System Based Conservation Agriculture

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Foreword

The challenge of ever increasing pressure on agricultural/arable lands for producing more with less has encouraged the adoption of conservation agriculture (CA) in India. The economization of resources through efficient use under CA not only reduces the cost of cultivation but also benefits the environment. The trend of depleting natural resources under conventional agricultural systems could be favourably reversed to the soil organic carbon build up, lesser fuel consumption and higher water productivity. A diversified cropping system under CA improves soil biodiversity, resists insect-pest-disease outbreaks, and prevents deterioration of natural resource base. The significance of wide-scale adoption of CA becomes more pertinent when we are at the verge of facing serious threats like declining partial factor productivity, climate change, and land degradation.

Globally 157 million hectare area, which constitutes 10.9% of the total arable area is currently under CA. There are enough research evidences which show this huge shift towards adopting conservation systems ensures soil health and production quality improvement brought through enhanced soil biological processes, indigenous nutrient supplying capacity and organic recycling. On the other hand, the emerging issues like nutrient stratification, misalliance of farm machinery and weed shift under CA need to be scientifically addressed. Further, CA technologies would also have to be standardized for specific crops under diverse ecologies in cropping system perspectives. Likewise, fabrication of appropriate machines can overcome the biasness of clean cultivation and constraints in adoption of CA technologies.

A remarkable success has been made in developing CA technologies for rice-wheat cropping system in Indo-Gangetic Plains of India, but the location-specific most critical intervention to break yield barrier through resource conservation technologies is still lacking. This book is a perfect compilation of consorted efforts of various researchers done in the direction of development, standardization and dissemination of the refined CA technologies. The emerging concerns of environmental unsustainability raised in the book necessitates the development of a policy framework promoting CA. I strongly believe that the book would be of great value to various stakeholders in addressing the goals of achieving sustainable agricultural systems through conservation agriculture.

Arvind Kumar

Preface

Conservation agriculture (CA) benefits agro-ecosystems by improving soil health and preserving biodiversity. Facilitation of good agricultural practices *viz.* land preparation, crop establishment, water management and stress management etc. through conservation agriculture ensures environmental safety and resource savings. Agricultural production intensification through diversified cropping systems and integration of various enterprises under CA could offer economically viable options for more than 86% small farm holders of the country. The minimum soil disturbance due to controlled traffic promotes biological tillage. An established CA system could address the emerging issues of nutrient imbalance and reliance upon the external organic inputs. The principles of CA are universally applicable, however its implementation through the set of practices has to be standardized in diversified situation and cropping system perspective. Since, CA in India is still in its nascent stage, through this book, the authors have made an attempt to suggest the possible package for wide scale adoption of CA.

The chapter 1, compares the scope and significance of adoption of CA in India with the global scenario. The chapter 2, 3, 4 and 5 discuss the nutrient dynamics, management alterations as per CA principles with both macro and micro nutrients perspectives. The chapter 6 and 7 carries a comprehensive assessment of water use, its efficiency and the possible ways to augment water productivity under CA. The chapter 8 has focused upon the differences to be considered at the time of weed management under CA as the weed expression, growing pattern and seed dispersal mechanism is altogether different than conventional systems. The chapter 9 discusses the role of mechanization and the need for suitable modifications in the existing machinery in terms of residue management and challenges offered in sowing with zero tillage. The chapters 10, 11 and 12 have focused that if CA technologies need to be up-scaled in wider domain, it has to be standardized for wider crops including pulses and oilseeds and also to the different soil types. The development of decision support system and soil quality indices for evaluation of CA based systems in long-term perspectives has been discussed in the chapter 13, 14 and 15. The higher on-farm resource use efficiency and by-product recycling through integrated farming system and organic farming for targeted crops and areas with CA principles for livelihood security on a sustainable basis has been discussed in chapter 16 and 17. The concluding chapters have shown the enhanced long-run profitability due to reduced inputs, higher resource use efficiency and higher economic returns due to stable yields.

We express our sincere gratitude to Dr. Trilochan Mohapatra, Secretary (DARE) & Director General, Indian Council of Agricultural Research (ICAR), New Delhi for his kind patronage and keen interest in conservation agriculture. During the process of compilation of this information, the continuous encouragement extended by Dr. A.K. Singh, (Director, Indian Agricultural Research Institute, New Delhi and Deputy Director General, Agril. Extension, ICAR) and Dr. Arvind Kumar, Vice-Chancellor, Rani Lakshmi Bai Central Agricultural University, Jhansi (Ex. Deputy Director General, Agril. Education, ICAR) was a great source of inspiration to us. In fact, this publication is the improved version of lectures delivered during the winter school "System based conservation agriculture" by selected resource persons/ subject matter specialists. We place our sincere thanks to all the contributors for their timely action for improving their write up as per requirement. The initial help extended in compilation of different chapters by Dr. K.K. Singh, Assistant Director General (Farm Machinery and Power), ICAR, New Delhi is duly acknowledged.

The help extended by Dr. Anil K. Choudhary, Drs. Kapila Shekhawat (Senior Scientist, Agronomy), Pravin Kumar Upadhyay, Rishi Raj (Scientist, Agronomy) in proof reading is thankfully acknowledged. We assume that our efforts in the form of this publication will be useful to all the stake holders involved in agricultural production in general and conservation agriculture in particular.

Vinod Kumar Singh
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Dr. V.K. Singh, is Head, Division of Agronomy at ICAR-Indian Agricultural Research Institute, New Delhi. Prior to this he was ICAR National Fellow and Principal Scientist at Indian Institute of Farming Systems Research, Modipuram. Dr. Singh has made significant contribution towards improving soil organic matters content and nutrient use efficiency in different cropping systems. Dr. Singh developed nutrient and water management protocols under conservation agriculture based system. In collaboration with international research organizations like IRRI, CIMMYT, ICRISAT, IPNI, TSI-FAI-IFA, Dr.V.K. Singh has generated findings of practical significance to restore the soil organic carbon and sustained productivity under different cropping systems. As ICAR-National Fellow, he explored the possibility of use of GIS in precision nutrient management under different cropping systems in Indo-Gangetic Plain. He has published more than 100 research papers in journals of repute, besides a number of review papers, popular article, bulletins and book chapters. Dr. Singh has excellent academic record, and is a recipient Fellow of Indian Society of Agronomy, NAAS Fellow/Associate, Fellow International Society for Noni Science, NAAS Young Scientist Award – National Resource Managment (2005-06), Young Agricultural Scientist (Natural Resource Management) Award (2003-04) by UPCAR, PPIC-FAI Award-2004, IPNI- FAI award 2014, ISSS-Dr. J.S.P. Yadav Memorial Award for Excellence in Soil Science (2011), P.S. Deshmukh Young Agronomist Award-2001 by Indian Society of Agronomy and the Sriram Award and Dhiru Morarji Memorial Award by the Fertilizer Association of India.

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Weed Management Strategies under Conservation Agriculture based Rice-Wheat System

N.K. Jat, R.S. Yadav, S. Kumarand M. Shamim

Rice-wheat (RW) cropping system is the world's largest agricultural production system occupying around 12.3 million ha in India, and around 85% of this area falls in Indo-Gangetic Plains (IGP) (Ladha *et al*., 2003). Both rice and wheat have been the staple food for a large population in Asia and their assured supply is essential for ensuring food security in future. In India, the two-crop system contributes nearly 26% of total cereal production and 60% of the national caloric intake (Singh and Paroda, 1994). By 2020, India's population is projected to reach 1.5 billion and the annual food demand will reach 343 million tonnes. To meet this demand, India has to increase the rice and wheat production by 33 and 35%, respectively (Malik *et al*., 2003).

This cropping system so far has maintained the balance between food supply and population growth but now the sustainability of this cropping system is at risk because of stagnant or declining productivity of both rice and wheat and declining total factor productivity (Ladha *et al*., 2009). This could be attributed to multiple factors, including (1) degradation in the natural resource base, especially soil and water; (2) rising scarcity of labour and water; (3) increasing costs of cultivation; and (4) higher weed abundance (Ladha *et al*., 2009).

In the RW system in India, rice is grown during the rainy season and wheat during the winter. Rice is primarily grown by conventional tillage-puddled transplanted rice (CT-TPR) method, in which approximately one month old rice seedlings are transplanted manually into puddled soil and fields are kept flooded thereafter. This practice of rice production is effective in (1) achieving good weed control and crop establishment, (2) reducing percolation losses of water and nutrients, and (3) enhancing nutrient availability (Johnson and Mortimer, 2005). However, CT-TPR is labour intensive, involves large amounts of water and is detrimental to soil health. Of late, alternative practices including dry direct-seeding rice (DSR) with reduced or zero-tillage (ZT) are being advocated. ZT-DSR can reduce water and labour requirements and overcome the adverse effects of puddling on soil health and productivity of the succeeding wheat crop (Ladha *et al*., 2009). Additionally, ZT in wheat reduces the time required for field preparation, resulting in timely sowing and higher yields. As it is estimated that each one day delay of wheat sowing after the optimal date results in a yield loss of 26.8 kg/ha/day (Tripathi *et al*., 2005). In wheat, ZT has been widely adopted, especially in the North-western IGP in the RW systems, and it has positive impact on wheat productivity, profitability, and resource use efficiency (Ladha *et al.,* 2009).

Despite multiple benefits of DSR and ZT in RW systems, weed control remains a major obstacle to its adoption. Weed control is particularly challenging in ZT in RW systems because of the diversity and severity of weeds and as it is typically associated with a shift away from flooding and tillage, both of which play an important role in suppressing weeds under conventional cultivation.

1. WEED MANAGEMENT IN RICE-WHEAT SYSTEM

Weeds in RW system are generally controlled manually and through cultural manipulations. Now-a-days, herbicide use for weed control in rice and wheat is becoming increasingly popular. Herbicide use has increased in both conventional and ZT systems because it provides effective and economical weed control and saves on labour, which has become more scarce and expensive. Although herbicides play an important role in facilitating adoption of ZT practices; however, over reliance has aggravated the problems of herbicide resistance in weeds. Additionally, public concerns about the potential adverse effect of herbicides on neighbouring water resources and human health have increased.

Hence, to expand the adoption of ZT in RW systems while minimizing the risks associated with herbicide use, it is important to adopt integrated weed management packages. Since, non-chemical management of weeds under ZT is challenging because both tillage and herbicides, two major weed control methods, are removed from the systems. However, the integration of multiple strategies, including the use of stale seedbed, crop residue as mulch, competitive cultivars, crop rotation, adjustment of sowing time and plant density etc. have been reported effective in suppressing the weeds and can be included as part of an alternative weed management programme.

2. WEED FLORA DYNAMICS IN RICE-WHEAT SYSTEM OF INDIA

The seasonal and regional variations in weed flora composition of a crop field are always a reality. An account of some weed species in RW system of IGP is presented in Table 1.

Table 1. Weed spectrum of rice-wheat cropping system in IGPs

Weed	*Rice*		*Wheat*	
	NW-IGP	*E-IGP*	*NW-IGP*	*E-IGP*
Grassy weeds				
Avena ludoviciana			√	
Brachiaris reptans		√		√
Cynodon dactylon				√
Dactyloctenium aegyptium	√			
Digitaria ciliaris	√			
Echinochloa crusgalli	√			
Echinochloa colonum	√	√		
Eleusine indica	√			
Eragrostis tenella		√		
Panicum repens		√		
Phalaris minor			√	√
Paspalum distichum	√			
Poa annua			√	
Polypogon monspeliensis				√
Broad leaves weeds				
Alternanthera sessilis		√		
Anagallis arvensis			√	√
Cannabis sativa				√
Celosia argentea		√		
Cirsium arvense				√
Caesulia axillaris	√	√		
Chenopodium album				√
Convolvulus arvensis			√	
Commelina benghalensis		√		
Cucumis spp		√		
Digera arvensis		√		
Eclipta alba	√	√		
Lindernia crustacea	√			
Medicago indica				√
Phyllanthus niruri	√			
Physalis minima		√		
Parthenium hysterophorus				√
Rumex dentatus			√	√
Sedges				
Cyperus iria	√			
Cyperus compressus	√			
Cyperus difformis	√	√		
Cyperus rotundus	√		√	
Fimbristylis quinquangularis	√			
Fimbrisstylis milicea		√		

Source: Gopal *et al*., 2010

NW-IGP- North Western Indo-Gangetic Plains; E-IGP- Eastern Indo-Gangetic Plains

The shift from CT-TPR to ZT-DSR, typically results in changes in tillage, crop establishment method, irrigation practices, and weed management that influence weed diversity and abundance. Under ZT-DSR, weed flora often shifts towards competitive grasses and sedges (Kumar and Ladha, 2011). Experiences with ZT-DSR in India and other Asian countries reveals that the shift from CT-TPR to ZT-DSR favours grassy weeds.

The shift from CT to ZT in wheat also results in shift in weed flora. Emergence of littleseed canary grass is lower under ZT than CT in wheat but higher for some of the broad leaved weeds (Chhokar *et al*., 2007). If ZT is adopted in both rice and wheat, then there are chances of a shift in weed flora toward perennial weeds like Bermuda grass. In the Eastern IGP, problems of some perennial grassy weeds like purple nutsedge and Bermuda grass are serious under ZT as tillage is not used to disrupt perennation and because of poor crop canopy to out-compete these weeds as a result of lower N use and late planting of the crop in the region (Kumar *et al*., 2013).

3. YIELD LOSSES CAUSED BY WEEDS

Yield losses because of weeds have been reported to be much higher in ZT-DSR compared with CT-TPR. Yield reductions in rice has been recorded high as 46% due to weeds in weedy plots (Chin and Sadohara, 1994). Similarly, in wheat losses because of weeds are reported higher in ZT compared with CT. Normally weeds offer severe competition to wheat and causes up to 40 to 50% reduction in grain yield if not managed at critical time. Among others, littleseed canary grass is the single most important grassy weed of wheat which is highly competitive, causing significant yield reductions in the range of 25 to 80% depending on the severity of infestation.

4. WEED MANAGEMENT IN DIRECT SEEDED RICE UNDER ZERO TILLAGE

4.1 Cultural Practices

4.1.1. Tillage Practices

Tillage practices like ZT seeding systems can reduce the weed problems, if managed properly. If weeds are controlled effectively for initial 2-3 years, ZT helps in reducing the effective weed seed bank as soil is not being disturbed and therefore, weed seeds from lower depths are not being brought back towards the soil surface where they can more readily germinate.

4.1.2 Stale Seedbed

The stale seedbed technique is recommended as part of an integrated weed management strategy in ZT-DSR. In this technique, weed seed germination is encouraged by applying light irrigation and then emerged seedlings are killed using a non-selective herbicide (paraquat, glyphosate etc.) before crop sowing. This method has great potential for suppressing weeds and is feasible under ZT-DSR because there is about a 45 to 60 days fallow period between wheat harvest and sowing of rice. This technique is effective not only in reducing weed emergence during the crop season but also in reducing the weed seed bank. In farmer field trials, 53% lower weed population was observed after stale seedbed practices in DSR (Singh *et al.*, 2009).

4.1.3 Crop Establishment

Spatially uniform establishment of healthy and vigorous rice seedlings increases crop competitiveness and suppresses weed growth. Zero-till rice can be established either by ZT-DSR or by ZT-TPR method by transplanting the seedlings manually or mechanically (using a paddy transplanter). Under DSR, weeds are more diverse and difficult to control compared with TPR. Many researchers found substantially lower weed biomass in ZT-TPR compared with ZT-DSR. Hence, where DSR is preferred for saving labour and water resources, ZT-DSR can be rotated with ZT-TPR every few years to keep weed pressure under check.

4.1.4 Seed Rate

Weed competition in ZT-DSR can also be reduced by optimizing seed rate and the crop geometry, as weed density and biomass declined linearly with an increase in seed rate (Chauhan *et al.*, 2011). However, most of the seed rate studies reported increase in rice grain yields with increase in seed rate under weedy conditions only, and not in weed-free conditions (Chauhan *et al.*, 2011). Under weed-free conditions, yields were not affected by seed rates while, under weedy conditions, weed biomass decreased linearly and yields increased quadratically with increased seed rates (Chauhan *et al.*, 2011). In the absence of weeds, optimal seeding rates are often lower because high seeding rates can cause N deficiency, higher spikelet sterility, fewer grains per panicle, higher incidence of insects and diseases, and crop lodging (Kumar and Ladha, 2011). In the IGP a seed rate of 20 to 25 kg/ha has been recommended for DSR (Kumar and Ladha, 2011) under optimum weed control. However, Chauhan *et al.* (2011) suggested a seed rate of 95 to 125 kg/ha for inbred varieties and 83 to 92 kg/ha for hybrid varieties to achieve maximum yields in competition with weeds.

4.1.5 Crop Geometry

Crop geometry, including row spacing and planting pattern, can also be employed to influence crop-weed competition. Narrow row spacing can shift the competitive balance in favour of rice by achieving faster canopy closure and reducing light availability to weeds (Chauhan and Johnson, 2011). Reductions in row spacing from 45 to 15 cm had no effect on yields under weed-free conditions but increased yields where weeds were present (Chauhan and Johnson, 2011). Weed competition can also be reduced for some cultivars by sowing rice in a paired-row pattern. Weed biomass was found 25% lower under paired-row sowing (15-30-15 cm) of rice compared with uniform row spacing of 23 cm (Mahajan and Chauhan, 2011). These results suggest that weed competition in

ZT-DSR can be reduced by growing rice with narrow spacing or in a paired-row planting pattern. However, narrow row spacing could make other weed control operations like hand/mechanical weeding more difficult compared to wide row spacing.

4.1.6 Residue Mulching

ZT rice systems create opportunities for exploitation of surface residues for weed suppression that are not available when puddling and flooding are used. Because, most rice weed species are sensitive to mulching, it can be an effective weed management strategy in ZT-DSR. Residue mulching ensures weed suppression by imposing a physical barrier to emerging weeds and through release of allelo-chemicals in the soil. A few studies on residue mulches in rice have demonstrated substantial reduction in emergence and growth of weeds. In ZT-DSR in the IGP, Singh *et al*. (2007) reported that application of 4 t/ha wheat residue as mulch reduced emergence of grasses and broad leaves weeds in the range of 44 to 47% and 56 to 72%, respectively.

Despite the significant positive effects of mulches on weed suppression, the limited availability of residue for mulch during the rice season is a constraint. In the IGP, previous wheat crop residue is used as animal feed and hence removed from the field. Therefore, there is a need to identify alternative ways to generate residue mulch. One way is to grow short duration additional crops such as mungbean during the fallow period between wheat harvest and rice planting and to retain the entire residue of this crop as mulch.

4.1.7 Sesbania Co-culture (Brown manuring)

"Brown Manuring" practice involves seeding of rice and *Sesbania* crops together and killing the *Sesbania* crop at 25-30 days after sowing with 2, 4-D ester at 0.40- 0.50 kg a.i./ha. Initially *Sesbania* grows rapidly and suppress weeds and this technology can reduce weed population substantially without any adverse effect on rice yield. Singh *et al*. (2007) reported 76 to 83% lower broad leave weed density and 20 to 33% less density of grassy weeds with this practice compared with rice sole crop.

4.1.8 Competitive Cultivars

Cultivars with with seedling vigour and spreading nature, which cover the ground quickly during the early vegetative stage, result in weed suppression (Kumar and Ladha, 2011). In general, it has been observed that early maturing (short duration) cultivars are more effective in smothering weeds than medium and long duration cultivars because of their early faster growth and ground cover. Besides, basmati varieties suppress weed growth more than short-statured, high-yielding, coarse-grain cultivars (Singh *et al*., 2009).

4.1.9 Water Management

Water management has been an important component of weed control in flooded CT-TPR, where flooding is employed from the first day of transplanting. Emergence and growth of many rice weeds are influenced by timing, duration, and depth of flooding. The emergence and growth of most weed species is inhibited only when fields are submerged shortly after seeding. In ZT-DSR, flooding cannot be applied immediately after sowing because rice seeds cannot germinate and survive under completely submerged conditions. Moreover, the duration of flooding is limited under ZT because water infiltration is faster in absence of puddling. Therefore, in DSR, many weeds can emerge before flooding is possible, thus making weed management difficult. Hence, development of rice cultivars capable of germinating under anaerobic conditions would greatly facilitate weed management through flooding in DSR (Chauhan, 2012). This trait would not only help in weed control but also in enhancing the adoption of DSR in both rainfed and irrigated areas as crop establishment can be improved with this trait.

4.1.10 Strategies to Reduce Weed Seed Bank

One way to deplete seed bank is to minimize weed seed production. Even after practicing weed control, some weeds escape and can produce large number of seeds, which further reduce yields or increase weed management costs in subsequent seasons. Attention should also be given to preventing seed production from weeds growing during the fallow period and on bunds and channels because they can contribute significantly to the soil seed bank. Weed seeds could also gain entry into rice fields via contaminated owner-saved seeds; manures or compost; and irrigation water. These sources should be prevented by using certified seeds and well-decomposed manures/compost free from weed seeds.

4.1.11 Strategies to Maximize Weed Seed Exhaustion

Another approach to diminishing weed seed banks involves enhancing weed seed predation and decay. ZT with crop residues could enhance weed seed predation and seed decay because in ZT a greater proportion of weed seeds remain on the soil surface where they are more prone to seed predation. Besides, residues might provide a desirable habitat for seed predators and decay agents. Improved soil characteristics under ZT could also facilitate seed predators and decay agents.

Chauhan *et al.* (2010) reported a high rate (78 to 91%) of rice for seed predation of grassy weed species, including *Eleucine indica* and *Digitaria* spp. from the soil surface in rice fields under ZT than under CT. Similarly, ZT with residue could play an important role in enhancing weed seed decay. Under ZT, the surface soil layer has a higher proportion of weed seeds, higher soil moisture and higher microbial diversity all of which favour microbial seed decay (Gallandt *et al.*, 2004). Therefore, crop management practices such as ZT and residue retention, which could enhance weed seed decay agents (microbes/fungal pathogen), might contribute to reductions in the weed seed bank in the long run.

4.1.12 Crop Rotation

Crop rotation is the effective way to control weeds. Every crop imposes a distinct set of biotic and abiotic stresses on the weeds and this will promote the growth of some weeds while inhibiting others. Rotating crops will rotate selection pressures, preventing one weed from being repeatedly successful, and thus preventing its further perpetuation and infestation. Rotations alter selection pressures through three main mechanisms including (i) altering managements (e.g., timing of field activities, herbicides), (ii) varying patterns of resource competition, and (iii) allelopathy. Some farmers in IGPs rotate rice with some pulse crops like pigeon pea, mungbean etc. that is very effective for weed management since volunteer rice seedlings failed to survive in pulse because of insufficient soil moisture. Inclusion of perennial forages such as alfalfa in a rotation has been shown to contribute in weed control for up to three years, and can be particularly effective in ZT systems (Ominski and Entz, 2001).

4.2 Chemical Weed Control

Herbicidal weed control is the most adopted and perhaps the most versatile approach throughout the world. The herbicides act to kill the weed plants by blocking different physiological functions which are essential for plant growth. A variety of herbicides are available depending upon their mode of action, chemical composition, formulation, selectiveness and efficacy. Individual herbicides have strength and weakness but the right herbicide for use in DSR depends on the weed flora composition of a field. However, rotational use of herbicides with different modes of actions is desirable to check the development of herbicide tolerant or resistant weed biotypes. Some herbicides recommended for weed management in ZT-DSR are given in Table 2.

Table 2. Herbicide molecules recommended for weed management in rice.

Herbicide	*Application time*	*Dose (a.i./ha) (spray vol. L water/ha)*	*Application DAS/DBS*	*Weed control*		
				Grass	*BLW*	*Sedge*
Sole application						
Glyphosate	PP	1.0-1.5 (500)	1-7 DBS	***	***	**
Paraquat	PP	0.5 (500)	0 DBS	**	***	*
Pendimethalin	PE	0.8-1.2 (500)	2-3 DAS	***	*	*
Pyrazosulfuron	PE	0.02 (500)	12-20 DAS	**	*	
2,4-D	PoE	0.5 (500)	30-35 DAS		**	*
Azimsulfuron	PoE	17 g (400)	12-25 DAS	*	***	***

(Contd.)

Herbicide	*Applicationtime*	*Dose (a.i./ha) (spray vol. L water/ha)*	*Application DAS/DBS*	*Weed control*		
				Grass	*BLW*	*Sedge*
Bispyribac	PoE	25 g (500)	15-25 DAS	***	*	**
Ethoxysulfuron	PoE	18 g (500)	12-20 DAS		**	**
Fenoxaprop	PoE	60 g (500)	14-21 DAS	**		
Penoxulam	PoE	22.5 g (500)	12-25 DAS	***	**	**
Tank mixtures						
Glyphosate+ 2,4-D-EE	PP	1.0+0.25 kg (300)	1-7 DBS	**	**	***
Azimsulfuron+ bispyribac	PoE	17+12.5 g (500)	12-20 DAS	***	***	***
Propanil+ Triclopyr	PoE	3.0+0.5 kg (500)	12-25 DAS	**	**	*

PP- Pre-plant; PE- Pre-emergence; PoE- Post-emergence; DAS- Days after sowing; DBS - Days before sowing. *, ** and *** indicates level of significance at 0.05, 0.01 and 0.001 respectively

Source: Gopal *et al.,* 2010

4.3 Bio-herbicidal control

Weed control through living organisms is an effective way to manage weeds. A large number of predators, pathogens and other plant competitors are being exploited to kill or suppress the weeds. To minimize the dependency on herbicides, some fungal pathogenic agents are also now being explored as mycoherbicides. To date, the most promising fungi for inundative biological control of *Echinochloa crusgalli* are *Exserohilum monoceras* and *Cocholiobolus lunatus* (Thi *et al*., 1999). Rice varieties IR50404 and CR203 were not affected by these fungi. *Setosphaeria* spp. cf. *rostrata* was also found to effectively control *Leptochloa chinensis* and not damaging to IR64. Besides, *Colletotrichum gleosporioides* for jointvetch (*Aeschynomene virginica*) and *Puccinia canaliculata* against yellow nutsedge (*Cyperus iria*) were found effective in rice. However, the use of bioherbicides at the farm level and the methods of delivery remain serious constraints to adoption so far.

5. WEED MANAGEMENT IN WHEAT UNDER ZERO TILLAGE

5.1 Cultural Practices

5.1.1 Use of Weed-free Certified Seed

Sowing seeds contaminated with weed seeds has been a major source for their spread. In contrast to rice, the majority of wheat farmers use their own seeds for sowing which contains weed seeds, particularly of the littleseed canary grass. Hence, the use of either certified seeds or proper cleaning of owner-saved seeds for planting is important in reducing littleseed canary grass populations.

5.1.2 Zero-Tillage and Residue Management

Zero tillage, even without residues, has been found helpful in reducing the population of littleseed canary grass (Malik *et al*., 2002). Moreover, ZT when combined with residue retention on the surface and early sowing, results in weeds suppression in wheat. When early seeding and rice mulch were combined, littleseed canary grass emergence was 83 to 98% lower compared with normal or delayed seeding without residue (Kumar *et al*., 2013). ZT wheat with rice residue mulch (6.0 t/ha) recorded the higher grain yield (6.14 t/ha) and lesser weed density (43.5%) over ZT wheat without residue management (Jat *et al*., 2014).

In rice-wheat systems of North-western IGP, most of the farmer's 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 littleseed canary grass and reduces the efficacy of soil-active herbicides like isoproturon and pendimethalin (Chhokar *et al*., 2009). However, with recent planting technology particularly, the rotary disc drill and turbo happy seeder sowing of wheat can be done in heavy residue mulch of up to 8 to 10 t/ha without any adverse effect on crop establishment (Sharma *et al*., 2008).

5.1.3 Crop Planting Date

Due to dormancy, many weeds germinate during specific seasons. If the approximate date of emergence is known for some weeds, crop planting dates can be adjusted so that either the crop emerges before the weeds for a competitive advantage or weeds are allowed to germinate and are controlled before or during crop planting. Planting earlier even a few days can give crop a significant competitive advantage over weeds. The potential weed suppression offered by early crop planting is proven in case of *Phalaris minor* in rice-wheat systems of the IGPs. As the ZT sown wheat can be sown 1–2 weeks earlier, allowing the crop to establish before emergence of *Phalaris minor* (Chhokar and Malik, 1999).

5.1.4 Sowing Methods and Seed Rate

Seed rate and sowing methods can also influence crop–weed competition in ZT wheat. Narrow-row planting with increased crop density can shift the competitive balance in favour of the crop. Narrow row spacing (15 cm) reduced littleseed canary grass biomass by16.5% compared with normal spacing of 22.5 cm (Mahajan and Brar, 2002).

5.1.5 Competitive Cultivars

Crop cultivars vary in their growing habit, which can influence markedly the crop–weed competition. Wheat varieties with faster growth, faster canopy formation, spreading habits and greater height are less susceptible to weed competition (Balyan and Malik, 1989). Although, the competitive ability of wheat is often negatively associated with yield potential under weed-free environments, the magnitude of yield loss under weedy conditions is greater in high-yielding, less competitive dwarf wheat cultivars than in tall competitive cultivars (Challaiah *et al*., 1986). Even among high-yielding cultivars, there is a large difference in weed competitiveness. Wheat cultivars 'WH-147' and'HD-2285' with medium height were more competitive with wild oats and other weeds compared with other cultivars, such as 'HD-2009', 'WH-291', and 'S-308' (Singh *et al*., 1990).

5.1.5 Crop Rotation

Rotating crops that have different cultivation practices is a very effective cultural practice for disrupting life cycles and improving control of problematic weeds like littleseed canary grass (Chhokar *et al*., 2008). The incidence of littleseed canary grass was greatly reduced in RW systems by growing clovers or oats for fodder once in 3 years instead of wheat after rice. Intensification of the RW system by including short-duration vegetables (pea or potato) followed by late wheat can also improves weed control without herbicide applications (Chhokar *et al*., 2008).

5.1.6 Water and Nutrient Management

Nutrients and water management practices can be manipulated to favour crops against weeds. High moisture in rice-wheat systems favours moisture-loving weeds like littleseed canary grass, Indian sorrel and foxtail grass (Singh *et al*., 1995). Because wheat can germinate under drier conditions than many weeds (Chhokar *et al*., 1999), sowing under dry conditions can facilitate reduced weed emergence and competition. Similarly, placement of fertilizer in the crop root zone can shift weed–crop competition in favour of the crop. Under ZT, seed drills can place basal applications of fertilizer below the seeds, thereby suppressing weeds as compared with normal practice of broadcasting of fertilizers.

5.2 Chemical Weed Control

In areas with high soil moisture, perennial weeds and some annual weeds germinate and start growing before wheat crop and offer a tough competition to wheat. These weeds can be controlled by application of herbicides (Table 3).

Table 3: Recommendations of herbicide molecules for weed management in wheat

Herbicide	*Application time*	*Dose (a.i./ha) (spray vol. L water/ha)*	*Application (DAS)*	*Weed control*		
				Grass	*BLW*	*Sedge*
Carfentrazone	PoE	20 g (500)	25-30		***	*
Clodinafop	PoE	60 g (400)	30-45	***		
Isoproturon	PoE	1.0 kg (500)	25-30	**	*	
Mesosulfuron+ Iodosulfuron	PoE	12+2.4 g (400)	30-35	***	**	**
Metsulfuron	PoE	4 g (400)	30-35		**	**

PoE- Post-emergence; DAS = Days after sowing

*, ** and *** indicates level of significance at 0.05, 0.01 and 0.001, respectively.

Source: Gopal *et al*., 2010

6. CONCLUSION

Sustainability of rice-wheat cropping system can be augmented with some conservation agriculture based resource conservation technologies such as zero-tillage, residue management and direct seeding of rice to overcome the problems associated with the conventional rice-wheat cultivation involving puddling and repeated tillage. In rice, the farmers are considering switching to ZT-DSR instead of CT-TPR which is labour intensive, requires large amounts of water, and is detrimental to soil health. Zero tillage technology has been widely adopted in wheat in the rice-wheat cropping systems in Indo-Gangetic Plains. Despite multiple benefits of ZT in RW systems, weed control remains a major obstacle to its adoption. To expand the adoption of ZT in RW systems while minimizing the risks associated with herbicide use, it is important to develop integrated weed management packages.

It is challenging to manage weeds under ZT without herbicides. However, when multiple tactics for weed control are integrated, dependence on herbicides can be reduced. In ZT rice, integration of stale seedbed, residue mulching, *Sesbania* co-culture, competitive cultivars, and appropriate cultural practices, including quality seed, seeding rate, crop geometry, crop establishment methods, water management, and strategies to reduce weed seed bank by minimizing seed input and enhancing seed mortality can reduce weed infestations and hence the herbicide use. In ZT wheat, an integrated approach comprising rice residue retention, earlier sowing of certified/clean seeds, higher seed rates and narrow row spacing of competitive cultivars, crop rotation can drastically reduce weed problems. Further research is needed concerning interactions between conservation agriculture practices with regard to weed control, particularly tillage and residue retention. Besides, location-specific synergistic combinations of technology options have to be identified and used to maximize economic returns to farmers and environmental benefits to the community.

7. FUTURE RESEARCH NEEDS

Additional research on the following aspects will help in further developing and strengthening weed management strategies of ZT RW systems:

- For maximizing effectiveness of weed control approaches, emergence periodicity of key weed species of rice and wheat under ZT should be determined.
- To achieve optimum weed suppression without affecting crop establishment, effects and amount of different crop residue mulches (rice, wheat, *Sesbania*, mungbean, etc.) should be quantified.
- Identification of vulnerable stages of weed species in ZT rice and wheat by studying weed population dynamics.
- Quantifying short and long-term effects of summer legume on weed suppression during cover cropping and after its termination in ZT rice crop.
- Estimating the role of irrigation water and manure/compost in seed dissemination and developing strategies to minimize it.

- Efforts are needed to integrate multiple tactics and to evaluate long-term effects of nonchemical weed management practices on sustainability of RW cropping system.
- Effect of different weed control measures should be quantified on population dynamics and long-term shifts in weed populations.
- Developing weed-competitive cultivars with anaerobic germination traits so that early flooding can be used in ZT-DSR for weed suppression.
- To study the effects of rotating crops and crop management practices on the evolution of weeds and the stability of grain yields over time.

References

Balyan RS, Malik RK. 1989. Influence of nitrogen on competition of wild canarygrass in wheat. *Pestology* 13, 5–6.

Challaiah OC, Burnside G, Wicks A, Johnson VA. 1986. Competition between winter wheat cultivars and downy brome. *Weed Science* 34, 689–693.

Chauhan BS. 2012. Weed ecology and weed management strategies for dry seeded rice in Asia. *Weed Technology* 26, 1–13.

Chauhan BS, Johnson DE. 2011. Row spacing and weed control timing affect yield of aerobic rice. *Field Crops Research* 121, 226–231.

Chauhan BS, Migo T, Westerman PR, Johnson DE. 2010. Post dispersal predation of weed seeds in rice fields. *Weed Research* 50, 553–560.

Chauhan BS, Singh VP, Kumar A, Johnson DE. 2011. Relations of rice seeding rates to crop and weed growth in aerobic rice. *Field Crops Research* 121, 105–115.

Chhokar RS, Malik RK, Balyan RS. 1999. Effect of moisture stress and seeding depth on germination of littleseed canarygrass. *Indian Journal of Weed Science* 31, 78–79.

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, Sharma RK, Singh RK, Gill SC. 2008. Herbicide resistance in littleseed canarygrass and its management. *(In) Proceedings of the 14th Australian Agronomy Conference*. Australian Society of Agronomy, Adelaide, South Australia, pp. 106.

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

Chhokar RS, Malik RK. 1999. Effect of temperature on germination of *Phalaris minor* Retz. *Indian Journal of Weed Science* 31, 73–74.

Chin DV, Sadohara H. 1994. Weed problems and weed control in direct-seeded rice in the Mekong Delta, Vietnam. *Weed Research* 39, 18-19.

Gallandt ER, Fuerst EP, Kennedy AC.2004. Effects of tillage, fungicide seed treatment and soil fumigation on annual mortality of *Avena fatua*. *Weed Science* 52, 597–604.

Gopal Ravi, Jat RK, Malik RK, Kumar V, Alam MM, Jat ML, Mazid MA, Saharawat YS, McDonald Andrew, Gupta R. 2010. Direct dry seeded rice production technology and weed management in rice based systems. Technical Bulletin. International Maize and Wheat Improvement Centre.

Jat NK, Yadav RS, Sudhir Kumar. 2014. Annual Report 2013-14. Project Directorate for Farming Systems Research (ICAR) Modipuram, Meerut - 250 110, India, pp. 45.

Johnson DE, Mortimer AM. 2005. Issues for integrated weed management and decision support in direct-seeded rice. *(In) Rice Is Life: Scientific Perspectives for the 21st Century*, pp. 211–214. Toriyama K, Heong L, and Hardy B (Eds.). International Rice Research Institute, Los Ban˜os, Philippines; Japan International Research Center for Agricultural Sciences, Tsukuba, Japan.

Kumar V, Singh S, Rajender, Chhokar RS, Malik RK, Daniel C, Brainard, 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.

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

Ladha JK, Dawe D, Pathak H, Padre AT, Yadav RL, Singh B, Singh Y, Singh Y, Singh P, Kundu AL, Sakal R, Ram N, Regmi AP, Gami SK, Bhandari AL, Amin R, Yadav C R, Bhattarai EM, Das S, Aggarwal HP, Gupta RK, Hobbs PR. 2003. How extensive are yield declines in long-term rice–wheat experiments in Asia? *Field Crops Research* 81, 159–180.

Ladha JK, Kumar V, Alam MM, Sharma S, Gathala M, Chandna P, Saharawat YS, Balasubramanian V. 2009. Integrating crop and resource management technologies for enhanced productivity, profitability, andsustainability of the rice-wheat system in South Asia. *(In)Integrated Crop and Resource Management in the Rice–Wheat System of South Asia,* pp. 69–108. Ladha J K, Singh Y, Erenstein O and Hardy B(eds.). International Rice Research Institute, Los Ban˜os, Philippines.

Mahajan G, Chauhan BS. 2011. Effects of planting pattern and cultivar on weed and crop growth in aerobic rice system. *Weed Technology* 25, 521–525.

Mahajan G, Brar LS. 2002. Integrated management of *Phalaris minor* in wheat: rationale and approaches-a review. *Agriculture Review* 23, 241–251.

Malik RK, Yadav A, Hobbs P R, Gill G, Sardana P K, Bellinder R. 2003. Integrated weed management and conservation agriculture in the Indian rice-wheat cropping system. (In) Proceedings of the 57th Annual Meeting of the NEWSS, Vol. 57. Baltimore, MD, USA. pp. 136-142.

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

Ominski P, Entz M. 2001. Eliminating soil disturbance reduces post-alfalfa summer annual weed populations. *Canadian Journal of Plant Sciences* 81, 881–884.

Sharma RK, Chhokar RS, Jat ML, Singh Samar, Mishra B, Gupta RK. 2008. Direct drilling of wheat into rice residues: experiences in Haryana and western Uttar Pradesh. *(In)Permanent Beds and Rice-Residue Management for Rice–Wheat Systems in the Indo-Gangetic Plain*, pp. 147–158. Humphreys E and Roth C H (Eds.). Australian Centre for International Agricultural Research (ACIAR),Canbera, Australia. Accessed on www. aciar.gov.au/publication/PR127.

Singh RB, Paroda RS. 1994. Sustainability and productivity of rice-wheat in the Asia-Pacific region: research and technology development needs. *(In) Sustainability of Rice-Wheat Production Systems in Asia*, pp. 1-35. Paroda R S, Woodhead T and Singh R B (Eds.). FAO, Bangkok.

Singh S, Ladha JK, Gupta RK, Bhusan L, Rao AN, Sivaprasad B, Singh PP. 2007. Evaluation of mulching, intercropping with *Sesbania* and herbicide use for weed management in dry-seeded rice. *Crop Protection* 26, 518–524.

Singh S, Malik RK, Balyan RS. 1990. Weed management in wheat. *Haryana Farming* 19, 15–16.

Singh S, Malik RK, Balyan RS, Singh S. 1995. Distribution of weed flora of wheat in Haryana. *Indian Journal of Weed Science* 27, 114–121.

Singh S, Chhokar RS, Gopal R, Ladha JK, Gupta RK, Kumar V, Singh M. 2009. Integrated weed management: a key to success for direct-seeded rice in the Indo-Gangetic plains.*(In) Integrated Crop and Resource Management in the Rice–Wheat System of South Asia.* pp. 261–278. Ladha J K, Singh Y, Erenstein O and Hardy B (Eds.). International Rice Research Institute, Los Ban˜os, Philippines.

Thi HL, Man LH, Chin DV, Auld BA , Hetherington SD. 1999. Research on some fungi to control barnyard grass and red sprangletop in rice. *(In) Proceedings of the 17th Asian-Pacific Weed Science Society Conference*, Bangkok, Thailand, pp. 562-566.

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

The present publication deals with the scope and significance of refinement, adoption and dissemination of conservation agriculture (CA) in Indian *vis-à-vis* global context. Through this book, an attempt has been made to help readers to gain a precise understanding of the role of mechanization and the necessity for suitable modifications in the existing machinery for efficient residue recycling, crop establishment, optimized nutrient and water use, and weed management. Highlighting the collective work of various CA researchers, this reference book helps to understand the aspects like dynamics of macro and micro-nutrients along with the desired management alterations as per the CA principles. For the wider adoption of CA, location-specific crop diversification suited for different soil types has also been discussed in the book. The approaches like integrated farming system and organic farming in conjunction with CA principles for enhanced resource recycling, sustained livelihood in long-term perspective has been documented in the book. The impact of CA on soil quality, technologies designed for adaptation/mitigation for climate vulnerability, economics and system sustainability has been the focal point in the present book.

. . . This book is a perfect compilation of consorted efforts of various researches done in the direction of development, standardization and dissemination of the refined CA technologies. The emerging concerns of environmental unsustainability raised in the book necessitates the development of a policy framework promoting CA . . . I strongly believe that the book would be of great value to various stakeholders in addressing the goals of achieving sustainable agricultural systems through conservation agriculture . . .

– Dr Arvind Kumar
Vice-Chancellor
Rani Laxmi Bai Central Agricultural University, Jhansi

Readership: Researchers working on conservation agronomy, soil science, soil physics, environmental sciences, farm machinery and power, agricultural economics and extension. Undergraduate, post graduate students of different natural resource management disciplines in SAUs, all the stake holders including policy makers, state agriculture development departments involved in agricultural production in general and conservation agriculture in particular.

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