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Conservation agriculture in South Asia

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SUMMARY

The Green Revolution era focused on enhancing the production and productivity of rice and wheat. New challenges demand that the issues of efficient resource use and resource conservation receive high priority to ensure that past gains can be sustained and further enhanced to meet the emerging needs. Extending some of the resource-conserving interventions developed for wheat to rice culture is a major challenge for researchers and farmers alike. The present paper shares recent research experiences on resource conservation technologies involving tillage and crop establishment options and associated agronomic practices which enable farmers in reducing production costs, increase profitability and help them move forward in the direction of adopting conservation agriculture.

INTRODUCTION

In South Asia, the Rice-Wheat Consortium (RWC) countries – Bangladesh, India, Nepal, and Pakistan – have devoted nearly half of their total land area of 401·72 million ha to agriculture to feed and provide livelihoods for 1·8 billion people (FAO 2001). Rice and wheat, the staple food crops of the area, are of great significance as they account for more than 0·8 of the total cereal production in these countries (Timsina & Connor 2001). Rice–wheat systems occupy nearly one-fifth of the total area under these crops (Hobbs & Morris 1996; Ladha *et al.* 2000). Thus, intensively cultivated irrigated rice–wheat systems are fundamental to the employment, income, and livelihoods of hundreds of millions of rural and urban poor in South Asia (Evans 1993; Paroda *et al.* 1994).

Suitable thermal regimes for rice and wheat crops during the annual cycle, development of short duration cultivars, irrigation, and ever-increasing demand for food were the driving forces for the expansion of rice–wheat systems during the Green Revolution. In the last few decades, high growth rates of food grain production (3 and 2·3% per decade, respectively, for wheat and rice) in RWC countries have kept pace with population growth (APAARI 2000). However, evidence is emerging that the continuous rice–wheat systems are exhausting the natural resource base (Duxbury *et al.* 2000). Thus, the food security of the region is under continuous threat, creating new challenges in post-Green Revolution agriculture.

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THE RWC AND RESOURCE-CONSERVING TECHNOLOGIES (RCTs)

The Rice-Wheat Consortium of the Indo-Gangetic Plains is an eco-regional programme of the Consultative Group of International Agricultural Research (CGIAR) convened by the International Maize and Wheat Improvement Center (CIMMYT). It involves the National Agricultural Research Systems (NARS) of Bangladesh, India, Nepal, and Pakistan and various other CGIAR centres, including the International Rice Research Institute (IRRI) and the International Crops Research Institute for Semi-Arid Tropics (ICRISAT). Its goal is to maintain food security and improve the livelihoods of farmers dependent on rice–wheat systems in a sustainable way and through deployment of natural resource-efficient, RCTs and conservation agriculture (CA) expertise. Any new technology that is more cost-effective for farmers

Table 1. *Area estimates of RCTs* in the Indo-Gangetic Plains of Bangladesh, India, Nepal, and Pakistan from 2001 to 2006*

Country	2001/02 (ha)	2002/03 (ha)	2003/04 (ha)	2004/05 (ha)	2005/06 (ha)
India	133 550	375 761	870 150	1 870 464	2 388 673
Pakistan	79 853	192 127	338 900	438 000	421 210
Bangladesh	10 372†	10 398†	10 560†	388 820	419 910
Nepal	380	560	2704	12 359	14 307
Total	224 155	578 846	1 222 314	2 709 643	3 244 100

* RCT is any new technology that is more cost-effective for farmers compared to the status quo.
† Area of surface seeded crops and reduced tillage with 2-wheel power tillers.

compared to the status quo is identified with RCTs. RCTs are divisible in application, flexible in operations, can be super-positioned for higher profits, resource efficiency and enhanced sustainability; RCTs are promoting paradigm shifts in conventionally tilled agriculture (e.g. tillage to minimal tillage and puddled transplanted rice to zero-till direct dry seeded rice) that allows us to move forward in the direction of sustainable CA. The objective of the RWC is not merely to raise production of rice and wheat, but also to 'help improve livelihoods and reduce poverty through more productive and sustainable agroecosystems based on the rice–wheat rotation, and to conserve natural resources devoted to these systems'. CA practices have been found to contribute substantially to this objective.

RCTs AND CA

The present paper presents data collected by the RWC partners on the role of RCTs in improving crop and water productivity. It is the endeavour of the Consortium to move forward in the direction of double no-till seeding systems (seeding both rice and wheat crops with minimal soil disturbance) with crop residues retained on the surface to reach a more complete manifestation of the tenets that define a CA production system.

The three key principles of CA are permanent residue soil cover, minimal soil disturbance and crop rotations. The FAO recently added controlled traffic to this list, to avoid soil compaction (Tullberg 2001; Tullberg *et al.* 2001) and obviate the need for tillage when zero till agriculture is practised over longer periods. According to the FAO: 'Conservation Agriculture maintains a permanent or semi-permanent organic soil cover. This can be a growing crop or dead mulch. Its function is to protect the soil physically from sun, rain and wind and to feed soil biota. The soil flora and soil fauna take over the tillage function and soil nutrient balancing. Mechanical tillage disturbs this process. Therefore, zero or minimum tillage and direct seeding are important elements of CA. A varied crop rotation is also important to avoid disease and pest problems' (Gustafson & Friedrich 2006).

Through farmer participatory research approaches, an attempt is being made to develop double no-till systems for flat and raised-bed planting of rice and wheat crops, which have contrasting edaphic requirements or tolerances. One of the major challenges is to grow zero-till direct dry seeded rice with agronomic practices already developed for wheat and other crops. The present paper considers a set of innovations for double no-till systems that enhance farmers' incomes while achieving the goals of CA.

The RWC has been promoting various RCTs for tillage and crop establishment of rice, wheat, and other crops grown in rice–wheat systems. The rice–wheat system occupies nearly 13·5 million ha in the Indo-Gangetic Plains, spread over nearly one-quarter of the total geographic area of the Indian subcontinent in South Asia. RCTs, which occupy more than 3 million ha in the Indo-Gangetic Plains (Table 1), can produce more food at less cost, significantly raise farmer profits, improve efficiency of natural resource use, and provide significant environmental benefits (RWC 2006). The expansion in area of RCTs in India and Pakistan has been exponential in recent years.

LAND LEVELLING, WATER SAVING, AND WATER PRODUCTIVITY

Although many soils in the Indo-Gangetic Plains appear to be fairly well levelled, in reality many fields have uneven soil surfaces that lead to wasted water and poor germination and crop stand. Crop plants suffer in low lying spots due to excessive wetness and nutrient leaching losses and in higher spots from water deficits. Precision land levelling is a complement and promotes adoption of RCTs (surface seeding, zero tillage, raised bed planting and intercropping).

Results of farmer participatory field trials indicate that compared with traditional levelling, laser-assisted

Table 2. *Effect of precision levelling, soil fertility, and crop establishment methods on yield and water productivity (WP)* of rice and wheat*

Treatments	Soil fertility	Land configuration	Yield (kg/ha)		WP (kg/m³)	
			Rice	Wheat	Rice	Wheat
Levelling						
Precision	High	R-beds	–	5007	–	1·90
Precision	High	Flat	6325	4618	0·91	1·31
Traditional	High	Flat	5033	4321	0·55	0·82
Traditional	Low	Flat	4100	2688	0·45	0·51
S.E. ±	–	–	311	165	0·11	0·05

* WP refers to kilograms of rice or wheat produced per m³ of irrigation water.

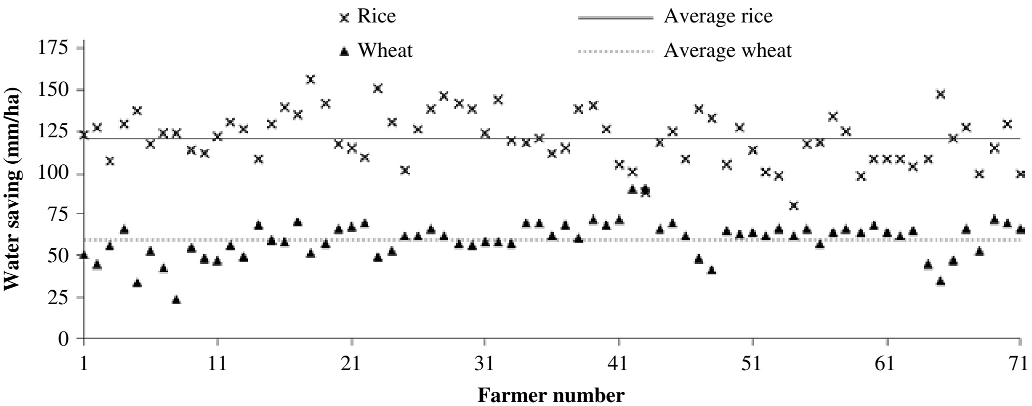

Fig 1. The effect of precision levelling on savings in irrigation water (mm/ha) for wheat (▲) and rice (×) measured in adjacent levelled and non-levelled fields.

precision land levelling saves on average a total of 180 mm of irrigation water in the rice–wheat system (Fig. 1). Irrigation water savings are defined as total irrigation water used in rice or wheat culture in traditionally levelled fields minus the water used in laser-levelled fields. Average water savings (shown with broken lines, Fig. 1) in rice and wheat cultures were found to be nearly 120 and 60 mm/ha, respectively. Besides water saving, land levelling also improved the crop production and water productivity (Jat *et al.* 2006*a*). Wheat yield was higher when soil fertility was improved in precisely levelled plots (Table 2).

TILLAGE AND CROP ESTABLISHMENT METHODS IN RICE–WHEAT SYSTEMS

Rice and wheat crops tolerate contrasting edaphic requirements. Whereas wheat is grown as an irrigated upland crop, rice is traditionally grown as a puddled transplanted crop. Puddling is achieved by stirring or ploughing of the surface layer in standing water to reduce soil permeability and preserve the aquatic, anaerobic conditions suited for growth of wetland rice. Combine harvesting of rice in wet soils creates ruts in some years, causes soil compaction, and makes the surface uneven. This forces farmers to disc harrow once or twice before establishing a wheat crop, in order to level the soil. To reduce compaction of moist soil and obviate the need for harrowing to level the fields, controlled traffic is being introduced in rice–wheat systems. With controlled traffic, the wheel of all implements track in the same place in the field for each operation. Paired row planting of crops is introduced to mimic the raised bed planting in normal or controlled traffic systems. Results of farmer participatory trials indicate that zero till reduces turnaround time and facilitates timelier planting of wheat and improves crop yields. Not planting wheat in traffic lanes (controlled traffic) does not result in any yield penalty, contrary to the general belief of the farmers. Paired row planting of wheat has been observed to improve crop productivity. The traffic lanes in due course convert the flat surface into a wide raised bed system of planting and the lanes serve as

Table 3. *Wheat yield with zero till (ZT) technologies in farmer participatory trials (average of ten trials conducted during 2000–02)*

Treatments	Total irrigation time (h/ha)	Savings in irrigation water* (%)	Grain yields (t/ha)
1. ZT drill	45·1	21	5·81
2. ZT with controlled traffic	45·0	19	5·96
3. ZT with paired rows†	48·0	13	6·13
4. ZT paired rows in controlled traffic	46·5	16	6·06
5. Farmer practice (tilled wheat)	55·3	–	5·45

* Compared with irrigation water used in conventionally tilled wheat plots planted a week later.
† Spacing between set-rows (140 mm); and between paired set-rows (250 mm).

irrigation channels and galleries for cultural operations without yield penalty (Table 3). Between the zero till treatments, average wheat yields improved slightly with pairing the rows and practising controlled traffic. Beside some yield gains, controlled traffic benefits the no-till system by restricting soil compaction to narrow tractor track zones. Free-wheeling of tractors has earlier been reported to compact the soils (Tullberg 2001).

NUTRIENT MANAGEMENT IN RCTs

Precision land levelling not only improves water productivity but also the use efficiency of fertilizer, especially N fertilizers (Jat *et al.* 2006*b*). In conventional well-tilled situations, half of the N is applied as basal and the balance is top-dressed. Results of on farm and station trials have shown that delaying the bulk of the N application to around the first node/stem elongation or later results in better yield (Sayre *et al.* 2005). In South Asia, the general practice is to apply half of the N as basal with the balance top-dressed in two equal splits, 40–45 and 60–70 days after sowing. Gupta *et al.* (2003) observed that early wheat planting with zero till and split application of N or single deep band placement of N along with the seed or between the seed rows had insignificant differences on wheat yield under the different treatments (Table 4).

It has been reported that need-based N management through use of leaf colour charts, shade 4, and a Soil Plant Analysis Development (SPAD) value of 42 reduces the N requirement by 12·5–25% without any reduction in yield in the rice–wheat system (Singh *et al.* 2002; Shukla *et al.* 2004). Sayre *et al.* (2005) reported that in minimum till or permanent bed situations, where soil is not tilled to incorporate the basal N fertilizer but is banded, the differences related to timing of N application are not as clear for either yield or grain protein content. Thus not tilling while maintaining residues on the soil surface, together with basal application of N fertilizer to keep the fertilizer and residues separated, appears to change the soil N dynamics. Residues present on the soil surface interfere with the movement of top-dressed N reaching the root zone and therefore banding at planting time is more efficient. When nitrogen was applied in three splits in zero till wheat, total N uptake (144·6 kg/ha) was lower than corresponding conventionally tilled wheat (184·4 kg/ha) with crop residues removed (Pasricha *et al.* 2006). Surface retention of residues seems to immobilize N when top-dressed and affects the decomposition rates of crop residues due to altered soil temperature and moisture regimes. Straw management is important as a strategy for replenishing K in micaceous soils of the Indo-Gangetic Plains, which have not been fertilized for a long period. In these soils the rate of K release is primarily dependent on the amount of biotitic micas only (Pal *et al.* 2005). These soils release enough K to meet demands of early rice in semiarid climatic conditions, but not of the intensive rice–wheat system practised in sub-humid environments. Straw management seems to slow down the rapid vermiculitization of biotitic mica and therefore, fixation of K^+ and NH_4^+ from the applied nitrogenous fertilizers.

DIVERSIFICATION/INTENSIFICATION OF RICE–WHEAT SYSTEMS

Whereas the rice–wheat system is practised in most northwestern parts of the Indo-Gangetic Plains, several other crops (winter maize, potato, *boro* rice, faba beans, vegetables, lentil, green peas, etc.) replace winter wheat in the eastern plains. It has been observed that wheat yields decline if planted in late winter, after 19 November (Fig. 2). The yield decline increases as one moves further east from Bihar (Jamui, Lakhi Sarai, Banka, and Munger cluster of districts, longitude 85·93°E and latitude 25·33°N) towards West Bengal (Mushirdabad and Nadia districts, longitude 88·60°E and latitude 22·96°N). A shift in longitude and latitude of 3° towards the southeast resulted in further decline in wheat yield of from 32 to 44 kg/ha/day (Fig. 2). The short winter season in the eastern Gangetic plains inhibits the expression of genetic potential of wheat cultivars such as PBW343, which is more than 5 t/ha in Punjab, 4 t/ha in Bihar and nearly 3 t/ha in West Bengal. In view of the short winter window available for wheat in the eastern Indo-Gangetic Plains, it is advisable to replace wheat with other crops such as potato and maize, which have the capacity to produce higher biomass and economic yields. In the northwestern

Table 4. *Effect of fertilizer N application method on conventionally tilled and no-till wheat*

Tillage practice	Nitrogen application methods	Total water applied (mm)	Grain yield (t/ha)
Tilled-wheat (farmer practice)	0·5 basal N with seed + two equal splits	247	4·89
Zero-tilled wheat*	0·5 basal N with seed + two equal splits	212	5·29
Zero-tilled wheat*	1·0 basal N with seed	215	4·90
Zero-tilled wheat*	1·0 basal N between seed rows	205	5·29
Bed planted wheat	1·0 basal N between rows	174	5·05

* Refers to retention of crop residues on the soil surface.
Source: Gupta *et al.* (2003).

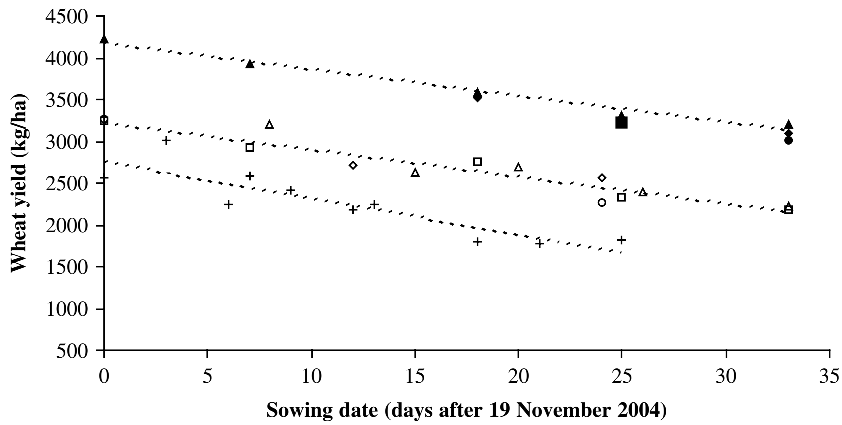

Fig. 2. Effect of tillage and sowing dates on wheat yield. Conventional and zero-till tilled wheat yields are shown by hollow and solid symbols respectively for four locations (◇ ◆, Banka; □ ■, Jamui; △ ▲, Lakhi Sarai; and ○ ●, Munger) in Bihar. The top line is the linear regression ($y = 4175 \cdot 1 - 31 \cdot 7x$; $R^2 = 0 \cdot 98$) for the zero till sites. The middle line is the linear regression ($y = 3219 - 32 \cdot 2x$; $R^2 = 0 \cdot 96$) for the conventionally tilled sites. The bottom line is the linear regression ($y = 2763 - 43 \cdot 9x$; $R^2 = 0 \cdot 77$) for zero till sites in West Bengal (symbol +).

Indo-Gangetic Plains, in order to promote crop diversification and intensification, efforts are being made to promote intercropping systems such as sugarcane + wheat/green gram/cowpea, wheat + mint, and to substitute long-duration pigeon pea with extra-short duration cultivars to increase the cropping intensity of the wheat–rice or pigeon pea–rice system. In lowland soils of the eastern Gangetic Plains, farmers practise rice–fallow–green gram or rice–fallow–cowpea system. When farmers are unable to plant a winter wheat crop, green gram or cowpea is sown in February in moist soils before the main rice crop of the rainy season.

Practices such as co-planting *Sesbania* with direct seeded rice and growing short duration legumes such as mungbean and cowpea in the sugarcane–wheat system are being promoted to provide surface cover for soils and to assist with weed control, especially for dry, direct seeded rice. Compared with sole crops, intercropping systems save irrigation water at the field and farm levels. In raised bed planting systems, wherein crops are planted on the beds and furrows are used for irrigation, yields and water productivity of most crops are reported to improve. This system is very popular with farmers growing high value cash crops such as vegetables.

WHEAT FOR GREEN FODDER TO ENHANCE LIVESTOCK PRODUCTIVITY

To maximize farm profits and productivity, efforts are being made to integrate crop and livestock production. Dual-purpose wheat for use as both fresh fodder and grain production (e.g. cultivars VLW 616, VLW 829, either with or without intercropping with Indian mustard) is being introduced in the northwest Indo-Gangetic Plains. This strategy has the potential

Table 5. *Performance of dual-purpose wheat cultivars for green fodder in 2004/05*

Wheat cultivars	Range of yield* (t/ha)	Dry matter (g/kg)	Crude protein (g/kg)	Coefficient of digestibility† NBDMD	Coefficient of digestibility† IVDMD
VL616	6·5–13·3	168	353	0·878	0·761
VL829	7·0–11·3	154	325	0·891	0·761
PBW343	6·0–13·0	175	345	0·861	0·766

* Average yields of fodder in 70 farmer participatory trials in progress in western Uttar Pradesh, Haryana, and Punjab. Grain yields as observed in (2004/05) in preliminary field trials were 4·8–5·1 t/ha with yield penalty of 150–200 kg compared to without cutting wheat for green fodder.

† NBDMD and IVDMD refer to nylon bag dry matter digestibility and *in vitro* dry matter digestibility, respectively.

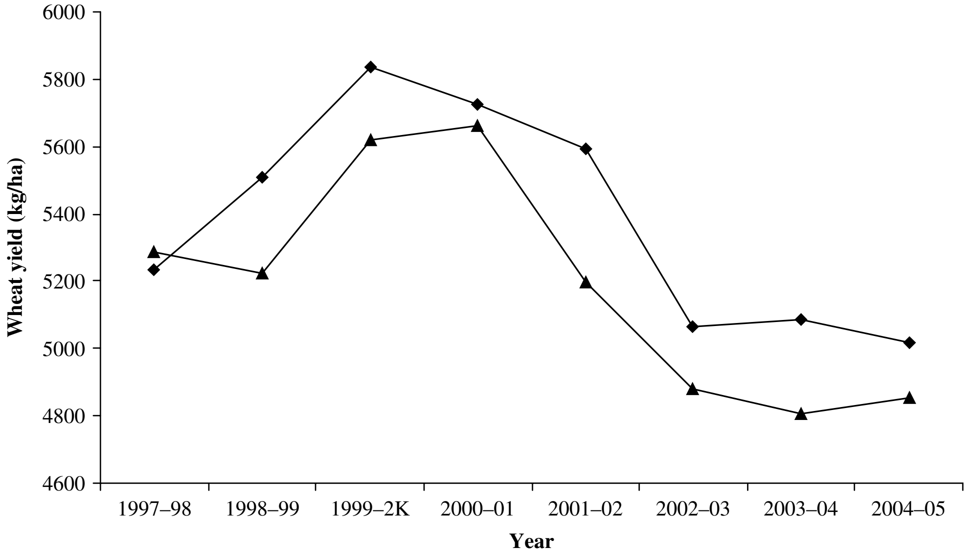

Fig. 3. Yields of wheat in zero tilled (◆) and conventionally tilled (▲) fields in Haryana (1999–2005).

to reduce the diversion of land resources solely to fodder production. Dual-purpose wheat can provide green biomass varying from 6 to 10 t/ha (Table 5), valued from US$150 to 200, with little yield penalty for grain. Green fodder helps meet fodder shortages and improves livestock productivity and, thus, the farm-level benefit.

ALTERNATIVE SOURCES OF PRODUCTIVITY GROWTH FOR WHEAT IN THE INDO-GANGETIC PLAINS

Several other crops in the Indo-Gangetic Plains, such as sugarcane, mint and potato, are grown as break crops in rice–wheat systems. When farmers plant sugarcane in the spring system, farmers miss out on at least two wheat crops over 3 years, or three crops if they prefer to plant mint. For intensification opportunities in sugarcane-dominated areas (1·7 million ha in western Uttar Pradesh, Haryana, and Punjab), a twin approach has been used by the Consortium. It includes development of a featherweight coulter double disc drill wherein the coulter cuts the rootstocks and the offset double discs help place seed and fertilizers in a narrow slit, for planting wheat into sugarcane stubble (the ratoon crop vacates the field late in November or December). In the second approach, the wheat crop is planted in mid-October or early November, between the sugarcane rows, which are spaced 1·34 m apart in traffic lanes. This facilitates early germination of the cane sets, which vegetate in the controlled traffic lanes until the spring season. Similarly, wheat is planted in the space between mint rows planted on either side of the traffic lanes. Results of numerous farmer participatory field trials indicate that such planting techniques provide alternate sources of productivity growth for wheat and also improve farmgate incomes by about 25% (US$400–500/ha).

WHEAT PRODUCTIVITY AND CLIMATE CHANGE

In order to promote CA in the region, second generation multicrop seed drills (double disc drills, Happy seeder, Turbo-seeder, rotary disc drills, and punch planters) have been developed that can place seed and fertilizer at appropriate line-spacing and soil depths with minimal soil disturbance in the presence of loose and anchored crop residues. There are more than 140 drill prototype manufacturers who make available the drill/planters to the farmers and the custom service providers.

Since 2000/01, climate change in the region appears to be associated with decreased wheat productivity. The yield declines have been associated (Fig. 3) with a rise in the minimal temperature by 3–4 °C during the grain filling period (Ortiz *et al.* in press). Raised bed planting (both narrow and wide beds) seems to offer more advantages in terms of adapting the nutrient and irrigation practices to climate change. It allows light and frequent irrigation, single deep placement of fertilizer nutrients, and more aerobic regimes in rice culture such as to reduce emission of greenhouse gases. Results of farmer participatory longer-term trials indicate that productivity of zero till wheat is higher than the conventional till wheat (Figs 2 and 3). Yield gain in wheat due to zero till was observed to be nearly 240 kg/ha over the conventional tillage practice (Fig. 3). When adapting to climate change in the eastern Gangetic plains of India and Bangladesh, it is only prudent to replace low yielding winter wheat with high yielding winter maize or *boro* rice in order to improve food availability in the region. Substitution of winter wheat with winter maize or *boro* rice is necessitated by the fact that productivity of winter wheat is 2·5–3·5 t/ha, whereas yield of winter maize or *boro* rice in the eastern plains is above 6·5 and 5 t/ha, respectively.

In conclusion, different RCTs reduce production costs, increase profitability and help farmers move forward in the direction of adopting CA. For example, zero tillage technology reduces turnaround time and facilitates timelier planting of wheat and improves crop yields. Similarly, laser-assisted precision land levelling not only saves irrigation water in the rice–wheat system but also improves the crop production, water productivity, and nutrient use efficiency.

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