. It covers an area of 30 Mha with an average yield of 3117 kg/ha (Anonymous 2012-13). This more than eight-fold increase in wheat production was mainly due to the adoption of short stature high yielding varieties, increased fertilizers, irrigation and herbicides use. The high nutrient and water requirements along with less competitive nature of these high yielding dwarf varieties have provided the conducive environment for increased weed infestation which poses challenge for successful wheat cultivation in India. The area under wheat has stabilized, and further expansion seems to be unlikely.

Growth in cereals yield has reached to a plateaue in many high-potential agricultural areas, owing to soil nutrient mining, declining organic matter, increasing salinity, falling water tables and the build-up of weed, pathogen and pest populations. The share of wheat output from high-income countries has fallen from about 45% in the early 1950s to about 35% in recent years. The challenge, therefore, is to further increase productivity while making agriculture more efficient, ecologically sound and sustainable. The farmers could produce more and help conserve their natural resource base by adopting conservation tillage practices (FAO 2001). Conventional tillage with tractors and ploughs is a major cause of severe soil loss in many developing countries. Infact soils in tropical countries are not required to be tilled. The most desirable form of tillage is to leave a protective blanket of surface residues.

Rice–wheat system is the dominant cropping system occupying about 18 Mha in Asia, of which 13.5 Mha area in Indo-Gangetic Plains (IGP) of India (10 Mha), Pakistan (2.2 Mha), Bangladesh (0.8 Mha) and Nepal (0.5 Mha) and feeds about 1.3 billion people (20% of the world population) (Farooq *et al.* 2007, Saharawat *et al.* 2010). Exhaustive nature of both the crops belonging to the same family and extreme tillage requirements particularly of rice has made the system unviable due to the development of hard pan, multi-nutritional deficiencies and destruction of soil structure. It has been reported that on average wheat yield is reduced by 8% when sown after puddled transplanted rice compared to wheat sown after direct-seeded rice in unpuddled conditions (Kumar *et al.* 2008). Now the system has started showing the signs of fatigue. Due to the long duration

***Corresponding author:** *apsinghagron@gmail.com*
[1]Department of Agronomy, Punjab Agricultural University, Ludhiana

rice varieties that decreases the turn-around period and poor rice-stubble management, unavailability of appropriate farm tools and machinery, the sowing of wheat gets delayed. The reduction in grain yield due to delay in wheat sowing has been recorded as 35–60 kg/day/ha in the IGP (Pathak *et al.* 2003). In no-till systems, seeds of weeds and volunteer crops are frequently deposited on the topsoil. Therefore, in no-till and reduced tillage systems, pre-sowing herbicides are a requisite.

Zero tillage in wheat

Reduced and zero tillage systems can overcome low wheat yields by timely sowing. The late harvesting of the preceding rice/cotton crop, often delays the planting of wheat which is the first fortnight of November. "With animal-drawn ploughs, farmers make 6-10 passes over the land to prepare a seedbed for wheat," says a recent report of the rice-wheat consortium for the Indo-Gangetic Plains, a joint program involving Bangladesh, India, Nepal, and Pakistan, and International Agricultural Research Centers. "the tractors prepare land more rapidly for wheat after rice, yet, 6-8 passes of the ploughing implement are common. Substituting mouldboard plough by other tillage equipments can, under some conditions, avoid an increase in weed pressure, as observed by Bàrberi and Cascio (2001), with regard to rotary harrow (reduced tillage). Soil tillage for preparation of autumn-winter cereal seedbed can improve the conditions for germination of weeds (Mirsky *et al.* 2010, Morris *et al.* 2010), which will increase the population density of the weeds in the crop (Bräutigam and Tebrügge 1997). With regard to no-till systems, which are characterized by depositing seeds on topsoil (Morris *et al.* 2010), it is necessary to follow an appropriate procedure, to avoid high weed densities and prevent unacceptable problems (Brainard *et al.* 2013). For the adoption of conservation agriculture systems and their wide spread uptake, weed flora and its dynamics must be understood (Brainard *et al.* 2013).

Sowing of wheat in North India is generally delayed due to cultivation of long and medium duration rice varieties and time required in field preparation of wheat. Tripathi *et al.* (2005) estimated that each one day delay of wheat planting past the optimal date results in a yield loss of 26.8 kg/ha/day. Zero tillage technique not only ameliorates the problem of delayed sowing but also reduces the incidence of most problematic weeds like *Phalaris minor* in wheat. Potential solutions include a shift from intensive tillage to no or reduced tillage and/or from transplanting to direct-seeding. Due to combine harvest of rice, large quantities of crop residues are left on soil surface and poses problem in tillage operations resulting delayed sowing of succeeding wheat crop. Recent estimates indicated that average area under zero-till wheat in India is 7.60 Mha and maximum area under zero-till is recorded in Punjab state (46.6%).

Weed flora and density

Weed flora of wheat differ from field to field, depending on environmental conditions, irrigation, fertilizer use, soil type, weed control practices and cropping sequences. The predominant weeds associated with conventional till wheat are *Phalaris minor*, *Poa annua, Polypogon monspeliensis, Avena ludoviciana*, *Rumex dentatus, R. spinosus, Anagallis arvensis, Convolvulus arvensis, Malva parviflora, Medicago denticulata, Chenopodium album, Vicia sativa, Lathyrus aphaca, Circium arvense, Melilotus alba, Coronopus didymus, Polygonum plebejum* and *Spergula arvensis*. Among grassy weeds, *P. minor* and among broad-leaved weeds, *Rumex dentatus* and *Medicago denticulata* are of major concern in irrigated wheat under rice-wheat system in India (Balyan and Malik 2000, Chhokar *et al.* 2006). *Phalaris minor* is major problem in heavy soils, whereas, wild oat is more prevalent in light textured soil under non rice-wheat rotation. Both *P. minor* and *R. dentatus* are highly competitive weeds and can cause drastic yield reduction under heavy infestation. Evolution of resistance in *P. minor* (Malik and Singh 1993, Chhokar and Malik 2002, Chhokar and Sharma 2008) against isoproturon has made it a single weed species limiting wheat productivity in the North-Western plains of India.

With the shift from CT to ZT, soil disturbance is reduced drastically and soil surface is often covered with previous crop residues. Tillage can influence the vertical weed seed distribution in the soil profile, soil moisture, diurnal temperature fluctuations, light availability, and activities of seed predators and microbes. All these factors can affect weed recruitment in the field by influencing seed dormancy, emergence, and seed mortality. Reduced tillage favoured the growth of *Cirsium arvense* and *Convolvulus arvensis* (Catizone *et al.* 1990). ZT wheat lowers the *P. minor* infestation, which is the main threat to the sustainability of wheat production under rice-wheat system (Franke *et al.* 2007). The less *P. minor* problem under ZT system was due to less soil disturbance as a result *P. minor* seeds present in lower soil layer fail to germinate due to mechanical impedance. Yadav and Singh (2005) observed that maximum *P. minor* population emerged from 0-3 cm soil depth. In both CT and ZT wheat, after direct-seeded unpuddled and puddled rice, there was no emergence of *P. minor* from 6-9 cm depth but still 5% population could emerge from this layer after transplanted rice. Under CT wheat, there was 16% increase in *P. minor* density during 15 to 20 days after sowing in the field before irrigation, but after first irrigation the density of this weed increased by 175% during 20 to 40 days after sowing. In ZT wheat, the density of this weeds increased by 61% before irrigation and after irrigation this increase was only 102%.

Radhey Shyam *et al.* (2009) reported that wheat sown with CT led to significantly higher density of *P. minor, M. indica, M. denticulata* and *C. album* as compared to ZT sown crop. Contrary to this, weed seeds remained in sub-surface under zero till sown crop due to puddling carried out during paddy transplanting and failed to germinate because of unfavorable conditions (Sinha and Singh 2005). ZT wheat helps to control weeds like *P. minor* (Franke *et al.* 2007), *C. album* (Mishra *et al.* 2010), *A. ludoviciana* (Yaduraju and Mishra 2002), *R. dentatus* (Chhokar *et al.* 2007). Singh *et al.* (2004), also reported that the minimum weed population was recorded in ZT sown crop which was significantly less than CT sown wheat. Rahman and Mukherjee (2006), while studying the effect of different tillage practices and herbicides observed that CT+ pendimethalin have more weed control efficiency and higher grain yield than zero tillage with application of different herbicides.

The shift from CT to ZT in wheat has resulted in a shift in weed flora. Main reason for change of weed flora seems to be the use of herbicides for control of grassy weeds and non adoption of any measure to control broad-leaved weeds in wheat over the time. This increases population of perennial and broad-leaved weeds in the zero-tillage system. Also control of *P. minor* reduces competition for other weeds. Singh *et al.* (2002) found in a long term experiment at Karnal (Haryana) that the intensity of *P. minor* decreased by 30-40% in ZT when compared to CT wheat, while the intensity of broad-leaved weeds increased. Laxmi *et al.* (2003), reported that 51% of farmers in Haryana and 85% of farmers in Bihar perceived that weed infestation had decreased due to adoption of ZT in wheat. Unchecked weed growth during crop season caused maximum yield loss in conventional tillage. In Pantnagar, average of 10 year data revealed that there was less intensity of weeds specially *P. minor, Melilotus* spp. and *Polygonum* spp. in ZT wheat as compared to wheat sown by conventional practice at 30 DAS, resulting less infestation of weeds and less competition with crop. The grain yield obtained was also higher in zero tillage wheat over the conventional practice. Mishra and Singh (2012) in Jabalpur found that wild oats showed a strong propensity to increase under all the tillage systems (ZT and CT in rice and wheat continuous and alternated) indicating its ability to persist under modern cropping systems. But in subsequent years, continuous zero tillage lowered its population. *Chenopodium album* seedling emergence declined significantly due to ZT wheat sowing during first year; in subsequent years, population of *C. album* was completely eliminated due the increased density of *A. ludoviciana* and *M. hispida* in all the tillage systems. Brar and Walia (2009) conducted a field survey in the three districts of Punjab *i.e.* Patiala, Sangurur and Moga and found slightly higher population of broad-leaved weeds in zero tillage as compared to the conventional methods while adverse trend was seen in case of grass weeds.

Wheat yield losses

Spectrum of weed flora in wheat has changed from dominance of broad-leaved weeds in the 1960s to mixed flora of broad-leaved and grassy weeds in early 1970s; and then the dominance of grass weeds, especially, *Phalaris minor* in late 1970s. The chemical weed control, therefore, became a necessity in late 1970s. Weeds have enjoyed dominance over crop basically because of poor agronomic management. To introduce good agronomic practices and the ecology, it is important to understand the competition between weeds and the wheat crop. Weed-crop competition begins when crop plants and weeds grow in close proximity and their root or shoot system overlaps. In rice-wheat system, due to enough soil moisture after harvesting of rice, weeds emerge earlier than wheat or along with wheat crop. Losses in wheat yield are primarily due to reduction in tillering. The average yield losses caused by weeds in different wheat growing zones ranges from 20 to 32%. The wheat yield losses due to weeds in North Western Plains Zone (NWPZ) Northern Hills Zone (NHZ) and North Eastern Plains Zone (NEPZ), are higher compared to Peninsular Zone (PZ) and Central Zone (CZ) (Mongia *et al.* 2005). The losses depend on weed species and density, time of emergence, wheat cultivar, planting density, soil and environmental factors (Chhokar and Malik 2002, Malik and Singh 1993, Malik and Singh 1995). Yield reductions due to weeds in wheat vary from 15-50%, depending upon the weed density and type of weed flora (Jat *et al.* 2003). Uncontrolled weeds in wheat caused 60.5% reduction in wheat grain yield under conventional tillage (CT) and 70% in zero-till (ZT) conditions. In extreme cases the losses caused by weeds can be up to complete crop failure (Malik and Singh 1995). The cases of complete crop failure were quite common during late seventies in the absence of effective herbicides and mid nineties due to heavy population of *P. minor,* after the evolution of resistance against isoproturon. Under both the situations, some of the farmers were forced to harvest their immature wheat crops as fodder (Malik and Singh 1993, Chhokar and Malik 2002). The critical period of weed control in wheat is 30-45 days after sowing and crop should be kept weed free during this period. Zero tillage or surface seeding technology is gaining popularity in wheat cultivation, as it not only reduces the incidence of weeds like *Phalaris minor* and *Chenopodium album,* but also improves the input-use efficiency (Mishra *et al.* 2005), improves soil condition due to in-situ decomposition of crop residues, increase in infiltration rate, reduced cost of seed bed preparation and timely sowing of wheat in rice-wheat system. No-till cropping system leaves most of weed seeds in top 1.0 cm of the soil profile (Chahal *et al.* 2003).

Herbicide management

Herbicide use has increased in both CT and ZT systems because it provides effective and economical weed control and saves labor, which has become more scarce and expensive (Rao *et al.* 2007). Hence, it is of paramount importance to work out weed management technology in zero tilled wheat. Mukhopadhyay and Rooj (1971) were the first to conduct the work on zero tillage in West Bengal (India) by using the non selective herbicide paraquat and reported that in zero tillage 3.75 l/ha of paraquat application produced more rice yield as compared to conventional tillage supplemented with one hand weeding (HW). Wheat crop grown as succeeding crop in same field also obtained more grain yield in zero tillage as compared to conventional tillage. Walia *et al.* (2005) reported that wheat sown with zero till after spray of paraquat exhibited significantly less dry matter of *P. minor* as compared to zero till sown wheat without paraquat application as well as conventional tillage sown crop. Hence, it was realized that chemical weeding with application of non selective herbicide would be a key factor for management of weeds and success of zero tillage in wheat.

The studies conducted in Punjab indicated that in areas where *P. minor* has not evolved resistance to isoporturon, its application at 600-1000 g/ha, depending on soil type, before or after first irrigation provided effective control of *P. minor, A. ludoviciana* and *Poa annua*, and many broad-leaved weeds in ZT wheat. In areas, where *P. minor* has evolved resistance to isoproturon, application of pinoxaden 50 g, sulfosulfuron 25 g, clodinafop 60 g, fenoxaprop 100 g/ha at 30-35 DAS of wheat provided effective control of *P. minor* and *A. ludoviciana* in ZT wheat. In case of broad-leaved weeds like *C. album, Anagallis arvensis, Medicago denticulata, Coronopus didymus, R. dentatus etc*., 2,4-D sodium salt or 2,4-D ethyl ester at 400-500 g/ha at 35-45 DAS when wheat is sown at normal time and at 45-55 DAS in late sown crop (December) are effective.

Metsulfuron 5 g/ha at 30-35 DAS provides effective control of *R. spinosus* along with other broad-leaved weeds, as 2,4-D do not control this weed. Carfentrazone-ethyl at 20 g/ha at 20-25 DAS provides effective control of all other broad-leaved weeds including *Malva parviflora* and *R. spinosus*. In fields where both grass and broad-leaved weeds are present, one post-emergence application of sulfosulfuron + metsulfuron at 30 g, mesosulfuron + iodosulfuron at 15 g, fenoxaprop + metribuzin at 500 g or tank-mixture of clodinafop 60 g + 2,4-D 400 g/ha, metsulfuron 5 g/ha at 30- 35 DAS is effective. In fields, where rapeseed and mustard crop is sown with wheat, use of only clodinafop and fenoxaprop is advisable. Do not use sulfosulfuron, sulfosulfuron + metsuflruon, mesosulfuron + iodosulfuron herbicides in wheat fields in which sorghum (jowar), maize or bajra is to be sown after wheat. Do not use the same herbicide year after year as it leads to the evolution of resistance in weeds. Herbicide rotation should be followed every year to prevent the evolution of resistance and for getting the best efficacy from the herbicides.

Crop residue management

The majority of farmers in rice-wheat systems, especially in North-Western IGP, burn residues of previous rice crop for its rapid disposal before wheat sowing because it can interfere with drilling. Such burning of rice straw increases the germination of *P. minor* and reduces the efficacy of soil-active herbicides like isoproturon and pendimethalin (Chhokar *et al.* 2009). Recent advances in planting technology have made it possible to sow wheat successfully into heavy residues and facilitated the use of residues as mulches for weed suppression. In particular, the rotary disc drill and turbo/happy seeder can sow/place the wheat seed in heavy residue mulch of up to 8 to 10 t/ha without any adverse effect on crop establishment (Kumar and Ladha 2011, Sharma *et al*. 2008). In addition to the suppressive effects on emergence of weeds, residues can contribute to weed seed bank depletion through seed predation. When rice residues are kept on soil surface as mulch, emergence of *P. minor, Chenopodium album*, and *R. dentatus* was inhibited by 45,83 and 88%, respectively at 6 t/ha rice residue load compared to without residue mulch (Kumar *et al*. 2013). With 8-10 t/ha of rice residue mulch, *P. minor* emergence was inhibited by 65% and that of *C. album* and *R. dentatus* by >90%. ZT also facilitates timely wheat planting which further create ecological conditions in favour of crop than *P. minor*. When ZT in wheat is combined with residue mulch (6-8 t/ha) and early planting (25 October), the emergence of *P. minor* was reduced by 83-98% compared with normal (mid November) or delayed (25 November) planting without residue. Chhokar *et al*. (2009) observed that 2.5 t/ha rice residue mulch was not effective in suppressing weeds, but 5.0 and 7.5 t/ha residue mulch reduced weed biomass by 26-46%, 17-55%, 22-43%, and 26-40% of *P. minor, Rumex dentatus, Meliloyus indica* and *Polypogon monspeliensis*, respectively compared with ZT without residue.

Herbicide resistance management

Herbicide resistance in *P. minor* against isoproturon was the most serious problem in wheat in rice-wheat cropping system (RWCS) during early 1990s. Efforts on herbicide resistance management before 1996-97 were concentrated around alternate crops (Malik *et al*. 2002). The problem of resistance was so serious that farmers in Haryana started sowing sunflower and in Punjab the farmers started growing mustard, sugarcane, egyptian clover (fodder) to exhaust the seed bank of *P. minor*. Crop rotation was possible only in small area and farmers needed a viable technology for herbicide resistance management. Zero-tillage made it possible to achieve three major objectives leading to create competition in favour of crop. These are optimum plant population, seeding at a time which is not conducive to *P. minor* emergence and accurate fertilizer placement. In a study conducted by Franke *et al*. (2007) at farmer's field in Haryana, correlating the number of germinable *P. minor* seeds in soil with the number of *P. minor* seedling emerged, it was found that ZT reduced the emergence rate of first flush of *P. minor* by 50%. Rate of emergence of second and third flush was also lower in ZT plots compared to CT plots. The first flush of *P. minor* is more damaging to the crops compared to later flushes and ZT is found relatively more effective in reducing first flush than other flushes.

The continuous use of alternate herbicides having similar mode of action, for many years, have resulted in reduced efficacy of a particular group of herbicides at farmers fields in Punjab and Haryana. This has happened with respect to the control of *P. minor* with the use of clodinafop and fenoxaprop and in some areas also with suflosulfuron group of herbicides. Recently, *Rumex dentatus* have evolved resistance to metsulfuron-methyl (Chhokar *et al*. 2013) and the problem of *Rumex dentatus* and *Malva parviflora* in wheat is increasing under no-till situations. In future, the menace of these weeds may increase due to increase in area under no till conditions and resistance evolution. This indicates that the farmers need to rotate herbicide mode of action every year.

The adoption of non-chemical approaches like early sowing of wheat from last week of November to first week of November reduces/minimizes the infestation of *P. Minor*. Its infestation can also be reduced by rotating wheat with other crops like berseem, potato, raya, gobhi sarson and winter maize. Sowing wheat in narrow rows (15 cm spacing) and selection of quick growing wheat varieties like '*WH 502*' , '*WH 542*' and '*HD 2967*' and '*PBW 621*' and '*HR 1105*' suppresses the growth and development of *P. minor*. The adoption of these non-chemical approaches and herbicides will delay the evolution of resistance in weeds.

This paper concludes that conventional tillage system can be replaced by more economical reduced tillage options with proper recommended weed management strategies, however, some long term research is needed to determine medium-term positive or negative effects of reduced tillage on sustaining wheat yields.

REFERENCES

Anonymous. 2013. *Agricultural Statistics at a Glance*. Directorate of Economics and Statistics, Department of Agriculture and Coperation.

Balyan RS and Malik RK. 2000. New herbicides for jungali palak (*Rumex retroflexus* L.). *Indian Journal of Weed Science* **32**: 86-88.

Bàrberi P, and Lo Cascio B. 2001. Long-term tillage and crop rotation effects on weed seed bank size and composition. *Weed Research* **41**: 325-340.

Brainard DC, Haramoto E, Williams II and MM Mirsky S. 2013. Towards a no-till no-spray future? Introduction to a symposium on non-chemical weed management for reduced tillage cropping systems. *Weed Technology* **27**(1): 190-192.

Brar AS and Walia US. 2009. Weed dynamics and wheat (*Triticum aestivum* L.) productivity as influenced by planting techniques and weed control practices. *Indian Journal of Weed Science* **41**: 161-166.

Bräutigam V and Tebrügge F. 1997. Influence of long-termed no-tillage on soil borne pathogens and weeds, pp 17-29. In: *Experience with the Applicability of No-tillage Crop Production in the West-European Countries* (Eds. Tebrügge F and Böhrnsen A). Proceedings of the EC-Workshoop - III -Évora.

Catizone P, Tedeschi M. and Baldoni G. 1990. Influence of crop management on weed population and wheat yield. *Proceeding of EWRS Symposium*, Helsinki, Finland, 4-6 June 1990.

Chahal PS, Brar HS and Walia US. 2003. Management of *Phalaris minor* in wheat through integrated approach. *Indian Journal of Weed Science* **35**(1&2): 1-5.

Chhokar RS and Malik RK. 2002. Isoproturon resistant *Phalaris minor* and its response to alternate herbicides. *Weed Technology* **16**: 116-123.

Chhokar RS and Sharma RK. 2008. Multiple herbicide resistance in littleseed canarygrass (*Phalaris minor*): A threat to wheat production in India. *Weed Biology and Management* **8**: 112-123.

Chhokar RS, Sharma RK, Chauhan DS and Mongia AD. 2006. Evaluation of herbicides against *Phalaris minor* in wheat in North-Western Indian plains. *Weed Research* **46**: 40-49.

Chhokar RS, Sharma RK, Garg R and Sharma Indu. 2013. Metsulfuron resistance in *Rumex dentatus*. *Wheat Barley Newsletter* **7**(2): 11.

Chhokar RS, Sharma RK, Jat GR, Pundir AK, Gathala MK. 2007. Effect of tillage and herbicides on weeds and productivity of wheat under rice–wheat growing system. *Crop Protection* **26**: 1689–1696.

Chhokar RS, Singh S, Sharma RK and Singh M. 2009. Influence of straw management on *Phalaris minor* control. *Indian Journal of Weed Science* **41**: 150–156.

FAO. 2001. *Spotlight Magazine.* FAO.

Farooq U, Sharif M and Erenstein O. 2007. *Adoption and Impacts of Zero Tillage in the Rice–Wheat Zone of Irrigated Punjab, Pakistan.* Research Report. CIMMYT India & RWC, New Delhi, India.

Franke AC, Singh S, Mcroberts N, Nehra AS, Godara S, Malik RK and Marshall G. 2007. *Phalaris minor* seed bank studies: Longevity, seedling emergence and seed production as affected by tillage regime. *Weed Research* **47**: 73-83.

Jat RS, Nepalia V and Chaudhary PD. 2003. Influence of herbicide and methods of sowing on weed dynamics in wheat (*Triticum aestivum*). *Indian Journal of Weed Science* **35**(1&2): 18–20.

Kumar V and Ladha JK. 2011. Direct-seeding of rice: Recent developments and future research needs. *Advances in Agronomy* **111**: 297–413.

Kumar V, Bellinder RR, Gupta RK, Malik RK and Brainard DC. 2008. Role of herbicide-resistant rice in promoting resource conservation technologies in rice–wheat cropping systems of India: A review. *Crop Prot*ection **27:** 290–301.

Kumar V, Singh S, Chhokar RS, Malik RK, Brainard DC and Ladha JK. 2013. Weed management strategies to reduce herbicide use in zero-till rice-wheat cropping systems of the Indo-Gangetic Plains. *Weed Technology* **27**: 241-254.

Laxmi V, Gupta RK, Swarnalatha A and Perwaz S. 2003. Environmental impact of improved technology - farm level survey and farmers' perception on zero tillage (case study). *Proceedings of Roles of Agriculture Workshop*, 20–22 October, 2003 - Rome, Italy. Indira Gandhi Institute of Development Research, Mumbai.

Malik RK and Singh S. 1993. Evolving strategies for herbicide use in wheat. Resistance and integrated weed management, pp. 225-238. In: *Integrated Weed Mmanagement for Sustainable Agriculture.* Proceedings of Indian Society of Weed Science International Symposium, 18-20 November, 1993, Hisar. India Vol. **1.**

Malik RK and Singh S. 1995. Littleseed canarygrass (*Phalaris minor* Retz.) resistance to isoproturon in India. *Weed Technology* **9**: 419-425.

Malik RK, Yadav A, Singh S, Malik RS, Balyan RS, Banga RS, Sardana PK, Jaipal S, Hobbs PR, Gill G, Singh S, Gupta RK and Bellinder R. 2002. *Herbicide Resistance Management and Evolution of Zero-tillage - A Success Story.* Research Bulletin, CCS Haryana Agricultural University, Hisar, India, 43 p.

Mirsky, SB, Gallandt ER, Mortensen DA, Curran WS and Shumway, DL.2010. Reducing the germinable weed seedbank with soil disturbance and cover crops. *Weed Research* **50**(4): 341–352.

Mishra JS, Singh VP and Yaduraju NT. 2005. Effect of tillage practices and herbicides on weed dynamics and yield of wheat under transplanted rice-wheat system in Vertisol, *Indian Journal of Agronomy* **50**(2): 106-109.

Mishra JS and Singh VP. 2012. Tillage and weed control effects on productivity of a dry-seeded rice–wheat system on a Vertisol in Central India. *Soil and Tillage Research* **123**: 11–20.

Mishra JS, Singh VP and Jain Namrata. 2010. Long-term effect of tillage and weed control on weed dynamics, soil properties and yield of wheat in rice–wheat system. *Indian Journal of Weed Science* **42**: 9-13.

Mongia AD, Sharma RK, Kharub AS, Tripathi SC, Chhokar RS and Jag Shoran. 2005. Coordinated research on wheat production technology in India. Karnal, India: *Research Bulletin No. 20,* Directorate of Wheat Research, 40 p.

Morris NL, Miller PCH, Orson JH and Froud-Williams RJ. 2010. The adoption of non-inversion tillage systems in the United Kingdom and the agronomic impact on soil, crops and the environment: A review. *Soil and Tillage Research* **110**(1-2): 1-15.

Mukhopadhyay SK and Rooj SK. 1971. Minimal cultivation of rice by use of gramoxone. *Indian Journal of Agronomy* **16**(3): 79-81.

Pathak H, Ladha JK, Aggarwal PK, Peng S, Das S, Singh Y, Singh B, Kamra SK, Mishra B, Sastri ASRAS, Aggarwal HP, Das DK and Gupta RK. 2003. Trends of climatic potential and on-farm yields of rice and wheat in the Indo-Gangetic Plains. *Field Crops Res*earch **80**: 223–234.

Radheyshyam, Singh R, Singh VK and Guru SK. 2009. Effect of wheat establishment methods and weed management practices on weed dynamics and productivity of wheat grown in succession to rice. *Indian Journal of Weed Science* **41**(1&2): 70-72.

Rahman S and Mukherjee PK. 2006. Effect of zero tillage, conventional tillage and their interaction with herbicides on weed control in wheat under tarai agro ecological region of West Bengal. *Proceeding of the National Symposium on Conservation Agriculture and Environment*, October 26-28, 2006.

Rao A N, Johnson DE, Sivaprasad B, Ladha JK and Mortimer AM. 2007. Weed management in direct-seeded rice. *Advances in Agronomy* **93**:153–255.

Saharawat YS, Singh B, Malik RK, Ladha JK, Gathala M, Jat ML Kumar V. 2010. Evaluation of alternative tillage and crop establishment methods in a rice–wheat rotation in North-Western IGP. *Field Crops Research* **116:** 260–267.

Sharma RK, Chhokar RS, Jat ML, Singh Samar, Mishra B and Gupta RK. 2008. Direct-drilling of wheat into rice residues: Experiences in Haryana and Western Uttar Pradesh, pp. 147–158.In: *Permanent Beds and Rice-Residue Management for Rice–Wheat Systems in the Indo-Gangetic Plain*.(Eds. Humphreys E and Roth CH). Canbera, Australia: Australian Centre for International Agricultural Research (ACIAR) Proceedings No. 127. www. aciar.gov.au/publication/PR127.

Singh S, Yadav A, Malik RK and Singh H. 2002. Long-term effect of zero tillage sowing technique on weed flora and productivity of wheat in rice-wheat cropping zones of Indo-Gangetic plains, pp.155-157. In: *Herbicide Resistance Management and Zero Tillage in Rice -Wheat Cropping System*. (Eds. Malik RK, Balyan RS, Y adav Aand Pahwa SK) CCSHAU, Haryana, India.

Singh S, Singh G and Singh VP. 2004. Weed dynamics in wheat as affected by rice and wheat establishment methods. *Indian Journal of Weed Science* **36**(3&4): 193-198.

Sinha AK and Singh RP. 2005. Influence of cultivars under different tillage and weed management in wheat. *Indian Journal of Weed Science* **37**(3&4): 175-179.

Tripathi SC, Mongia AD, Sharma RK, Kharub AS, and Chhokar RS. 2005. Wheat productivity at different sowing time in various agro-climatic zones of India. *SAARC Journal of Agriculture* **3**:191–201.

Walia US, Singh Manpreet and Brar LS. 2005. Weed control efficacy of herbicides in zero-till wheat. *Indian Journal of Weed Science* **37**(3&4): 167-170.

Yadav SK and Singh G. 2005. Studies on the depth and periodicity of *Phalaris minor* emergence in wheat under different crop establishment methods. *Indian Journal of Weed Science* **37**(1&2): 29-32.

Yaduraju NT and Mishra JS. 2002. Zero-Tillage in rice–wheat cropping system on vertisols in Madhya Pradesh: Prospects and problems, pp.117–119. In: *Herbicide Resistance Management and Zero Tillage in Rice-Wheat Cropping System*. (Eds. Malik RK, Balyan RS, Yadav A and Pahwa SK). CCSHAUH, Haryana, India.