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Managing weeds in rice (*Oryza sativa*)-wheat (*Triticum aestivum*)-greengram (*Vigna radiata*) system under conservation agriculture in black cotton soils

V P SINGH[1], K K BARMAN[2], P K SINGH[3], RAGHWENDRA SINGH[4] and ANIL DIXIT[5]

Directorate of Weed Research, Jabalpur, Madhya Pradesh 482 004

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ABSTRACT

Conservation agriculture (CA) does have several advantages over conventional tillage (CT) based agriculture in terms of soil health parameters. However, weeds are the major biotic constraint in CA, posing as a great challenge towards its adoption. Field experiment was conducted at Directorate of Weed Research , Jabalpur (MP) during 2012–14 to monitor weed dynamics, crop productivity, and soil health parameters in a rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.)-greengram [Vigna radiate (L.) Wilczek] cropping sequence under CA system. The treatments consist of ZT (DSR)+*Sesbania* brown manuring – ZT (wheat) – ZT (greengram), with or without crop residue cover; CT (DSR)+*Sesbania* brown manuring – CT (wheat) – ZT (green gram), with or without crop residue cover; farmers practice, i.e. CT (TPR) – CT (wheat). The lowest total weed density was recorded under ZT (DSR)+*Sesbania.* Compared to CT, significantly lower density of *Cyperus iria,* but higher density of *Caesulia axillaris* was recorded under ZT; while CT (TPR) recorded the lowest population of *P. minima* and *D. retroflexa* during rice. Similarly, in wheat, significantly lower population of *Phalaris minor* and *Chenopodium album* was noticed under ZT. Highest grain yield (3.42 t/ha) was recorded with transplanted rice; whereas, higher yield of wheat was recorded when sown after DSR and crop residues were recycled. Tillage systems did not differ significantly in terms of soil respiration rate when crop residues were recycled. There was significant gain in soil organic carbon pool only when the complete conservation package of ZT along with crop residue recycling was adopted. A preliminary survey conducted in the adjoining localities of Jabalpur during 2012-13 showed lack of awareness among the farmers about the resource conservation technology (RCT) to grow wheat. Subsequently, the trials laid out in 3 farmers' field during *rabi* seasons of 2012-13 and 2013-14 also showed that wheat performed much better under CA, as compared to the conventional farmers' practice, resulting in lower cost of production, higher income and higher benefit: cost ratio. Green gram, sown with RCTs and chemical weed control measure in the same farmers' fields following wheat, also provided higher B:C ratio and an additional net return of ₹28 975/ha over farmers practice. It was concluded that the RCTs like ZT and residue cover could be practiced in the black cotton soils to increase farmers' income.

Key words: Conservation agriculture, RCT, Soil health, Weed dynamics

The Conservation agriculture technologies are said to be efficient for improving production and income, and addressing the emerging problems associated with conventional intensive tillage based agriculture. Literatures are available to indicate multipronged benefit due to the adoption of this technology, viz. (i) reduced cost of production (Malik *et al*. 2005); (ii) enhanced soil quality, i.e. soil physical, chemical and biological conditions (Gathala *et al*. 2011b); (iii) increased carbon (C) sequestration and build-up in soil organic matter (Saharawat *et al*. 2012); (iv) increased water and nutrient-use efficiencies (Jat *et al*. 2012, Saharawat *et al*. 2012), (v) increased system productivity (Gathala *et al*. 2011a); (vi) advances in sowing date (Malik *et al*. 2005); (vii) greater environmental sustainability (Pathak *et al*. 2011); (viii) increased residue breakdown with legumes in the rotation (Fillery 2001); and (ix) reduced temperature variability (Gathala *et al*. 2011b).

Although CA systems have been adopted by the commercial farmers in the Americas and Australia (Derpsch 2002, Bolliger *et al*. 2006), adoption by smallholders has lagged well behind that on large and mechanized farms (Derpsch *et al*. 2010). Several problems, which varies in different situations, are to be addressed to popularize CA systems across the farming communities.

Conservation agriculture addresses the complete agricultural system—the 'basket' of conservation-related agricultural practices. Three key principles have been identified, viz. minimal soil disturbance, permanent residue cover and planned crop rotations, which are considered

[1]Principal Scientist (e mail: vpsinghnrcws@gmail.com), Division of Crop Production, ICAR-Indian Institute of Sugarcane Research, Lucknow (UP) 226 002. [2,3]Principal Scientist (e mail: barmankk@gmail.com,drsinghpk@gmail.com); [4]Senior Scientist (e mail: singhraghu75@gmail.com); [5]Principal Scientist (e mail: dranildixit@gmail.com).

essential to its success. Weeds being one of the most difficult management issues within this system, it was advocated to include integrated weed management as a fourth component that is crucial for successful implementation of CA (Farooq *et al*. 2011). Crop-weed competition and management strategies also affect CA yields and sustainability; as it was argued by Giller *et al*. (2009), weeds are 'Achilles heel' of CA. In the conventional agriculture system, tillage affects weeds by uprooting, dismembering, and burying them deep enough to prevent emergence. Ploughing also moves weed seeds both vertically and horizontally, and changes the soil environment; thereby promoting or inhibiting weed seed germination and emergence. However, absence of tillage practice under ZT system leads to presence of more weed seeds in the soil surface, which favours relatively higher weed germination. Hence, reduction in tillage intensity and frequency are responsible for increased weed infestation under CA. Further, a weed flora shift in the crop field is another problem often encountered due to changes from conventional to conservation farming practices. There are instances of disadoption of ZT practice by farmers' due to increased weed problems (Farooq *et al*. 2007). It was noted that the ZT adopters, non-adopters, and disadopters differ significantly in terms of their resource bases; and disadopters also had more problems in controlling weeds (Tahir and Younas 2004).

Although the CA technology like ZT wheat in the rice–wheat system is a success story and is currently being practiced by the farmers on >3 million ha in north-western parts of the Indo-Gangetic plains, the concept of CA as a whole is yet to make its presence felt across the agro-ecological regions of the country. There cannot be a universal prescription of CA for all situations; efforts to promote conservation agriculture will have to be tailored to reflect the particular conditions of individual locales (Knowler and Bradshaw 2007). Accordingly, an attempt was made to evaluate the performances of CA technologies in combination with improved weed management technologies in black cotton soils of central India under farmers' field condition. The observation made in respect to crop yields, farmers' perception, and the issues relating to weed management and soil health are reported here.

MATERIALS AND METHODS

Field experiment was conducted during 2012–14 to monitor weed dynamics, crop productivity, and soil health parameters in a rice (*Orzya sativa* L.)-wheat (*Triticum aestivum* L.)-greengram [*vigna radiata* (L.) Wilczek] cropping sequence under conservation agriculture system at Directorate of Weed Research, Jabalpur (23°90′N, 79°58′E, 412 m above MSL), India.The climate of the area is sub-tropical, with an average annual rainfall of 1 386 mm (75–80% of which is received during June–September), minimum temperature of 4–7°C in January, and maximum temperature of 42–45°C in May. The soil was clay loam (Typic chromusterts) in texture, low in available nitrogen (159 kg/ha), medium in available phosphorus (18 kg P/ha), and high in available potassium (325 kg/ha), with organic carbon 0.54% and pH 7.5. The treatments consist of five crop establishment methods, viz. (i) conventional tillage (CT) direct-seeded rice (DSR)-CT(wheat)-zero tillage (ZT) (greengram) without crop residue recycling, (ii) CT(DSR)-CT(wheat)-ZT(greengram) with crop residue recycling, (iii) ZT(DSR)-ZT(wheat)-ZT(greengram) without crop residue recycling, (iv) ZT(DSR)-ZT(wheat)-ZT(greengram) with crop residue recycling, and (v) Transplanted rice (TPR)-CT(wheat) in main plots; and three weed control measures, viz. repetitive use of herbicides, rotational use of herbicides and unweeded (control) in sub plots (8.75 × 18 m). Under repetitive herbicide treatments, bispyribac-sodium 25 g/ha in rice and ready mix of idosulfuron + mesosulfuron at 12+2 g/ha in wheat were applied every year. While, under rotational treatments rice received bispyribac-sodium 25 g/ha in first year and fenoxaprop-ethyl 60 g/ha followed by *(fb.)* 2,4 D 500 g/ha in second year. In case of wheat, tank mix of clodinafop+2,4 D at 60+500 g/ha in first year and metsulfuron-methyl at 4 g/ha in second year were applied. All the herbicides were applied as post-emergence at 25 days except 2,4-D, which was applied at 30 DAS after sowing (DAS) in 500 L water using knapsack sprayer. Tillage operation for CT (rice) included one pass of mould board plough *fb* two passes of cultivator and one planking (leveling with a wooden bar). While, only two passes of cultivator and oneplanking operation was performed prior to sowing of CT (wheat). All ZT plots received pre-sowing application of paraquat for control of prevailing weeds. Direct seeding of rice (var. IR64, 80 kg/ha) was done in the second week of June; and on the same day nursery of rice was also sown for transplanting operation performed in the second week of July. *Sesbania* was grown in all DSR plots as intercrop, which was killed *in-situ* using 2,4-D ethyl ester at 25 DAS (brown manuring). The wheat cultivar 'GW 273' (semi-dwarf with 135–140 days duration) was seeded at 120 kg/ha during third week of November.

Both rice and wheat received 120 kg N, 60 kg P_2O_5, and 40 kg K_2O per ha through urea, di-ammonium phosphate and muriate of potash. Direct seeding, and basal application of full dose of phosphorus, potash and ½ dose ofnitrogen at 2–3 cm below the seed, was done by using an improved version of seed-cum-fertilizer drill known as 'Happy Seeder'. This new seed-drill, besides seeding, also cuts the existing crop residues and simultaneously mulches the inter-row spaces. Remaining ½ dose of nitrogen was applied in two equal splits at mid-tillering (35 DAS) and panicle initiation (60 DAS) stages in rice, and at crown root initiation (CRI; 21 DAS) and maximum tillering (50 DAS) stages in wheat.

Weed count, for estimating weed density and weed dry weight at 60 DAS in rice and wheat, was recorded with the help of a quadrate (0.5 × 0.5 m) placed randomly at four spots in each plot. The data were analyzed by following split-plot design with three replications.

Soil samples were collected from 0-15 cm depth after harvest of 2nd year winter crops and analyzed for organic carbonand available N content. The soil respiration measurement was carried during 1st week of March. Polyethylene plastic made cylindrical shaped closed chambers were used to measure the CO_2 flux. The area of the bottom of the chamber was 314 cm^2 (Diameter 20 cm), and the height was 24 cm. Following the removal of litters, on each experimental plot the chamber was placed inter-rows covering 15 ml of 2 N NaOH taken in a petri dish having inner bottom area of 64 cm 2 (9.5 cm diameter) and 2 cm height. The edge of the chamber was inserted about cm into the soil, and the petri dish was placed at 2-3 cm above the soil surface using a stand. The alkali trap absorption area was thus about 20% of the CO_2 flux area, which is considered optimum for respiration rate measurement (Ivo and Salcedo 2012). The alkali traps were left in the field for periods of 24 h, thus avoiding daily fluctuations in the CO_2 flux estimates. At the end of the measurement period, the alkali was transferred to air tight plastic tubes with lids, and taken to the laboratory. Total CO_2 absorbed was determined by adding excess $BaCl_2$ to the alkali followed by titration with 0.2 N HCl using phenolphthalein indicator. The calculation of the soil respiration was done by the following equation:

$$CO_2\ (mgCO_2\ m^{-2}\ h^{-1}) = [(V_1 - V_2) \times N \times 22] / (A \times T)$$

where, V_1: ml of HCl solution reacted with NaOH prior to CO_2 absorption; V_2: ml of HCl solution reacted with NaOH at the end of CO_2 absorption; N: Normality of HCl used; M: molar mass of CO_2; A: CO_2 flux area in m^2; T: respiration determination time in h.

A preliminary survey was conducted in the adjoining localities of Jabalpur during 2012-13 to find out the extent of awareness of the farmers about the RCT to grow wheat. Subsequently, trials were laid out during *rabi* season of 2012-13 and 2013-14 in 3 farmers' field with two sets of treatments, viz. farmers' practice, and RCT for wheat. The farmers practice included sowing of wheat following conventional tillage after removal/burning of preceding rice residue, plus manual weeding at around 25-30 DAS. The improved package of practice, i.e. RCT, consisted of wheat sowing using a `happy seeder' without tilling and removing the existing rice stubbles, plus application of herbicides for managing weeds. Glyphosate @ 2 kg/ha were applied prior to sowing to control the existing weeds. The post-applied (20-25 DAS) herbicides used in farmers's field were 2,4-D (500 g/ha), ready-mix of mesosulfuron + iodosulfuron (24 +12 g/ha), ready-mix of clodinafop + metsulfuron (60+4 g/ ha), and metsulfuron (4g/ha) alone, and were applied on the basis of the weed flora prevailing in the concerned fields. Following wheat, green gram was sown in the same fields. Application of glyphosate prior to sowing, and imazethapyr @ 100 g/ha 21 DAS was made to manage the weeds in greengram under CA. Herbicides were applied using 500 L water/ha withknapsack sprayer having flat-fan nozzle. Each package of practices was imposed in 0.4 ha of land in each farmer's field.

RESULTS AND DISCUSSION

Weed dynamics and soil health

Dominant weed floras in rice were *Echinochloa colona,* and *Dinbera retroflexa* among grasses; *Physalis minima,* and *Ceasulia axillaris* among broadleaved weeds; and *Cyperus iria* was only sedge presents. Different crop establishment techniques significantly influenced the emergence of different weed flora, except *E. colona* and *D. retroflexa,* as well as total weed population and dry matter accumulation at 60 DAS (Table 1). Significantly lower density of *C. iria* was recorded under ZT (DSR)+*Sesbania* with or without retention of previous season crop residue compared to CT (DSR) or TPR. Whereas, ZT (DSR)+*Sesbania* with or without crop residue recorded higher population of C. *axillaris.* CT (TPR) recorded lowest population of *P. minima* and *D. retroflexa* in -rice. So far as the total weed population and weed dry matter accumulation is concerned, the lowest total weed density was recorded with ZT (DSR)+*Sesbania* without residue retention, but it was statistically at par with TPR. However, CT (DSR) being at par with ZT (DSR) without retention of residue of previous season crop recorded significantly lower weed dry matter production. Amongst the weed control measures, continuous use of bispyribac + pre-sowing non-selective herbicides in ZT recorded significantly lower weed population and weed dry matter compared to weedy check. The highest grain yield of rice was recorded with CT-TPR (3.42 t/ha) which was statistically similar to ZT-DSR with residue recycling (3.14 t/ha).

Dominant weed flora in wheat were *Phalaris minor*, and *Avena ludoviciana* among grasses, and *Medicago denticulata, Chenopodium album* and *Lathyrus aphaca* amongst broad-leaved weeds. Different crop establishment methods influenced significantly the distribution of weed flora in wheat. Significantly lower population of *P. minor* and *C. album* was noticed in ZT (DSR)-ZT (wheat), it was statistically comparable with TPR-CT (wheat) over CT (DSR)-CT (wheat). On the other hand, there was lower population of *A. ludoviciana* in TPR-CT (wheat) and CT (DSR)-CT (wheat). However, CT (DSR)-CT (wheat) recorded significantly lower population of *M. denticulata*. Whereas significantly lower weed population and weed dry matter was recorded with CT (wheat) sown after CT (TPR/DSR). Amongst weed control measures, significantly lower population and weed dry biomass were recorded with recommended herbicide + pre-sowing non-selective herbicide in ZT (Table 2).

The wheat grown after DSR combined with either crop residue retention significantly produced higher grain yield of wheat in both CT/ ZT (wheat), and these were statistically higher than that recorded in the conventional treatment of TPR-CT (wheat). Amongst weed control treatments, application of recommended herbicides with and without manual weeding produced significantly higher grain yield over weedy check.

The crop establishment techniques showed significant effect on soil health parameters. In absence of crop residue

Table 1 Weed density, weed dry weight and grain yield in rice as influenced by different tillage systems and weed management measures (average of 2 years)

Treatment	Density (number/m^2)					Weed dry weight (g/m^2)	Grain yield (t/ha)
	E. colona	*C. iria*	*P. minima*	*C. axillaris*	Total weed		
Tillage and crop establishment							
CT(DSR)+S– CT(wheat)– ZT (greengram)	1.1 (0.7)	3.8 (13.9)	1.5 (1.7)	1.3 (1.3)	5.0 (24.3)	3.4 (10.7)	2.34
CT(DSR)+R+S – CT(wheat) +R – ZT(greengram)+R	1.2 (0.9)	3.8 (13.9)	1.3 (1.1)	1.2 (0.7)	4.5 (19.7)	5.8 (31.9)	2.96
ZT(DSR)+S – ZT(wheat) – ZT (greengram)	1.1 (0.7)	2.6 (5.7)	0.9 (0.3)	1.6 (1.7)	3.3 (10.3)	4.3 (17.9)	3.08
ZT(DSR)+R+S – ZT(wheat) +R – ZT(greengram)+R	1.0 (0.5)	2.9 (7.9)	1.5 (1.7)	2.0 (3.1)	4.2 (17.1)	5.4 (28.6)	3.14
CT(TPR) – CT (wheat)	0.9 (0.3)	3.3 (10.3)	0.7 (0.4)	1.9 (3.1)	3.9 (14.7)	5.0 (24.5)	3.42
LSD (P=0.05)	NS	0.56	0.43	0.64	0.90	0.10	0.39
Weed management							
Weedy check	1.1 (0.7)	6.4 (40.4)	0.9 (0.1)	2.6 (5.7)	7.3 (52.7)	10.2 (103.5)	2.41
Repetitive use of herbicide	1.3 (0.9)	1.0 (0.5)	1.6 (2.0)	1.0 (0.4)	2.3 (4.7)	2.4 (5.2)	3.35
Herbicide rotation	0.8 (0.1)	2.5 (5.7)	1.1 (0.7)	1.2 (0.9)	3.0 (7.9)	3.5 (11.7)	3.20
LSD (P=0.05)	0.37	0.43	0.29	0.53	0.21	0.47	0.19

DSR – direct-seeded rice, TPR – transplanted rice, S – *Sesbania*brown manuring, CT – conventional tillage, ZT – zero tillage and R – residue. Data subjected to $\sqrt{x+0.5}$ transformations. Figures in parentheses are original values. Amongst weed control treatments, continuous use of bispyribac-sodium @ 25 g/ha at 25 DAS being at par with rotational use of herbicides, recorded significantly higher grain yield of rice compared to weedy check.

recycling, the rate of soil respiration was significantly higher in ZT-ZT than in CT-CT and puddle-CT systems. Crop residue recycling increased soil respiration rate in both ZT-ZT and CT-CT systems; and the tillage systems did not differ significantly in terms of soil respiration rate when crop residues were recycled. There was no effect of weed control measures on rate of soil respiration.

The tillage and crop residue management practices

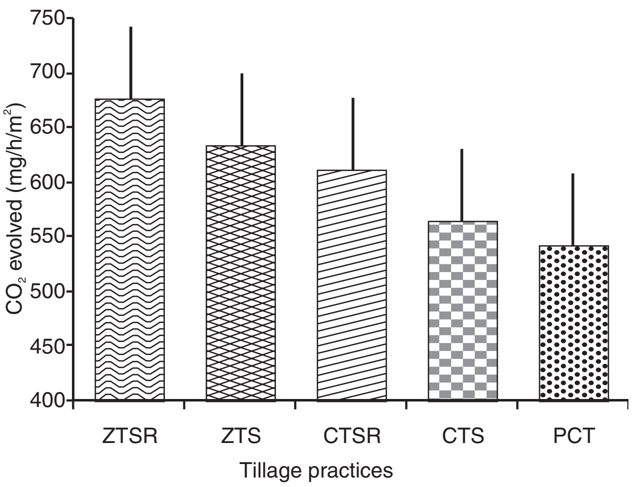

Fig 1 Effect of crop residues and tillage practices on soil respiration under wheat (CT: conventional tillage, ZT: zero tillage, S: *Sesbania* brown manuring, R: crop residue recycling and PCT : puddled/conventional tillage)

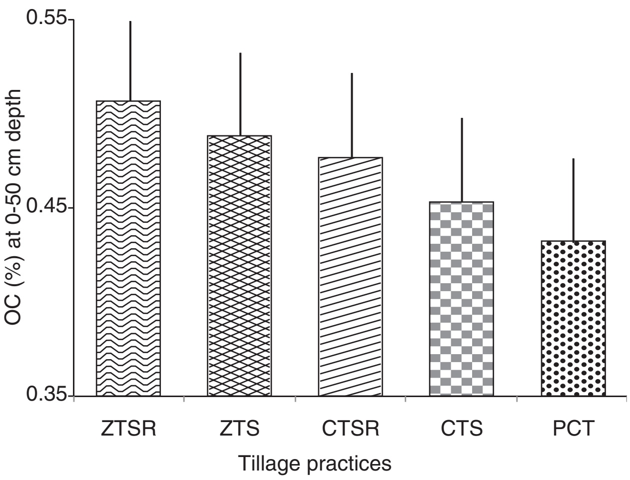

Fig 2 The organic carbon content in the soil as influenced by tillage and residue recycling practices (CT: conventional tillage, ZT: zero tillage, S: *Sesbania* brown manuring, R: crop residue recycling, PCT: puddled/conventional tillage)

Table 2 Weed density, weed dry weight and grain yield in wheat as influenced by different tillage systems and weed management measures (average of 2 years)

Treatment	Weed density (number/m^2)					Weed dry weight (g/ m^2)	Grain yield (t/ ha)
	P. minor	*A. ludoviciana*	*M. denticulata*	*C. album*	Total		
Tillage and crop establishment							
CT (DSR) + S– CT (wheat)– ZT (greengram)	6.4 (40.4)	1.7 (2.3)	9.3 (85.9)	3.9 (14.7)	12.4 (153.2)	8.2 (66.7)	3.86
CT (DSR) + R + S – CT (wheat) +R – ZT (greengram) + R	6.0 (35.5)	2.0 (3.5)	10.5 (109.7)	2.6 (6.2)	12.8 (163.3)	8.0 (63.5)	4.07
ZT (DSR) + S – ZT(wheat) – ZT (greengram)	2.5 (5.7)	2.8 (7.3)	21.1 (444.7)	1.2 (0.9)	24.6 (604.6)	8.6 (73.4)	3.51
ZT(DSR)+R+S – ZT(wheat) +R – ZT (greengram) + R	1.6 (2.0)	2.6 (6.2)	22.5 (505.7)	0.9 (0.3)	23.3 (542.3)	12.1 (145.9)	3.84
CT(TPR) – CT (wheat)	3.8 (13.9)	1.6 (2.0)	8.2 (66.7)	3.8 (13.9)	12.0 (143.5)	6.8 (45.7)	3.58
LSD (P=0.05)	1.0	1.1	1.8	1.4	2.60	5.4	0.25
Weed management							
Weedy check	4.5 (19.7)	2.0 (3.5)	19.41 (375.8)	3.0 (8.5)	21.1 (444.7)	14.7 (215.5)	3.14
Repetitive use of herbicide	3.9 (14.7)	2.3 (4.7)	10.59 (109.7)	2.8 (7.3)	13.2 (173.7)	4.2 (17.1)	4.44
Herbicide rotation	3.7 (13.1)	2.0 (3.5)	12.9 (165.9)	1.7 (2.3)	16.7 (278.3)	7.3 (52.7)	3.74
LSD (P=0.05)	1.0	0.74	1.07	0.55	1.15	3.9	0.47

DSR – Direct-seeded rice, TPR – transplanted rice, S – *Sesbania*brown manuring, CT – conventional tillage, ZT – zero tillage and R – residue. Data subjected to $\sqrt{x+0.5}$ transformations. Figures in parentheses are original values.

significantly affected the soil organic carbon (OC) content (Fig. 2). The highest value of the mean OC content was 0.51% under ZTSR followed by 0.49, 0.48, 0.45 and 0.43% under ZTS, CTSR, CTS and PCT treatments, respectively. Although the magnitude of OC content increased with the addition of preceding crop residues, the differences between ZTSR and ZTS, and between CTSR and CTS were not significant. Similarly, no difference in this regard was noticed between CTSR and ZTSR treatments. However, there was significant difference between ZTSR and CTS treatments. This indicated that, compared to conventional practice, there was significant gain in soil organic carbon pool only when the complete conservation package of ZT along with crop residue recycling was adopted. Simply shifting the practice from CT to ZT, or mere recycling of crop residue under conventional tillage system may not provide the desired benefit in short-term.

On-farm trial

The preliminary survey showed that farmersusuallysow wheat by following conventional tillage, after burning the stubbles of preceding rice crop. The farmers' were not aware about RCT of retaining the standing crop residues in the field, and expressed serious doubt that it could be a feasible proposition of sowing and growing a good crop without burning/removing the standing crop stubbles. The extent of their suspicion could be realized from the fact that the selected farmers' agreed to provide their lands for demonstration of the proposed CA technologies after a great deal of persuasion.

Major weeds were *Lathyrus sativa, Vicia sativa, Chenopodium album, Medicago denticulate* and *Melilotus alba* among broadleaved weeds; and A*vena* sp.(wild oat)and *Phalaris minor* among grasses. The herbicides controlled the weed flora effectively. The crop performed much better under CA and increased wheat yield as compared to the conventional farmers' practice. The result also showed lower cost of production and higher income, resulting in sharp increase in benefit:cost ratio, under CA system (Table 3).

Performance of greengram sown in the same farmers' fields following wheat is shown in Table 4. Result revealed that CA with chemical weed control measure was effective and gave a seed yield of 1.30 t/ha, as compared to 0.73 t/ ha under conventional practice; and provided an additional net return of ₹ 28 975/ha with higher B:C ratio (2.54) over farmers practice.

A field day was organized to demonstrate the performance of wheat and profitability under CA in the farmer's fields. The farmers' visiting the demonstration sites expressed their satisfaction after observing the crop performance under CA; and contrary to their initial response

Table 3 Performance of wheat crop in farmers' field under conventional and conservation agriculture practices in Panagar locality (average of 2 years)

Weed control measure	Weed count (no./ m^2)	Dry weight (g/m^2)	Grain yield (t/ha)	Total income (₹/ha)	Cost of production (₹/ ha)	B:C ratio
a. under conventional practice						
Chemical weed control	27.9	13.6	2.90	40963	19188	2.12
Farmer's practice	69.9	54.8	1.80	26294	18000	1.46
b. under conservation agriculture						
Chemical weed control	33.3	20.1	3.17	45554	16906	2.70
Farmer's practice	70	57.8	2.00	29000	15500	1.87

Table 4 Performance of green gram crop in farmers' field under conventional and conservation agriculture practices in Panagar locality (Average of 2 years)

Treatment	Weed count (no./ m^2)	Weed dry weight (g/m^2)	Grain yield (t/ha)	Cost of production (₹)	Gross return (₹)	B:C ratio
Conservation agriculture	44.0	28.2	1.30	19850	58395	2.94
Conventional agriculture	100.6	65.6	0.73	23400	32970	1.41

as was noticed during preliminary survey, they happily volunteered to provide their lands for subsequent trials on CA. Some farmers' expressed their willingness to adopt the technology and enquired about the availability and price of the 'happy seeder.'

Conservation agriculture is a holistic approach aims towards increased productivity and improved soil health. Higher weed infestation under this practice is an important problem. The outcomes of the experiments conducted in farmers' fields and research farm showed that the benefits of CA can well be taken in black cotton soils with rice-wheat-green gram system as weed menace under this system can be managed by integrating suitable herbicides in the weed management programme. However, as this is a highly technology driven agriculture and its very basic principles of sowing the seeds in an untilled land and without removing the crop residues are in a sharp contrast to the traditional belief, tremendous amounts of efforts will be needed to pursue the farmers' for adoption of this technology. It may be concluded from the present study that the whole package of conservation agriculture practice, i.e. ZT (DSR) +S+R-ZT+R-ZT+R with effective management of weeds with post-emergence herbicides was superior to traditional practice of TPR-CT in terms of higher system productivity, higher return and built up of soil organic carbon and available N. There was no difference between residue incorporation and residue mulching in terms of the above soil parameters as well as CO_2 flux from soil in the DSR plots.

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