Indian Journal of Weed Science **46**(1): 31–35, 2014

Conservation agriculture and weed management in south Asia: perspective and development

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Received: 11 January 2014; Revised: 13 February 2014

ABSTRACT

It was 20 years ago which marked the beginning of conservation agriculture (CA) with introduction of zero-tillage (ZT) in wheat to (1) reduce cultivation cost so that farmers can afford to purchase new but expensive alternate herbicides for the control of herbicide-resistant population of *Phalaris minor* Retz., the most troublesome weed of wheat, and (2) reduce land preparation period for timely wheat planting. Worldwide, CA has spread mostly in the rain-fed agriculture but India witnessed its success more in irrigated rice-wheat cropping systems (RWCS) of the Indo-Gangetic Plains (IGP). High input based crop culture in the North West IGP has enabled weeds such as *P. minor* in wheat and *Echinochloa crusgalli* (L.) Beauv. in rice to dominate the weed flora. In wheat, zero tillage (ZT) is widely adopted by farmers in North West India and recently it is widely accepted by farmers in the eastern IGP also. In North West India, under ZT wheat, emergence and biomass of *P. minor* was reduced, but weed flora shifted toward more broad-leaf weeds such as *Rumex dentatus* (L.). In the Eastern IGP, perennial weeds such as *Cynodon dactylon* L. Pers. and *Cyperus rotundus* L. are also problematic weeds in some cases under ZT. In rice, the focus now is on dry direct-seeded rice (DSR) and machine transplanting of non-puddled rice (MTNPR) as an alternate option to puddled transplanted rice (PTR). Shifting from PTR to DSR results in changes in tillage, crop establishment method, water and weed management which often results in changes in weed composition and diversity. Weedy rice has emerged as a major threat for DSR in countries where DSR is widely adopted. In the eastern IGP, *Physallis minima* and *Cyperus rotundus* are also becoming major problematic weeds in DSR. Increased net profit for farmers by using this new technology was the main reason for rapid adoption of ZT. Since 2009, the Cereal Systems Initiatives for South Asia (CSISA), project funded by Gates Foundation and USAID and implemented by four consultative group on International Agricultural Research (CGIAR) (CG) Centers (CIMMYT, IRRI, IFPRI and ILRI) in collaboration with national partners, has explored options for sustainable intensification across the IGP, including CA-based crop management. This paper highlights the weed management scenario in conservation agriculture in India.

Key words: Conservation agriculture, Herbicide resistance, South Asia, Weed management, Zero tillage

Farmers in India adopt conservation tillage (CA) because, in the short-term, the technology can reduce operating costs, increase profitability and make better use of resources especially labor, water, and land. In the long run, farmers adopt these technologies because of benefits associated with sustainable intensification of cropping systems. In the present era, the climate change and sustainability of cropping systems have emerged as an area of importance. These are sound reasons for introduction of CA in South Asia. It was 20 years ago which marked the beginning of CA with introduction of zero-tillage (ZT) in wheat to (1) reduce cultivation cost so that farmers can afford to purchase new but expensive alternate herbicides for the control of herbicide-resistant population of *Phalaris minor* Retz., the most troublesome weed of wheat and (2) reduce land preparation period for timely wheat planting (Harrington *et al.* 1992, Malik and Singh 1995, Malik *et al.* 2002). Simplification of weed flora have had its effect on the adoption of herbicides in both rice and wheat and in the same way CA will have its impact on shift in weed flora and adoption of improved weed management in India. Worldwide, CA has spread mostly in the rain-fed agriculture but India witnessed its success more in irrigated rice-wheat cropping systems (RWCS) of the Indo-Gangetic Plains (IGP). How radical shift in weed flora may or may not happen with the shift in tillage and crop establishment methods in South Asia has been explained in the recent publications (Kumar and Ladha 2011, Kumar *et al.* 2013)

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Weed problems in rice-wheat cropping systems

High input based crop culture in the North West Indo-Gangetic Plains IGP has enabled weeds such as *P. minor* in wheat and *Echinochloa crusgalli* (L.)

Beauv. in rice to dominate the weed flora. In the Eastern IGP, where input use is less and productivity levels are low, weed flora is dominated by both annual grasses and broad-leaved weeds and some perennial grasses and sedges. However, the increasing use of more inputs has meant a shift in flora in favor of *P. minor* and *E. crusgalli* in the Eastern IGP also. The high input based crop management is mainly responsible for fostering the dominance of a simplified weed flora. Simple weed flora leads to the adoption of herbicides. After long periods of continuous use of a single herbicide, isoproturon, accompanied by poor spray techniques resulted in evolution of resistance in *P. minor* against isoproturon in 1990s. Resistance was so severe that it led to large reductions in wheat productivity in North West IGP in 1993-94. The major challenge facing the RWCS in India now is to sustain its long-term productivity. There are signs that the productivity and economic gains of this cropping system are consistently becoming smaller.

In wheat, zero tillage is widely adopted by farmers in North West India and recently it is widely accepted by farmers in the Eastern IGP also. In North-west India, under ZT wheat, emergence and biomass of *P. minor* was reduced, but weed flora shifted toward more broad-leaf weeds such as *Rumex dentatus* (L.). The higher population of *R. dentatus* under ZT wheat after puddled transplanted rice (PTR) may be because the seeds of this species concentrate on the soil surface under ZT than under conventional tillage (Chhokar *et al.* 2007, 2009). After puddling operations in rice, it has been seen that seeds of *R. dentatus* float (because seeds are light and have a perianth) and accumulate on the soil surface and remain on soil surface in a ZT wheat system; in contrast, under CT wheat, seeds are buried during tillage operations and hence emergence is reduced. Since seeds of *R. dentatus* are sensitive to burial depth, it has been found that seeds buried at a depth of 4 cm could not emerge (Dhawan 2005). In the Eastern IGP, perennial weeds such as *Cynodon dactylon* L. Pers. and *Cyperus rotundus* L. are also problematic weeds in some cases under ZT.

In rice, the focus now is on dry direct-seeded rice (DSR) and machine transplanting of non-puddled rice (MTNPR) as an alternate option to puddled transplanted rice (PTR). The weed growth medium in rice is different in different ecological zones based on the rice crop establishment method. In DSR, weeds are more diverse and severe compared to PTR because of (1) lack of flooding at early stage to control initial flush of weeds and (2) weeds in DSR emerge early or simultaneously with the emergence of crop, hence more competitive to emerging seedlings than transplants (Kumar and Ladha 2011). The imbalance between crop and weed growth makes this system vulnerable to losses caused by weeds. Shifting from PTR to DSR results in changes in tillage, crop establishment method, water and weed management which often results in changes in weed composition and diversity. Our inability to predict and manage weeds for those species which will dominate with this shift poses major threat for the sustainability of DSR production systems. Adoption of DSR may result in shifts in weed flora towards more difficult-to control and competitive grasses and sedges. Weedy rice has emerged as a major threat for DSR in countries where DSR is widely adopted (Kumar and Ladha 2011). In the IGP, in addition to *Echinochloa* species, other difficult-to-control grasses such as weedy or volunteer rice, *Leptochloa chinensis*, *Dactyloctenium aegyptium* and *Eragrostis japonica* have started dominating in DSR. In the eastern IGP, *Physallis minima* and *Cyperus rotundus* are also becoming major problematic weeds in DSR.

Typically in the Eastern zone, rice is grown as upland rice fully grown in rainfed dry land and lowland rainfed rice in which soil is puddled for transplanting or wet seeding. Much of the rainfed rice in lowland plains is dominated by *Echinochloa crusgalli* and *Paspalum scrobiculatum* among annual grasses, *Cyperus iria* L., *Cyperus difformis* L. and *Fimbristylis miliacea* (L.) vahl among sedges and *Sphenoclea zeylanica* Gaertn and *Monochoria vaginalis* (Burn f) Presi among broad-leaf weeds. Two farmer friendly booklets on weed flora of wheat and rice and their management have been published recently (Malik *et al.* 2012, 2013)

Participatory approach

Farmers' participatory approach is the process of collaboration that optimizes greater technology extension and then adding value to it. It gives an extra-ordinary access to modify technologies. It relies on farmers' experimentation and farmers' interaction with important market opinion, backstopping and follow up research. Even longterm trials may be monitored to anticipate and deal with any kind of undesirable consequences that may arise out of recommendations. Scaling out strategies have been discussed by Coventry *et al.* (2003). Increased net profit for farmers by using this new technology was the main reason for rapid adoption of ZT. Zero tillage has been accepted; it has to some extent, delayed resistance, but could not prevent the development of cross resistance against the alternate herbicides recommended in 1997-98.

Among scientist, there is increased interest to extend CA to the RWCS as a whole extending it further in maize based cropping systems. They are now experimenting with DSR, establishing rice without soil puddling and using ZT and permanent bed planting systems. In the rice phase, weed control is more difficult and use of residue mulch, development of equipment to seed into loose residues, efficient use of herbicides, crop diversification through rotations, stale seedbed techniques and competitive varieties will all be included in an integrated approach to resolve new and emerging problems as we go along. An expanded stakeholder partnership including innovative farmers will allow faster success in this endeavor. Use of herbicide resistant rice and other crops would also help resolve the weed problem in future.

Cropping system optimization

During last five decades, productivity growth of cereal in Bihar and Eastern Uttar Pradesh which constitutes the Eastern Indo-Gangetic Plains (EIGP) has been markedly slower than the Western IGP (WIGP). During green revolution phase, introduction of high yielding varieties helped farmers to improve their yields across the IGP. To meet contemporary challenges to improving crop performance among the dominantly small holder agriculture in the EIGP, it is essential that elite varieties are combined with improved crop management practices that will help farmers cope with water limitations, high energy costs, and a contracting market for agricultural labour. In rice wheat cropping system (RWCS) of these ecologies, late transplanting of rice followed by late seeding of wheat leads to a cascading sequence of abiotic stresses that reduce the yield of both crops and hence system productivity. Since 2009, the Cereal Systems Initiatives for South Asia (CSISA), project funded by Gates Foundation and USAID and implemented by four CG Centers (CIMMYT, IRRI, IFPRI and ILRI) in collaboration with national partners, has explored options for sustainable intensification across the IGP, including CA based crop management.

In the present study (3 years for rice and 4 years for wheat), on-farm participatory research in Bihar and Eastern UP has identified several critical entry points for improving cereal systems productivity. Major gains in the cropping system productivity are possible with DSR, MTNPR and early wheat sowing under ZT. The study area included five districts of Eastern UP and 4 districts of Bihar. For example, in 2012 the average paddy yields of 202 DSR, 95 MTNPR and 14 PTR trials in Eastern UP was 5.6, 6.0 and 5.3 t/ha, respectively for DSR, MTNPR and PTR with attendant gains in net returns and timeliness of harvest for both DSR and MTNPR. During the last 4 years, grain yield of wheat declined by approximately 50% with delays in wheat sowing from November to December due to the influence of terminal heat stress. Sowing in the first 20 days of November resulted in grain yield of wheat in the range of 5.4-5-6 t/ha under zero tillage (ZT) compared to a range of 4.2-4.7/ha under conventional tillage (CT). When the sowings were done after December 10, the grain yield of wheat was in the range of 3.4-3.7 t/ha under ZT and 2.7 -3.2 t/ha under CT. Results demonstrate that it is possible to increase both rice and wheat yields by introducing DSR and MTNPR technologies and to further advance the timing of wheat sowing by using ZT technology. These management approaches hold the promise of providing a stable foundation for sustainable intensification in the EIGP under contemporary climates and projected climate changes.

Herbicide use

New herbicides promised to control *P. minor* in wheat are now showing the signs of cross resistance (Walia *et al.* 1997). Development of effective weed management strategies for DSR has played an important role in the expansion of area under DSR. Diverse and complex weed flora and prolonged weed emergence pattern contribute to the complexity of weed management in DSR. In North West IGP, integrated weed management strategies based on herbicides and manual weeding has been successful in DSR. Based on on-farm and on-station trials, bispyribac-sodium 25 g/ha sprayed at 15-25 days after sowing (DAS) was extremely effective against *Echinochloa* species and some broad-leaf weed (BLW) and sedges in DSR and transplanted rice. Tank-mix of azimsulfuron 20 g/ha or pyrazosulfuron 25 g/ha with bispyribac-sodium 25 g/ha has also provided excellent control of complex weed flora including BLW and sedges including purple nutsedge. Azimsulfuron alone also provided effective control of most BLW and sedges. Halosulfuron alone at 60 g/ha was found excellent on sedges including *C. rotundus*. Many researchers have reported that pendimethalin (pre-emergence) followed by post-emergence application of bispyribac or azimsulfuron or bispyribac-sodium + azimsulfuron 15-20 DAS yielded similar to weed-free conditions (Walia *et al.* 2008, Kumar and Ladha 2011, Yadav *et al.* 2013).

In the EIGP, most herbicides available in the market are used in transplanted rice. This has put DSR farmers under pressure to use alternate methods like hand weeding which is becoming costly and scarce. Bispyribac-sodium + pyrazosulfuron or halosulfuron or azimsulfuron ares potential mixture which can control complex weed flora dominated by sedges including *C. rotundus* in these ecologies. The DSR based herbicides and/or their mixtures are being accepted in transplanted rice as well. Some weeds like *L. chinensis, D. aegyptium* and *Eragrostis* spp. are not controlled by bispyribac-sodium. For these weeds, fenoxaprop-ethyl with safner (Ricestar) at 60-90 g/ha or cyhalofop–butyl or propanil have been found effective. Pre-emeregnce herbicides such as pendimethalin at 1000 g/ha or oxadirgyl at 90 g/ha are also found very effective against these weeds.

Herbicide resistance management

Herbicide resistance in *P. minor* against isoproturon was the most serious problem in wheat in 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 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. Zero-tillage in wheat reduces the emergence rate of *P. minor* compared to CT (Franke *et al.* 2007). 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% (Fig. 1). Rate of emergence of second and third flush was also lower in ZT plots compared to CT plots (Fig. 1). 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.

Reduced population of this weed does not mean that *Phalaris* problem will be solved by ZT alone. It also does not mean that farmers will stop using herbicides. Long term trials at different sites in different villages indicate that farmers can skip herbicide once in 3-4 years. Emergence of very heavy population during early phases of crop cycles can be prevented with ZT. There is a constant danger that this weed will constantly evolve resistance to new herbicides. Using herbicides alone is not a long term solution for managing resistance. Details of resistance development and its management using integrated approach with focused attention on ZT have been published (Malik *et al.* 2002, Franke *et al.* 2007, Kumar *et al.* 2013).

Zero-tillage when combined with residue mulch improve weed control in CA based systems (Kumar *et al.* 2012). When rice residues are kept on soil surface as mulch, reduced weed emergence of key weeds of wheat in the range of 45-99%, depending on species and mulch amount. 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 favor 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

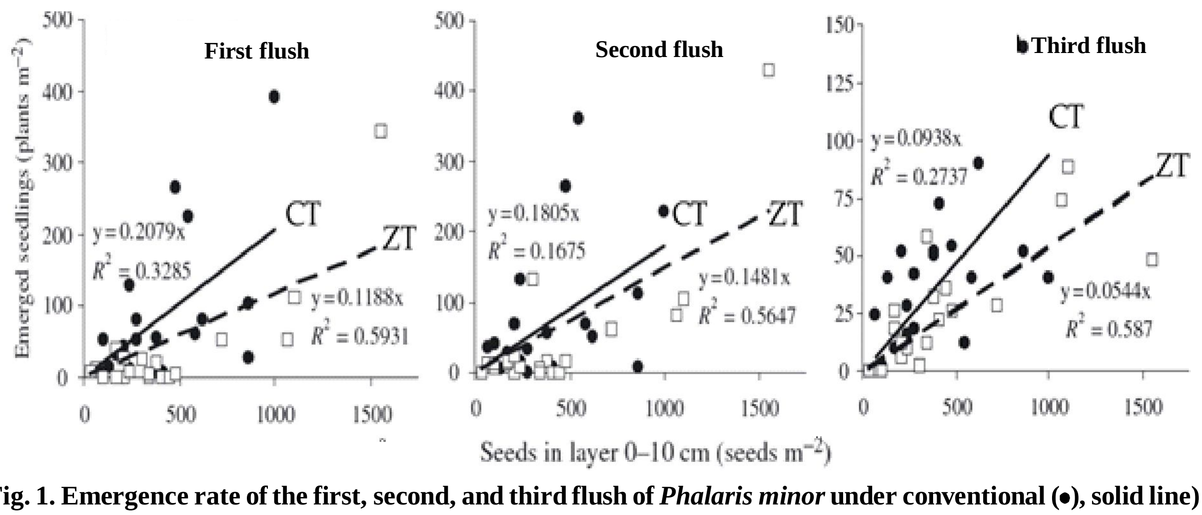

Fig. 1. Emergence rate of the first, second, and third flush of *Phalaris minor* under conventional (●), solid line) and zero-tillage (◻), dashed line) in wheat

Source: Franke *et al.* (2007).

by 83-98% compared with normal (mid November) or delayed (25 November) planting without residue. In a long term experiment at CSSRI Karnal, where wheat is planted early (30 October) under ZT with full rice residue as mulch, weeds in wheat are managed without any herbicide applications from last two years after effective control in initial 2-3 years.

The majority of farmers in RWCS, especially in North Western IGP, burn residues of previous rice crop for its rapid disposal before wheat sowing because it can interfere with drilling. However, 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, turbo happy seeder can seed wheat in heavy residue mulch of up to 8 to 10 t/ha without any adverse effect on crop establishment.

In addition to the suppressive effects on emergence of weeds, residues can contribute to weed seed bank depletion through seed predation. Preliminary studies conducted in India indicate that post dispersal seed predation of *P. minor* during a 1-week period between wheat harvest and rice planting was 50 to 60% under ZT with residue compared with 10% under CT (Kumar *et al.* 2013). This could be one of the many reason for lower population of *P. minor* under ZT.

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