Indian Journal of Weed Science **50**(3): 218–222, 2018

Print ISSN 0253-8040 Online ISSN 0974-8164

Conservation agriculture-based resource-conserving practices and weed management in the rice-wheat cropping systems of the Indo-Gangetic Plains

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Article information

DOI: 0.5958/0974-8164.2018.00051.5

Type of article: Review article

Received : 22 September 2018
Revised : 4 October 2018
Accepted : 7 October 2018

Key words

Conservation agriculture

Direct-seeded rice

Indo-Gangetic Plains

Herbicide resistance

Rice-wheat

Zero tillage

ABSTRACT

Conservation agriculture (CA) was used interchangeably with terms like conservation tillage, no tillage, zero tillage (ZT), direct drilling *etc*. ZT has been the function of weed management, not just in wheat but in rice too. ZT in India was at the dead end in the early 1990s. Until the evolution of herbicide resistance (HR) in *Phalaris minor.* By now ZT machines are recognised not only as a commercial venture but also attracts major technological step towards intensification of agriculture. With the availability of the "*Happy Seeder*"– a ZT machine that can plant rice and wheat in high-residue conditions – has made it possible to retain the residues on the soil surface, thereby providing an alternative to residue burning. It has been reported that ZT in combination with residue mulch reduced the weed problem over time in ZT wheat than CT wheat. In direct-seeded rice (DSR), no single method can provide effective and sustainable weed management solutions. Therefore, combining cultural methods in tandem with judicious use of modern herbicides is crucial. For successful weed control in DSR, pre-emergence (pendimethaline or oxadiargyl or pretilachlor with safner) followed by post-emergence (bispyribac or bispyribac based tank mixture including bispyribac + pyrazosulfuron/ azimsulfuron/2,4-D/halosulfuron or fenoxaprop with saftner or fenoxaprop based tank mixture including fenoxaprop + ethoxysulfuron) herbicide application has provided effective weed control in DSR.

INTRODUCTION

Conservation agriculture (CA), a term used in 1970s was adopted by FAO in 1990s (FAO CA website 2004). This term was used interchangeably with terms like conservation tillage, no tillage, zero tillage, direct drilling *etc*. But, it is much more than that. Zero tillage (ZT) is one of the three pillars of that. Others are permanent cover and crop rotation. From its evolution to its sustainability, ZT has been the function of weed management, not just in wheat but in rice too. ZT in India was at the dead end in the early 1990s. Until the evolution of herbicide resistance (HR) in *Phalaris minor*, a major grass weed in wheat against isoproturon in the early 1990s, farmers could dodge the question of ZT but the crisis of HR convinced them to take the new initiative. In addition, this time, an innovative approach was conceptualized and popularized for its wide-scale dissemination. The approach was a major shift towards a bottom-up farmer's participatory rather than a top-down linear model approach of technology dissemination. By now ZT machines are recognised not only as a commercial venture but also attracts major technological step towards intensification of agriculture. Numbers of ZT machine manufacturers have increased from almost one or two in the early 1990s to hundreds of them now. Over the time, ZT machine was modified to sow the wheat crop in full rice residue load to address the problem of residue burning. With the availability of the "Happy Seeder"– a ZT machine that can plant rice and wheat in high-residue conditions – has made it possible to retain the residues on the soil surface, thereby providing an alternative to residue burning. Agriculture Engineers brought ideas and design for the machines but agronomist brought it to the forefront as a tool to intensify agriculture, to conserve resources, and to bring about resilience in agriculture against climate change.

Three factors have brought about the wide-scale adoption of ZT in wheat. One of them is the mind-set issue which took a bit longer than expected but could be resolved through farmer's participatory process and by demonstrating the clear benefits of the technology in reducing the cost of cultivation and improving wheat yield. Second is the investment that came from machines manufacturers. With the availability of machines, it went into new areas. The third is that resistance in *Phalaris minor* which facilitated the adoption of ZT to reduce the cost of cultivation to enable farmers to use new but expensive herbicides to manage resistant *P. minor* populations which otherwise could have done significant harm to wheat production in the grain bowl of India. A major advantage of ZT technology in wheat is that it facilitates early planting by reducing the turnaround period by reducing land preparation time because of directly drilling in ZT conditions. Early wheat planting has demonstrated a positive impact on wheat yield by mitigating the negative effect of terminal heat stress (Kumar *et al.* 2018, CSISA 2015). These results suggest that ZT provides resilience in the changing climate change conditions.

Because of clear and positive impacts of ZT technology in wheat on productivity, profitability, resource use efficiencies and resilience to terminal heat stress (Keil *et al.* 2015, Erenstein and Laxmi 2008), ZT wheat has been widely adopted in north west India (e.g. 0.26 Mha in Haryana state alone) and now it is gaining popularity in the eastern Indo-Gangetic Plains (IGP) (e.g. >0.05 Mha in Bihar and Eastern Uttar Pradesh) (CSISA 2015, CSISA 2016, CSISA 2017). Keil *et al.* (2005) based on 40 village survey in Bihar observed an additional yield gain of 498 kg/ha (19%) and economic gain of US$ 110/ha with the adoption of ZT wheat as compared to farmer's practice of conventional till wheat.

The performance of ZT technology will be different in different ecologies and different crops, and will depend on stage of its development and refinement. Recent work shows that ZT direct-seeded rice (ZTDSR) is not yet fully ready for its wide-scale dissemination at farmer's field until weed management issues are resolved. DSR followed by ZT wheat (ZTW) has the potential to increase the system productivity with lower environmental footprint (Kumar *et al.* 2018, Laik *et al.* 2014, Bhushan *et al.* 2007). There is no technological difficulty in introducing ZT DSR followed by ZT wheat as part of full-conservation agriculture (full-CA) as this is economically and environmentally more attractive. The temptation to introduce ZTDSR *fb* ZTW could be costly because weed management is still a concern in ZTDSR but not in ZTW. Till full CA for the rice-wheat system is fully perfected at farmer's field, partial CA (DSR in non-puddled condition instead of under ZT *fb* ZT wheat) can be more economical with lower resource use.

Weed management in CA-based resource conserving practices

CA-based practices are promoted to address the emerging issues of resource scarcity (e.g. labor and water), declining factor productivity, and climate change. Despite multiple benefits with these alternative CA-based resource efficient practices, weed control remains a major bottleneck in their wide-scale adoption. In addition, one of the major criticisms associated with CA-based practices is more dependence on herbicide for weed control. Therefore, integrated weed management strategies are needed to reduce dependence on herbicides and minimize risks associated with their overuse, including the evolution of herbicide resistance in weeds and shift in weed flora towards more difficult-to-control weeds.

Weed management in zero tillage wheat

With shift from CT to ZT in wheat, weed control did not pose a major constraint in its adoption as this shift also created non-favourable conditions for some of the most important weeds of wheat such as *P. minor* and also opened up new opportunities to use for weed control (*e.g.* residue mulching) which ultimately resulted in crop-weed competition in favour of wheat crop. The lower emergence of *P. minor* under ZT may be attributed to (1) higher soil strength in ZT because of crust development in the absence of tillage after rice harvest, which can mechanically impede seedling emergence (Chhokar *et al.* 2007), and (2) higher weed seed predation under ZT (Kumar *et al.* 2013). Other possible factors could be (1) less soil temperature fluctuation because ZT helps in moderating soil temperature (Gathala *et al.* 2011) or (2) lower levels of light stimuli, N mineralization, or gas exchange, all of which are known to stimulate germination of many weed species following tillage (Franke *et al.* 2007).

It has been reported that ZT in combination with residue mulch reduced the weed problem over time in ZT wheat than CT wheat (Kumar *et al.* 2015). In a medium-term permanent plot experiment, the seedbank of wheat weeds including *P. minor*, *Rumex dentatus*, *Melilotus indica* and *Coronopus didymus* decreased by 90-100%, 75-100%, 70% and 78%, respectively in four years under CA-based systems (ZTDSR *fb* ZT wheat or PTR *fb* ZT wheat) with full retention of rice residue as mulch compared to conventional-till system (PTR *fb* CT wheat) (Kumar *et al.* 2015). Seed predation of *P. minor* was also found higher in CA-based compared to conventional systems.

In ZT wheat, integration of rice residue mulch, early wheat sowing, use of certified/clean seeds, and crop rotation has been found effective in reducing weed problems. If not managed well, shift in weed flora has been observed in partial CA-based system (PTR *fb* ZT wheat without residue). Higher population of *Rumex dentatus* has been observed in farmer's field with shift from CT to ZT in partial CA-based systems (Chhokar *et al.* 2007 and 2009). The higher population of *R. dentatus* may be due to higher concentration of their seed on soil surface because after puddling seeds of *Rumex* float being light with perianth and remained on soil surface in ZT wheat, whereas in CT, seeds are buried during tillage, hence emergence is reduced in CT wheat. Also there is risk of shift in weed flora towards difficult to control perennial weeds with shift from CT to ZT wheat if these perennial weeds are not controlled by glyphosate prior to sowing of ZT wheat.

At research farm of CCS Haryana Agricultural University, zero-tillage has been practiced for more than 17 years in pearl-millet-wheat rotation and for 15 years in sorghum – wheat rotation. Perennial weeds in the rainy season have been managed by using glyphosate applied few days before seeding pearl-millet or sorghum. Such plots continue to fare better during all years and the perennial weed pressure continued to be more under conventional tillage. The decline in the overall perennial weed pressure is even more impressive because both glyphosate in the rainy season and excellent wheat canopy cover in the month of March and beginning of April does not allow accumulation of food into the underground parts of perennials. Another way to look at this is that net flow of food material into the underground parts of perennials is less. On the whole, once the pre-seeding herbicides are used on case by case basis, ZT is set to reduce the stress of perennials.

Herbicide resistance management

Herbicide resistance was the most serious problem in wheat in the Rice-Wheat Cropping System 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 is 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. Reduced population of this weed doesn't mean that *Phalaris* problem will be solved by ZT alone. It also does not mean that farmers will stop using herbicides. Our long-term trials at five sites in different villages indicated that farmers can skip herbicide once in 3-4 years. There is a constant danger that this weed will constantly evolve resistance to new herbicides and the cross resistance was expected to happen (Malik *et al.* 2002), which has happened now. Using herbicides alone is not a long term solution for managing resistance. Emergence of very heavy population during early phases of crop cycles can be prevented with ZT. Details of resistance development and its management using integrated approach with focused attention on zero-tillage have been published (Malik *et al.* 2002 and Franke *et al.* 2007)

Weed management in DSR

In spite of best efforts during last 20 years, we have seen weakest growth in area under direct-seeded rice (DSR) throughout except some successes in basmati rice areas of Haryana and also in low productivity areas of Punjab. Two factors were important: one competitive varieties and the other water with assured irrigation. Both these factors are not prevalent in the Eastern India as most of rice is rainfed in these ecologies and access to new herbicide molecules is limited because of poor market development. Availability of right moisture at the time of pre- and post-emergence herbicide application and afterward is questionable in these ecologies because of rainfed nature.

In DSR, no single method can provide effective and sustainable weed management solutions. Therefore, combining cultural methods in tandem with judicious use of modern herbicides is crucial. Preliminary evidence suggests that practices which stimulate germination of rice weeds and their termination prior to rice planting may be extremely beneficial for reducing weed populations, particularly of problematic species such as weedy rice (*Oryza sativa* L.), *Dactyloctenium aegyptium* Willd. (crowfootgras), *Leptochloa chinensis* (L.) Nees (Chinese sprangletop) *etc*. that are difficult to control with herbicides. For example, inclusion of mungbean or through stale seedbed techniques during the fallow period between wheat and rice resulted in an 84 and 40% reduction in population of *D. aegyptium* in the subsequent rice crop under ZT and CT systems respectively (Rao *et al.* 2017).

Similarly, creating dust/soil mulch is very effective in suppressing weeds and conserving soil moisture in DSR. It has been observed that DSR fields established after pre-sowing irrigation (dust mulching) under conventional tillage have less weed infestation than when established in dry condition followed by immediate post-sowing irrigation because of dust mulch effect created in former (Malik *et al.* 2015). Irrigation immediately after sowing creates conditions favourable for weed emergence and growth. In contrast, in DSR with dust mulch in which rice is seeded after pre-sowing irrigation followed by tillage, the first post sowing irrigation is delayed for almost 2-3 weeks because broken capillaries (as a result of tillage) minimize continuum of moisture loss from lower soil layer to atmosphere and create dust mulch; hence conditions are less favourable for weeds to emerge. Detailed quantification of dust mulch on weeds and moisture conservation is going on.

For successful weed control in DSR, several herbicide combinations have shown promise. Based on our studies in Bihar/EUP, Odisha, and Haryana, pre-emergence (pendimethaline or oxadiargyl or pretilachlor with safner) followed by post-emergence (bispyribac or bispyribac based tank mixture including bispyribac + pyrazosulfuron/azimsulfuron/ 2,4-D/halosulfuron or fenoxaprop with saftner or fenoxaprop based tank mixture including fenoxaprop + ethoxysulfuron) herbicide application has provided effective weed control in DSR. In the absence of pre-emergence application, bispyribac or bispyribac based tank mixture mentioned above followed by one hand weeding/mechanical weeding effectively controlled weeds in DSR. Nutsedge (*Cyperus rotundus*)-dominated weed flora in rice commonly found in eastern India was effectively controlled with the tank mix combination of bispyribac with pyrazosulfuron, applied 15-20 days after sowing (DAS).

Weed management in DSR in rainfed ecologies of eastern India is more challenging and complex because of more intensified and diversified weed flora, uncertainly of time of weed management due to uncertainty of rains, and also lack of herbicide availability and knowledge on application methodology. Current experiences through CSISA efforts in these ecologies clearly revealed that an approach of integrated weed management including use of suitable pre- and post-emergence herbicides in sequence, and then also supplemented by manual or mechanical weeding (cono-weeder or Power-weeder) and other cultural practices as discussed above depending on case-by-case will provide more effective weed management than any of these options in isolation. In these ecologies, effective land preparation is critical to kill existing weeds prior to rice seeding.

Ploughing/tillage just prior to crop establishment in wet season is relatively less effective in killing existing weed because of sufficient soil moisture following tillage operation which allows weeds to re-grow. Therefore, a summer ploughing could be more effective in killing existing weeds because of dry period following tillage which create conditions for desiccation of uprooted weeds. If weed pressure is high and tillage is delayed till rainy season starts, applying non-selective herbicide such as glyphosate (1-2 days prior to tillage) followed by tillage has been found effective in killing existing weeds than by tillage alone.

Weedy rice in direct-seeded rice

Weedy rice is also emerging and important problem in areas where DSR is practiced. Stalebed technique to exhaust the existing seedbank and use of weedy rice free clean seed including use of hybrid seed to solve seed contamination problem should be an effective strategy. This will help facilitating the adoption of DSR especially under conventional tillage (CT). Like any other technology, such practicalities may get in the way forward. Hybrid rice also makes it possible to boost the early crop canopy cover.

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