Resource Conserving Technologies for Sustainable Food Production System: Some Experiences from Eastern Region of India

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सचिव एवं महानिदेशक

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FOREWORD

Sustainable food production is at the stake due to over exploitation of the natural resources in many parts of India. Most resources, *i.e.*, land and water are shrinking at an alarming rate and prone to ever increasing diversion to non-agricultural use. According to the Global Hunger Index (2008), India is ranked 66 out of 88 countries, which needs an immediate attention. Hence, a long term profitable and sustainable production of food, feed and fibre for meeting the human and livestock requirements can be made possible through conservation and judicious use of natural resources.

Conservation Agriculture removes the emphasis on tillage and addresses an enhanced concept of the complete agricultural system. It involves major changes in many aspects of the farm cropping operation. Resource conservation technologies (RCTs) make use of natural resources more efficiently and saves input for food production. Appropriate RCTs encompass innovative crop production systems that combine the objectives such as dramatic reductions in tillage with an ultimate goal to achieve zero till or controlled till seeding for all the crops in a cropping system if feasible, rational retention of adequate levels of crop residues on the soil surface to arrest run-off and control erosion, improve water infiltration and reduce evaporation, increase soil organic matter and other biological activity to enhance land and water productivity on sustainable basis, identification of suitable crop rotations in cropping system and crop diversification and intensification to boost food security, incomes and thereby provide the livelihood security to the people.

Eastern region of India has been focused to user second Green Revolution so as to meet out the ever increasing demand of food in the country. However, it is possible only through improving the soil health, minimizing the impact of biotic stresses, increasing the water productivity, development of suitable varieties, and integrated approach of land use. Conservation agriculture, therefore, is need of the hour, particularly in Eastern Indo Gangetic plains where Rice-Wheat cropping system is predominant.

The present document on "Resource Conserving Technologies for Sustainable Food Production System: Some Experiences from Eastern Region of India" is a praiseworthy endeavor to cover the efforts made by the Institute to promote the conservation agriculture in eastern states of India. I compliment to the authors for this timely publication since Conservation Agriculture in the order of the day.

(S. Ayyappan)

Preface

Farmers throughout the world are beset by new challenges related to globalisation and climate change. In recent years, many concerned farmers have begun to adopt and adapt improved crop management practices that lead towards the ultimate goal of sustainable farming. Conservation Agriculture (CA) removes the emphasis on tillage and addresses an enhanced concept of the complete agricultural production system. Extensive tillage for land preparation or mechanical weed control can lead to the breakdown of soil organic matter with the associated release of CO_2. Further CO_2 is released from burning fossil fuels for the associated tractor power. When these tillage operations are combined with burning of crop residues, the combined contribution to green house gases (GHGs) from conventional farming practices is significant. In addition, the continuing inefficient use of nitrogen fertilisers can increase production costs, contribute N_2O to GHGs, or result in widespread leaching and nitrate pollution of groundwater.

Conservation agriculture includes resource conservations technologies (RCTs) which is better understood as crop management that minimizes soil disturbance, maintains residue mulch on the soil surface and uses rotations to control various biotic stresses. Globally, CA has emerged as a way for sustainable intensive crop production system. About 120 m ha of land is cultivated world-wide based on the concept of CA. However, the area under CA in Eastern region is very limited.

ICAR Research Complex for Eastern Region, Patna is the pioneer institute for implementing and popularizing CA based Resource Conserving Technologies, particularly in eastern Indo-Gangetic Plains (IGP). The present document deals with the RCTs being adopted by the farmers and problems associated with its horizontal expansion. Authors express their gratitude to the former Directors of the institute namely, S.R. Singh; A.K. Sikka, M.A. Khan and other dignitatories like R.S. Paroda, Panjab Singh, Mangala Rai, G.B. Singh, J.S. Samra, S. Ayyappan and Raj Gupta for encouraging the work on CA.

We would also like to record our appreciation for the efforts made by S.S. Singh, U.S. Gautam, Ujjwal Kumar, A. Haris, A.R. Reddy, T.K. Srivastava, R.C. Bharati and technical field staff/RAs/SRFs for the propagation of the CA in the region. Thanks are also due to Shri Ajay Kumar for secretarial assistance. The response and contribution of progressive farmers is also acknowledged who made popularization of RCTs possible on the one hand and to be the ambassadors to the state government for their pro RCTs policies on the other.

Authors

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Executive Summary

In Eastern Indo-Gangetic Plains (EIGP), the major challenge is to develop rice-wheat cropping system (RW) that produce more at less cost/ water and improve profitability and sustainability. Conservation Agriculture plays an important role, particularly in RW cropping system. Over the past 30 years, the RW system has emerged as the region's major production system, and accounts for more than 30% of the total rice area and 40% of the total wheat area, producing nearly one-third of the region's rice and more than half of its wheat. ICAR Research Complex for Eastern Region, Patna is the pioneer institute for implementing and popularizing CA based Resource Conserving Technologies, particularly in EIGP. Some of the salient achievements are :

- Resource Conserving Technologies (RCTs) practices consisting of sowing (equal row, paired row and control traffic) and different zero till drills like double disc planter, eleven tynes zero till machines, were used and crop was monitored throughout the season till harvesting. There was net monetary gain of ₹ 7500-8000/ha in rice and ₹ 6000-6800/ha in wheat cultivation mainly due to adoption of RCTs.
- Zero tillage enabled sowing even in wet soil and advanced the sowing by a minimum of 12-15 days. Sowing could be advanced by 25-30 days in surface seeding. Savings of ₹ 1700 and ₹ 2200 per ha, respectively, were observed with the two types of methods, over the traditional method due to reduced cost in land preparation, sowing and first irrigation. As a result, high demand of ZT drill has emerged from farmers.
- RCTs could also save upto 40% of irrigation water compared to conventional puddled transplanted fields. Likewise, under bed planting method, there was a saving of 26.0 and 42% of irrigation water, in case of wheat and paddy respectively, compared to flat surface irrigation besides increase in crop yield.
- In Bihar alone, about 1.6 m ha area is under rice-wheat cropping system. The average saving of ₹ 6,500/ha in R-W system has the potential to save the resources of ₹ 10,400 million through RCTs adoption. Further, increase in grain yield by 0.8 t/ha/yr has potential to contribute an additional 1.28 m tons of food grains. This will increase the income of the farming families and contribute to food security of the nation from high potential-low productive zone.
- Increase in area under zero tillage direct seeded rice was 545 ha in 25 villages during three years and total input saving by this practice was ₹ 4.9 million. In addition to this, there was increase in rice yield upto 218 tons @ 0.4 t/ha.
- Increase in area under second generation zero tillage wheat was 10,870 ha in three years and the total input saving by this practice was ₹ 65.2 million. In addition to this, there was increase in rice yield by 76.09 t (@ 07 t/ha).

- Use of leaf colour chart (LCC) in rice saved around 25-45 kg nitrogen per hectare. Savings up to 60 kg were observed in irrigated canal area.
- Diversification of potato + maize on raised bed in Rice-Wheat cropping system through RCTs was undertaken which resulted into 25% more income besides significant resource savings. After the harvest of potato, farmers grew vegetables for additional income.
- About 38-40 kg nitrogen per ha was saved through co-culture of *Sesbania* (brown manuring) in rice field. Reduction in pest attack and increase in organic carbon was also observed.
- Average productivity of direct seeded rice and zero tillage wheat increased by 0.44 and 0.85 t/ha, respectively, in RCTs adopted areas.
- By refinement of surface seeding, there was increase in yield from 1.2 t/ha to 2.2 t/ha in 1250 ha operated area in last three years. Thus additional grain yield of 1250 tons was recorded in project areas.
- An extra early short duration (150 days) Pigeon pea variety (ICPL 88039) was introduced in place of traditional medium and long duration type (180-270 days) during *kharif* yielding 0.8 -1.1 t/ha grain yield for diversification and intensification of crop. Another crop was taken in rabi season after harvest of pigeon pea. Farmers' response was encouraging since they could take wheat after harvest of pigeon pea during the month of December. This has increased the income of the farmers and improved soil health.
- Crop intensification (green gram) in rice-wheat system was carried out through summer moong bean (green gram) as paira/relay/ZT crop before/after the harvesting of wheat. This crop mature in 60-65 days and harvested by the end of May before the rice cultivation. It has increased the cropping intensity and income of the farmers apart from addition of atmospheric nitrogen and improvement in soil properties. The average yield was about 0.90 t/ha.
- For real time nitrogen application in rice by use of leaf colour chart, there was total saving of 21.9 tons of nitrogen in 730 ha covered area, which could save 47.5 tons of urea.
- Extra early pigeonpea (153 ha), maize + potato (50 ha) and summer moong (35 ha) has given best example of crop diversification.

Introduction

Conservation agriculture (CA) implies a complete change in the agricultural production system as it includes a number of components. A practical field measurement to define conservation tillage is the degree of soil cover (minimum 30%) covered by the crop residues at the time of planting or during non-crop period. CA offers an opportunity for arresting and reversing the downward spiral of resource degradation, decreasing cultivation costs and making agriculture more resource-use-efficient, competitive and sustainable (Abrol and Sangar, 2006). Globally, CA is being adopted over 120 m ha of land (Joshi *et. al*., 2010). Appropriate Resource Conserving Technologies (RCTs) encompass an innovative crop production system that combines the dramatic reduction in tillage with the ultimate goal to achieve zero till or controlled till seeding for all crops in a cropping system, if feasible.

CA plays an important role, particularly in rice-wheat (RW) cropping system. In South Asia, the RW region occupies nearly 13.5 m ha across the Indo-Gangetic Plains (IGP) of Bangladesh, India, Nepal and Pakistan (Gupta *et al*., 2003). This region alone is home to 1.6 billion people, nearly 40% of whom live in extreme poverty (FAO, 2010). Over the past 30 years, the RW system has emerged as the region's major production system, accounting for more than 30% of the total rice area and 40% of the total wheat area; and producing nearly one-third of the region's rice and more than half of its wheat.

RW cultivation is characterized by two contrasting edaphic environments namely, puddling in rice and excessive ploughing in wheat. Although puddling is known to be beneficial for growing rice, it can adversely affect the growth and yield of a subsequent upland crop (e.g. wheat) because of its adverse effects on soil physical edaphic properties, which include poor soil structure, suboptimal permeability in the subsurface layer, poor soil aeration, and soil compaction (Kumar *et al*., 2008). In addition, intensive tillage and crop establishment (CE) methods require a large amount of labour and water, resulting in a rise in the cost of cultivation (Ladha *et al.*, 2009). The excessive tillage in wheat results in late planting and, therefore, the yield is drastically reduced. Singh *et al.* (2002) had also reported a yield reduction of wheat by 44 per cent if the sowing is done after 23 December in south Bihar. The states of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal are the heartland of RW cropping systems (Yadav, 1998). On an average, RW systems provide 85% of the total cereal production and 52% of the total calorie intake in India (FAO, 2007).

The policy makers are predicting that future productivity growth would come through better agricultural management strategies in the drought/ flood prone regions of the Eastern-Indo-Gangetic plains (EIGP) since the region has the potential to usher in the much needed Second Green Revolution to meet the food requirement of the ever increasing population. The present publication deals with different RCTs validated and up-scaled in EIGP.

Fatigue in Total Factor Productivity

The Success of green revolution was reflected through more efficient dry matter partitioning to reproduction and therefore, higher harvesting index with significant gain in the yield potential. Farmers were able to double the rice production and boost wheat output by almost five times in just three decades by using the improved wheat and rice varieties, irrigation and higher doses of fertilizer. RW is the most important crop rotation covering nearly 10 m ha area in India. The area under rice and wheat cultivation in Bihar alone is 3.8 and 2.2 m ha, respectively.

Sustainability and profitability of RW cropping system in Indian agriculture is the lifeline and future of Indian economy since agriculture is the mainstay of economy of more than 60 per cent people and these are the two staple food crops of the country. Hence, concern has been expressed about the long-term sustainability of the RW system as there are indications of yield stagnation or a tendency to decrease with time over parts of the Indo-Gangetic plains (Khan, 2010). It appears that now the RW system suffers from fatigue due to reduction in total factor productivity (TFP) and degradation of the natural resource base. The sustainability of the RW system is threatened by declining soil fertility and groundwater depletion (Humphreys *et al.*, 2010). Continuous cropping of RW system for several decades as well as contrasting edaphic needs of these two crops have resulted in increased pest pressure, nutrient mining, and decline in yields in some areas**.** The reasons for declining in the productivity growth rate are multiple. Analysis of several long-term experiments on RW indicated a negative average yield (0.02 t/ha/year or 0.5 per cent per yr) trend of rice (Duxbury *et al*., 2000). The income of farmers is further reduced due to increase in cost of farm inputs (seed, fertilizer, tillage, irrigation and labour etc.).

The RW cropping system being an intensive cropping system, is heavily taxing the two most important natural resources soil and water (Prasad and Nagarajan, 2004). Trends of resource fatigue, stagnating yield and little area available for horizontal expansion suggest that RW production systems of Indo-Gangetic plains may not keep pace with anticipated increase in demand for food driven by population and income growth (Mishra and Chatrath, 2010). Hence, need of the hour was to initiate work on integrated RW research towards development of technologies and varieties with efficient input use and complete compatibility with each other.

Need of Technologies for Resource Conservation and Sustainability in Rice-Wheat Cropping System to usher the Second Green Revolution in Eastern Region

During the Green Revolution era, production increases in the RW system were mainly due to expansion in area and productivity. However, future demand will have to be met mainly through increase in yield per unit area. Further, the average 2% increase in rice and wheat yield per annum, achieved from 1970 to 1990, has dropped down because of a combination of factors which include deterioration in soil health, change in weather conditions, pest and agronomic management, and reduced support for public agricultural research (Ladha *et al*., 2003). The challenges of the RW system are to produce more food at less cost and to improve water and labour productivity. Farmers need alternatives to conventional intensive tillage and crop establishment practices so as to help them conserve water, labour, and energy; cope with the increasing cost of cultivation; and improve the quality of life of farm families. One of the strategies is to grow rice and wheat through reduced-tillage with the use of a zero till seed drill and precise water management. The shift from puddled-transplanted rice and direct drill-seeded rice (DSR) and wheat after zero-tillage on the flat- or raised-bed system affects the productivity and resource use efficiency of the RW system (Ladha *et al.,* 2009). Therefore, the potential benefits and constraints of alternative tillage and crop establishment systems need to be quantified on a short- to long-term basis, and optimum layouts and management systems need to be identified to maximize yield and input-use efficiency (Gathala *et al.,* 2011).

In Eastern IGP (EIGP),the major challenge is to develop RW system that produce more at less cost/ water and improve profitability and sustainability. About 50 per cent of the area of the eastern region suffers from various forms of land degradation resulting in lower productivity (Khan *et al*., 2006). A vast stretch of area (0.35 m ha) is permanently or seasonally waterlogged and/or faces serious drainage congestion problem owing to flat topography (Singh and Khan, 2002). The farmers depend on the vagaries of the monsoon for crop production. Owing to poor utilization of water resources, the cropping intensity in the region is also low and therefore, assessment of the scientific, technical and institutional issues associated with cropping system is essentially required. The challenges are enormous ranging from conservation of natural resources to investment in newer area of research including RCTs.

Historical Background

National

Departments of Agriculture, Punjab and Haryana launched zero till extension activities with their own resources and later on with the support of RW Consortium

Dr. S.R. Singh, the then Director of the Institute addressing farmers' meeting in presence of Dr. A.P.J. Abdul Kalam, the then Principal Scientific Advisor to Hon'ble Prime Minister

Dr. A.K. Sikka, the then Director of the Institute inaugurating the RCTs project in farmers' fields on 1st July 2004

for the Indo-Gangetic Plains. Zero till moved to the eastern Indo-Gangetic Plains (EIGP) especially in eastern UP and Bihar by 1999.

Eastern-Indo-Gangetic plains (EIGP)

ICAR Research Complex for Eastern Region, Patna is the pioneer institute in EIGP to start and popularize RCTs with ZT wheat since 1999 through Centre for Environment, Agriculture and Development (CEAD), Technology Information, Forecasting and Assessment Council (TIFAC), Development for International Development (DFID) and National Agricultural Technology Project (NATP) projects. Initial sensitization to farmers and Agriculture and Extension Officials of state government was conducted and Zero Till wheat was demonstrated in 22 districts of Bihar covering an

Visit of first QRT members to RCTs Trial at farmers' fields on 5th October 2006. The members are Dr. S.M. Virmani (Chairman), Dr. A.P. Mishra, Dr. R.M. Pandey and Dr. M.S. Gill.

Visit of second QRT members to RCTs Trial at farmers' fields on 14th October 2011. The members are Dr. R.P. Singh (Chairman), Dr. I.S. Singh, Dr. G. Goswami, Dr. K.N. Tiwari, Dr. N. Sarangi and Dr. B.P. Bhatt, Director, ICAR-RCER, Patna.

area of over 6,000 ha and 7200 stakeholders. At the fag end of NATP project, few field trials on direct seeded rice were also evaluated. Several capacity building programmes were organised for Scientists, District Agricultural Officers and Extension workers in the RCTs fields.

RWC/CIMMYT sponsored two USAID and IFAD projects on "Accelerating the tillage revolution in the Indus-Ganges basin: Fostering adoption of RCTs to promote economic growth, resource conservation, and food security". RCTs were assessed, refined and demonstrated on the farmers' fields in different districts of Bihar, eastern U.P. and West Bengal through on-farm research in participatory mode, capacity building and through traveling workshops. Direct seeded rice through Zero Tillage was also given prominence for field trials in Bihar and training was also imparted to Agricultural and Extension officials of West Bengal for initiating ZT Direct seeded rice.

Two projects on Cereal System Initiative for South Asia (CSISA) sponsored by Bill & Melinda Gates Foundation and USAID were started as Platform Research and Delivery & Rolling out conservation agriculture based RCTs were taken up by the institute in 2009. Various other national and international agencies like ICAR, RWC, CIMMYT, IRRI, USAID, IFAD etc. are sponsoring different projects on RCTs based CA in eastern Indo-Gangetic plains (EIGP). Various RCTs including Zero Till direct seeded rice, wheat, other crops, system diversification and intensification through bed planting, laser leveling, residue management, summer pulses in RW cropping system were revalidated and up scaled in EIGP on farmers' fields in participatory mode. Different second and third generation RCTs on RW and other crops are being popularized in eastern region by the institute. About 25000, 500, 1000 and 200 ha of wheat, rice, maize and other crops, respectively, have been brought under RCTs in different parts of Bihar in collaboration with SAUs and KVKs etc.

Validation of RCTs through Participatory Research

No-Till/Zero - Till technical components used in CA, involve the absence of tillage/ploughing operations on the soil. Crops are planted directly into an untilled seed bed after harvesting the previous crop. National Agricultural Research System (NARS) is at the forefront of this work and because it is implemented in participatory mode, adoption is accelerated. Rice Wheat Consortium, CIMMYT and IRRI encouraged the State Agricultural Universities, State Governments, NGOs, the private sector and extension agencies to test and adapt these approaches and feature them in rural development strategies. The state governments were convinced for subsidy on RCTs machines and service providers were trained.The policies influenced the State Governments and emergence of service providers for RCTs adoption / sustainability were also achieved. In general, following technologies were tested, evaluated and up- scaled in EIGP:

- Zero Till Direct Seeded Rice (ZTDSR),
- Direct sowing of rice in puddled field through drum seeder,
- Unpuddled transplanting,
- Use of Leaf Colour Chart (LCC) for nitrogen management,
- Brown manuring of *Sesbania* in rice,
- Bed planting in rice and wheat,
- Use of second generation RCTs and refinement in sowing techniques,
- Double Zero Tillage in RW system,
- Surface seeding of rice and wheat,
- Residue management for improving soil health,
- Bed planted maize (QPM),
- Bed planted potato,
- ZT lentil/gram,
- Crop diversification
  - Extra early pigeon pea (ICPL 88039-150 days) ,
  - Bed planting of potato + maize,
  - Bed planting of sugarcane + vegetables,
  - ZT moong/cowpea,
  - Relay moong in RW cropping system,
  - Spring maize through reduced tillage,
- Inclusion of summer pulses after RW for crop intensification, and
- Laser aided land leveling for increasing land and water productivity.

Rice-Wheat Cropping System in Eastern IGP

The area, productivity and productivity potential of RW system in EIGP is presented in Table 1. There is a huge gap between present productivity and productivity potential of RW systems in this region and attempts are being made to minimize the gap through the propagation of RCTs.

Table 1. Area, productivity and productivity potential of rice-wheat in eastern IGP

Crop/system	Area (m ha)			Productivity (t/ha)			Productivity potential (t/ha)		
	Bihar	Eastern UP	West Bengal	Bihar	Eastern UP	West Bengal	Bihar	Eastern UP	West Bengal
Rice	3.7	3.05	5.7	1.65	1.72	2.6	4.5 - 8.0	5.0 - 8.5	4.2 - 9.7
Wheat	2.3	3.06	0.35	2.18	2.49	2.3	3.0 - 4.0	3.5 - 4.5	2.9 - 5.2
Rice-wheat	1.6	2.2	0.30	4.50	5.2	4.2	7.5-12.0	8.0-12.5	5.2 - 9.5

Source: Khan (2010)

Major Activities and Salient Achievements

Wet (*kharif*) season cultivation through RCTs

Direct seeded Zero Tillage rice

Zero Till (ZT) drill machine opens a narrow slit in fields and plants 11 rows of crop at 20-cm distance in one pass. Eleven row Zero-Till Drill takes forty five minutes for sowing one acre area. On average, HP 35-45 tractors are used. Now seed metering is introduced for seeding of different crops. To control the seed rate and fertilizer, machine is calibrated before sowing.

Zero tillage cum fertilizer drill machine and Zero Till Direct Seeded Rice (ZTDSR)

Separate boxes for seed and fertilizer in
ZT drill machine

Calibration needle of ZTdrill machine

Seed Metering System

Seed sown through ZT drill machine

Direct sown rice crop through ZT Drill till machine

Resource saving in Zero till direct seeded rice (ZTDSR)

Direct dry seeding in rice has advantage of faster and easier planting, reduced labour requirement and drudgery with earlier crop maturity by 10-15 days, efficient water use and high tolerance of water deficit, less methane emission and higher income due to less cost of production (Balasubramanian and Hill, 2002). Various technologies were evaluated and up scaled with different combinations of component technologies like zero till direct seeded rice (ZTDSR) with use of herbicides and direct sowing of rice in puddled field through drum seeder. Details of the cropping area, yield and resource saving in rice cultivation through second-generation ZT of USAID sites at three districts of Bihar namely, Patna, Vaishali and Buxar are presented in Table 2**.**

Zero Tilled Direct Seeded Rice (ZTDSR) in the farmers' field

Nitrogen management in rice through co-culture of *Sesbania* (brown manuring) and leaf colour chart (LCC)

Farmers participatory trials were conducted to evaluate the nitrogen saving and yield gain in HYV rice by using second generation RCTs. Brown manuring practice was introduced, where both rice and *Sesbania* crops @ 20 kg/ha were seeded together and allowed to grow for 30 days. *Sesbania* crop was knocked down by herbicide after 30 days when it was tender and succulent so as to make the nitrogen available to rice. It was dried by spraying 2,4-D ethyleaster @ 800 g a.i./ha dissolved in 800-liter water. Weed population was also reduced by nearly half without any adverse effect on rice yield. Farmers found that there was less incidence of pests due to the brown manuring. Besides organic matter, other recycled nutrients were added to the soil. The soil organic carbon increased by 0.03-0.05 per cent due to brown manuring (Table 3). Response was move in sodic soils.

Table 2. Resource saving and production of rice through RCTs under USAID project (2006)

Treatments/ RCTs adopted	Average cost of input (₹/ha)				Total	Total (₹/ha)	Yield difference over normal practice (₹/ha)	Remarks (t/ha)**	
	Tillage	Crop establishment	Nutrient use	Weed mgt	Irrigation*				
Zero till direct seeded rice (88 sites)	00	1485	2,116	4,000	220	7,821	4,099	4.26	● Herbicide- 800 g/ha ● Weeding – ₹ 3200/ha · Saving in seed @ 65 kg/ha· Saving in N in LCC 45 kg/ha and in *Sesbania* 35 kg/ha ● Balance use of NPK and saving of excess N
Co-culture of *Sesbania* with rice (12 sites)	00	1485	1,927	4,000	220	7,632	4,288	5.17	
N management under lowlands in DSR (80% basal + rest on the basis of LCC)(8 sites)	00	1485	1,873	4,000	220	7,578	4,342	4.43	
N management in irrigated mid-lands through LCC in puddled transplanted rice (36 sites)	1400 (ploughing before puddling)	5580	2,877	1,600	220	11,677	243	4.00	● Nursery raising– ₹ 880/ha ● Puddling– ₹ 2000/ ha ● Nursery uprooting and transplanting– ₹1200 /ha ● Excess use of N (150-160 kg/ha)
Puddled trans-planted rice (Conventional) (4 sites)	1400	5580	3,120	1,600	220	11,920	-	3.84	
Crop divers-ification through Pigeon Pea (ICPL 88039) (15 sites)	1,000	1500	1200	1000	-	4500	-	1.50	● Fields are under process of sowing of wheat

* Total area is canal irrigated and its charge in kharif season is @ ₹ 220/ha

** Patna centers includes the area of Patna, Vaishali and Buxar Districts

Excess N use (110-150 kg/ha) through urea is a common practice in RW system against recommended dose of 80-100 kg/ha. LCC helped farmers to measure the leaf colour intensity, which is directly related to leaf chlorophyll content and leaf nitrogen status. The timing of nitrogen top dressing can be easily determined based on soil N supply and crop demand. This simple tool helped farmers to reduce the excess use of nitrogen fertilizers. On an average, there was a saving of 42 kg N/ha due to LCC and 36 kg N/ha due to *Sesbania* co-culture (Table 3). Savings up to 60 kg were recorded in irrigated canal areas.

Brown manuring through co-culture of *Sesbania*

Leaf Colour Chart for optimum Nitrogen application

Brown manured field

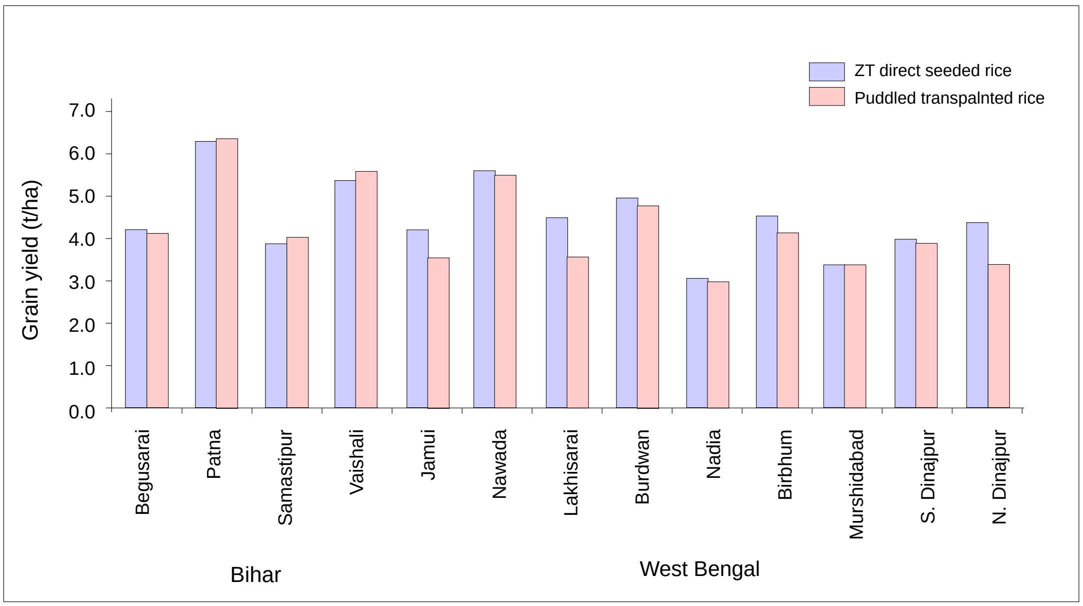
Field training to farmers in the use of Leaf Colour Chart (LCC)

Table 3. Resource Conservation for N management under RW system of south Bihar in alluvial soils (mean of 5 years – 2004-2008)

Treatments	N use by urea (kg/ha)	Yield (t/ha)	N saving by BM/ LCC (kg/ha)	Net gains over control (₹/ha)	Dry matter added by BM (t/ha)	Status of soil OC (%)	
						Initial	After
LCC based N use	65	6.1	42	3,248	-	0.63	0.63
BM of *Sesbania*	75	6.3	36	3,733	1.75	0.63	0.68
BM of *Sesbania* + LCC based N	55	6.7	51	5,843	1.75	0.63	0.66
Control (110-150 kg N/ha) by urea	110	5.5	-	-	-	0.63	0.62

Performance of ZTDSR

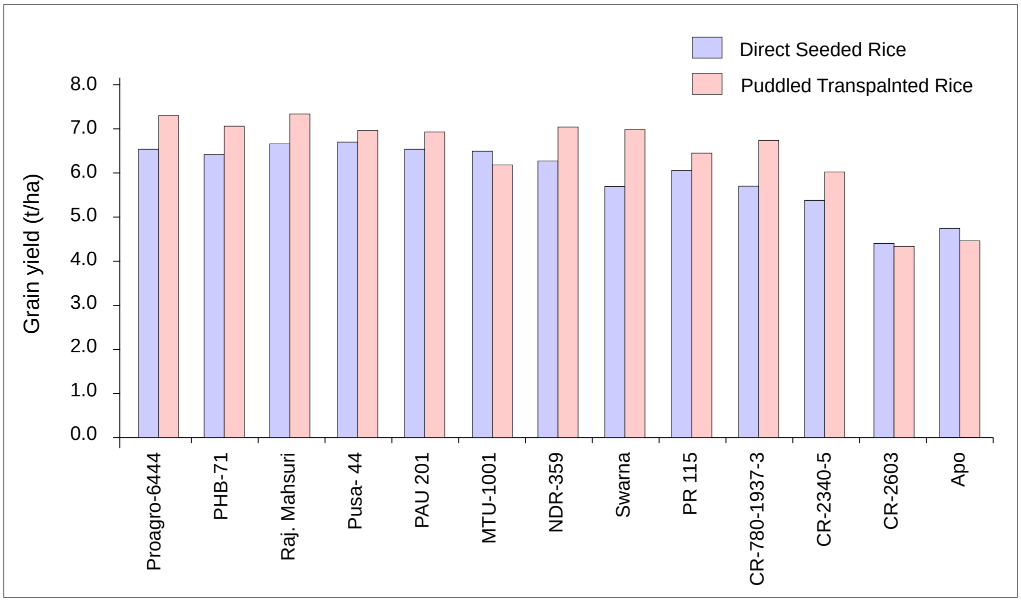
No significant differences were recorded when rice was cultivated under zero till or conventional puddled transplanted system in different districts of Bihar and West Bengal (Fig. 1). Higher yields of ZTDSR are associated with fertilizer placement, uniform and sufficient plant stand (40–50 plants/m^2) and timely planting of rice. Contrary to this, in some cases, lower yield in ZT-DSR was associated mainly to poor weed control and stand establishment. The highest yield was found in Patna district where the yields of ZT and puddled rice were at par.



Source: Singh *et al.* (2010)

Fig. 1. Performance of direct seeded ZT rice in Eastern Indo-Gangatic Plains

Performance of rice cultivars for Direct seeded rice (DSR) is presented in Fig. 2. Short duration cultivars like Saket – 4 and Pusa 834 (semi dwarf & 105 days variety) yielded better under DSR. Among medium duration cultivars, Sarjoo-52, a photo period sensitive, semi dwarf 135-days variety and NDR 359, a 122-day semi dwarf, resistant to lodging and shattering, tolerant to BLB, brown spot, sheath rot and leaf steak also seemed better for DSR. Nevertheless, Rajshree, a pure line selection semi tall variety and moderately resistant to stem borer, lodging shattering seemed a good variety for low land water logged (50-80 cm) areas (*tals* and *chaurs*) of Bihar.



Source: Singh *et al.*, (2010)

Fig 2. Evaluation of rice cultivars

Rajendra Mahsuri, a semi dwarf and long duration (148 days) variety adapted well and out yielded other long duration cultivars under DSR conditions. Sawrna, a semi dwarf (150 days), and Rajendra Sweta, a semi dwarf profuse tillering, fine grain (fetching high price) cultivars also performed well under DSR conditions. Hybrids like RH 664 and NK sahyadri, PHB 71, Proagro 6444, can do better under DSR due to vigorous growth and tolerance to lodging. In dry years, short duration cultivars like Shusk Samrat and specially developed aerobic rice variety APO performed better than other long duration cultivars.

Direct sowing of rice in puddled field through drum seeders

Drum seeders are used to sow pre-germinated seeds in puddled fields. Excess water is drained out before sowing, but soil surface is kept moist. Rice seed should be pre-germinated (24 hr for proper germination). The sprouted seeds should be air dried for half an hour to facilitate separation of seeds before sowing and thereafter, sprouted seeds are filled in drum boxes (about 2/3 of the boxes). Around 1.5 acres can easily be sown by one person with a steady speed walk. Irrigation is avoided for 3 - 4 days after sowing so as to allow the roots to anchor in the soil. In *kharif* season, immediate rainfall after seeding, however, may wash away the sown seeds. The depth of irrigation water should be gradually increased with the seedling growth and complete submergence is avoided till the full establishment of the plant. Seed rates for coarse, medium and fine seeds are 30, 25 and 20 kg/ha, respectively.

IRRI – India had supplied Vietnam made plastic drum seeders for popularizing in EIGP. The success story of drum seeders in Bangladesh was a driving force for adopting this technology at project sites of Bihar. The performance was, however, average in Patna and Vaishali districts of Bihar but farmers in Buxar area were enthusiastic due to better performance and resource saving (Table 8).

Table 8. Performance of drum seeder in canal & tube well command area of Bihar 2007

Districts	No. of sites	Yield (t/ha)			
		Drum seeder		Puddled rice	
		Grain yield	Straw yield	Grain yield	Straw yield
Patna	6	3.80	4.70	4.70	5.90
Buxar	15	4.50	5.90	4.20	5.70
Vaishali	11	3.70	5.45	4.42	5.56

Pre-germinated rice seeds

Placing the pre-germinated rice seeds in drum seeder

Box of Drum Seeder with Pre-germinated rice seeds

Sowing of pre-germinated rice seeds in puddled field through drum seeder

Cultivar Choice

Varieties of rice suitable for various eco systems and quality for the EIGP are given in Table 9. These varieties are widely used by the farmers and performances of the varieties are satisfactory for the existing eco-systems.

Table 9. Rice Varieties recommended for Bihar

Particular	Varieties
Upland	Prabhat, Richharia, Saroj, Dhanlakshmi, Saket, Pusa 2-21, PAU-201
Medium land	Sita, Kanak, IR 36, Saroj, Gautam, Santosh, Sujata, Rajendra Dhan 201, Swarna, MTU 1001, PAU-201
Low-land	Rajshree, Satyam, Mansoori, Rajendra Mansuri-1, Pankaj, Sakuntla, Rajendra Sweta, Sudha, MTU 1001, NDR 359, Swarna sub 1
Scented rice	Sugandha, Kamini, Rajendra Kasturi, Rajendra Savasini

Seed rate and seeding depth

Broadcasted direct seeded rice through conventional ploughing is still in vogue and generally has a high seed rate (80-120 kg/ha). High seed rate causes nitrogen deficiency, reduced tillering, and increased proportion of ineffective tillers, attack of brown plant hoppers and crop lodging. Based on research work, it was found that for cultivars with medium fine grain, seed rate of 20-25 kg/ha is optimum for DSR crop.

Use of planters having precise seed metering device (inclined plate devices or cupped metering system) were best for precision seeding (optimum, precise depth and seed rate). The seed depth should be 2-3 cm for a good crop stand. It is also important that seeding depth should be calibrated and maintained using depth control wheels only. Using hydraulic for controlling depth was ineffective and led to uneven seed depths resulting in to poor crop establishment. Use of spirit level is also advised to check the level of planters. The optimum line to line spacing should be 20 cm with a planting density of 30-40 plant/m^2.

Weed Management in Direct Seeded Rice

Weed flora in direct seeded rice is one of the deterrents for its adoption and expansion among the farmers. Puddling has the advantage of killing and controlling weed flora and no single herbicide molecule is able to control all the weeds. Broad spectrum herbicide or a combination of herbicides alongwith cultural practices is needed for effective control of grassy, broad leaved and sedges in direct seeded rice.

In DSR, weeds like *Cyperus rotundus*, *Leptochloa* sp., *Fimbristylish* sp. and *Cynodon dactylon* become uncontrolable and highly competitive; *Cynodon* is especially becoming a real problem in permanent no-till field in EIGP (Singh *et al.*, 2010).

Weeds, Herbicide application and weed free field before ZTDSR

Long term multi-location trials at Patna, Pusa and Begusarai were conducted by RWC-CIMMYT for selection of suitable molecules for DSR and a few herbicides were recommended to the farmers. Bispyriback sodium and penoxulam both @ 25g ai/ha were effective on most of the grasses but weak on perennial sedges. On the contrary, Azimsulfuron @ 25-35 g ai/ha or Ethoxysulfuron @15-18 g ai/ha were found very effective in controlling broad leaved weeds and sedges in DSR. Pre plant application of Glyphosate @ 2.5 kg/ha with good quality water (not saline or muddy) was found effective in controlling perennial established weeds and Fenoxaprop @ 55-60 g ai/ha at 18–25 days after sowing was able to manage *Cynodon* in standing rice crop. Pre emergence application of Pendimethalin, followed by bispyribac controlled the complex weed flora in DSR. After application of bispyribac, 1-2 cm standing water is essential for its better efficacy. For uniform standing water, laser land leveling is prerequisite. However, high cost of herbicides limits its application.

Cultural practices like retained crop residue, *Sesbania* co-culture and cover crops like moong bean or cowpea helped in reducing broad leaved and sedges weeds. Hence, cropping system based weed management strategies like better water management, laser leveling, timely planting and competitive rice cultivars were found helpful in managing weeds in DSR. Moreover, weed surveillance may also prove beneficial in selecting suitable herbicides and weed management strategies in a region. Different experiments were conducted by RWC in Bihar for effective control of weeds in ZTDSR. The list of herbicides recommended for controlling weeds in direct seeded rice is given in Table 10.

Table 10. Herbicide use schedule in direct seeded rice (DSR)

	Name of the herbicide	Time of application	Amount of active ingredients (ai) /ha	Affected weeds
Before Sowing	Glyphosate	4-8 days before sowing	1.0 kg / 500 liters of water	Perennial weeds like *Cynodon dactylon* & *Cyperus rotundus* etc.
	Paraquat	1-2 days before sowing	500 g/500 liters of water	Annual weeds
Immediately after sowing to control germination of weeds	Pendimethalin (Stomp)	Within 1-2 days of sowing in moist field at evening time	1.0 kg / 600 -750 liters of water	For all germinating weeds
	Pretilachlor with Safner (Sofit/ Erase–N)	Within 1-2 days after sowing (*with wet soil moisture regimes for few days*)	500 g/600 liters of water	For all germinating weeds
Weed emergence after 20-25 days of sowing	Almix (Chlorimuron + Metsulfuron)	20- 30 days after sowing	4.0 g/600 liters of water	For broad leaved, sedges & for some time for *Cyperus spp.*
	Azimsulphuron	20- 30 days after sowing	30 g/600 liters of water	Weeds including *Cyperus spp.* except grasses
For *Sesbania*	2,4 – D easter/ sodium salt	25 -30 days after sowing	500–750 g/ 600 liters of water	Broad leave weeds including *Sesbania*
Control of weed emergence after 20-25 days of sowing	Pendimethalin (Stomp)	Moist fields	500– 600 g/ 600-7000 liters of water	All germinating weeds

Source: Singh and Khan (2008)

Role of direct seeded rice for enhancing water productivity

The benefits of the resource-conserving tillage options listed above are lost when rice soils are puddled. Most rice farmers traditionally puddle their soils to help pond water, reduce percolation losses and control weeds. Whereas, puddling results in degrading soil physical properties, particularly for fine textured soils, and subsequently results in degraded soil physical properties and creates difficulties to provide good soil tilth for subsequent wheat crop (Sharma *et al*., 2002).

Several studies indicate that rice-fields do not need to be flooded after the first few weeks and that puddled soils have more cracking and need more water once the fields are dry. Though, water percolation will be higher in non-puddled situations, but the total water use may be less, since no water is needed for nursury raising or puddling the main field. Also, when puddled soils dry and soils crack, field needs more water to fill the profile when water is applied subsequently (Table 11). It has also been reported that maintaining saturated soil conditions throughout the crop growth period (puddled transplanted rice) saved more than 40% of irrigation water compared to continuous shallow flooding. If the rice is sown in the middle or end of June, then it utilizes most of the rain water of the season (Khan, 2010).

Cracked puddled rice fields during dry spell of monsoon

Table 11. Saving of inputs, water and grain yield of rice under different planting methods in Bihar

Treatments	Average yield (t/ha)	Input saving (Ex-water) (₹/ha)	Water saving (%)
Zero till direct seeded rice	2.5	3352.50	67
Direct seeded rice on FIRB	2.4	2106.00	86
Puddled Transplanted rice (Control)	2.8	0.00	0

Bed planting

Bed planting refers to a cropping system where the crop is grown on beds and the irrigation water is applied in furrows between the beds. The technique offers a number of advantages such as improved fertilizer efficiency, better weed control and reduced seed rate. It also saves irrigation water compared to a flat inundated field as the evaporation surface is reduced and water application and distribution efficiency are increased. In addition, the rooting environment is changed and the aeration of the bed zone is better than flat planting. Under bed planting, water savings (compared to flat surfaces) of 26 per cent for wheat and 42 per cent for transplanted rice, and yield increases of 6.4 per cent for wheat and 6.2 per cent for rice have been reported (RWC-CIMMYT, 2003).

Transplanting date

If the rice seedlings and crop can be established early, the rice crop can benefit from the monsoon rains and grow without the need for irrigation. Timely transplanting of rice also results in earlier harvests and allows timely planting of the wheat. The results of farmer participatory field trials showed that the strategy of timely transplanting of rice improves wheat yields. The productivity of the rice- wheat system was nearly 12-13 t/ha when rice was transplanted before 28th June. This was reduced to 6-7 t/ha (more than 40%) when fields were planted after 15 August (Singh *et al*., 2002). Effect of raising bund height on water, nutrient and sediment yield was studied in rice fields and it was observed that raising bund height by 6.0 and 30.0 cm could save 57 and 99 per cent of water application, respectively (Mishra *et al.*, 1997).

Water saving in zero tilled direct seeded rice

Rice production consumes about 45 per cent of all fresh water used in Asia (Barker *et al*., 1999). Flood-irrigated rice uses two to three times more water than other crops such as wheat and maize. According to one estimate, by 2025, about 15 out of 75 m ha of Asia's flood-irrigated rice crop will experience water shortage (Toung and Bouman, 2003).

Savings in irrigation water for rice establishment in heavy soils of south Bihar is presented in Table 12. On an average, 3-4 irrigations could be saved in zero till direct seeded rice compared to puddled transplanted rice in Patna. Zero till direct seeding of rice in early monsoon phase saved rain/canal water required for puddling (up to 300 mm) and need of excess water for irrigation in case of dry spell and cracking of heavy soils. Further, savings of 113 liters of diesels in ZTDSR was also recorded (Table 12).

Table 12. Effect of seeding method on irrigation requirement, diesel saving and rice yield

Rice establishment method	Hrs required per irrigation by 5.0 HP pump	Days interval required between two irrigation	Irrigation required at flowering under delayed rice establishment due to water crises for timely transplaning	Total no. of irrigation applied	Total diesel requirement* (liter/ha)	Diesel saving (lt.)	Grain yield (t/ha)
ZT direct seeded after ploughing	16	20-25 days	01	04	72	113	4.2
Puddled transplanted	-	-	15-20 cm (2 irrigation)	6-7	185	-	3.8

It excludes 5.0 liter diesel to irrigate nursery field (500 m^2) required for 1 ha and 40 liter diesel for puddling

Rainwater Management through ZT sown Direct Seeded Rice

Average annual rainfall (mean of 40 years) of Patna is 1142.5 mm and 90 per cent of it is received during June to October (Table 13). Generally farmers wait for heavy rains to puddle the field for rice transplanting. In the process, sometimes, they wait till late August and on an average lose 600 to 700 mm of rainwater (Khan, 2010). In ZTDSR, the rice sowing starts from middle of June to middle of July and utilizes maximum rainfall and therefore, irrigation water is hardly needed. Only erratic and long gaps of rainfall, compel the farmers for canal/tube well irrigation.

Table 13. Rainwater Utilization in Rice in Patna

Month	Average of 40 years	Rainfall (mm)					
		2006	2007	2008	2009	2010	2011
June	84.2	253.5	63.1	451.78	81.9	53.2	316.8
July	375.9	325.5	655.1	463.04	155.9	205.3	94.6
August	247.8	161.74	380.5	413.57	267.2	266.5	292.8
September	239.5	229.20	266.1	210.09	163.3	66.7	318.9
October	84.9	2.36	11.91	3.0	40.5	79.3	01.4
Total Rainfall in *kharif*	1032.3	972.3	1376.71	1541.48	708.8	671	1024.5

Economics of ZTDSR

A net saving of ₹ 6,800/ha in crop establishment could be made due to ZTDSR as against the conventional puddled transplanted (PT). A saving of ₹ 320/ha per irrigation was also observed. Saving of 5-6 irrigations in drought year has thus saved around ₹ 6,240/ha (Table 14).

Table 14. Economics of DSR and puddled transplanted rice in south Bihar (2004)

Practice	Cost (Rs/ha)	
	DSR/ZT	Puddled Transplanted
Four irrigations for nursery raising (500m^2)	00	800
Nursery uprooting	00	600
Field preparation (DSR & Puddled transplanted)	1,600	3,200
Irrigation cost in puddling (40 hrs)	00	1,600
Puddling	00	1,600
Transplanting (40 labour)	00	1,200
Herbicide use	1,400	00
Weeding @ ₹ 30/labour for half day	1,200	2,000
Total costs	4,200	11,000

Winter (*rabi*) Season Cultivation through RCTs

Wheat cultivation by different RCTs methods

Sowing of wheat in some parts of EIGP is done in first week of January due to heavy moisture in the field. Optimizing sowing time of wheat through use of improved implements like zero till drill, however, enabled sowing even in wet soil and advanced the sowing by minimum of a 15-20 days. Sowing could be advanced by 25-30 days in surface seeding. Different practices of RCTs sowing (equal row, paired row and control traffic), double zero till wheat and different zero till machines like double disc planter, rotary disc drill, eleven tynes zero till machines, turbo seeded etc. were used and crops were monitored throughout the season till harvesting. Double zero till wheat in the same field without ploughing after the harvest of zero till direct seeded rice (ZTDSR) was also tested. Wheat crop was also sown in the presence of the residue of rice crop harvested in the month of November. The residue of rice left was to the tune of 4.0-4.5 t/ha in manually harvested fields (Khan and Singh, 2008). Turbo seeder was, however, used with 8-10 t/ha residue. The mean yield performance (2004-05 to 2007-08) of wheat under varying RCTs practices is presented in Fig 3. The highest yield was obtained in traffic control with residue.

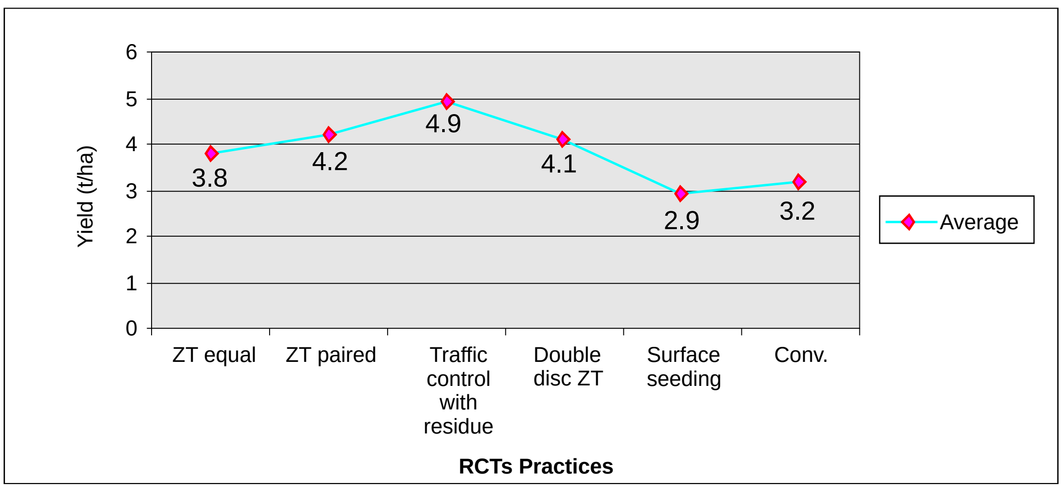


Fig 3. Effect of RCTs on wheat (Var. HD-2733) yield at Patna

Comparative Studies of RCT Methods on Yield, Savings in Cost of Cultivation and Net Benefits

The comparative studies of different RCT methods for wheat cultivation like sowing by rotary disk drill for wheat establishment in the presence of residues of rice crop after ZTDSR with traffic control, double zero till practice for wheat establishment, paired row wheat sowing after ZTDSR, equal row wheat sowing after ZTDSR, surface seeded wheat with balance NPK in standing conventional rice, conventional wheat after conventional rice (control), on yield, saving in cost of cultivation and gross benefit are presented in Table 15. Maximum benefit was obtained by wheat establishment in the presence of residue of rice crop after ZTDSR with traffic control, followed by double zero till practice for wheat establishment. Other RCT practices also have an edge in profit over conventional methods.

Equal Row planting (PR) of wheat

Paired row planting (PR) of wheat

Rotary till disk drillmachine

Wheat sown through ZT Drill Machine

Wheat crop through control traffic method

Visit of Bill & Melinda Gates Foundation Team along with Dr. Raj Gupta and Dr. A.K. Sikka to RCT being adopted in farmers' field on 4th February 2007

Visit of Mr. A.K. Upadhyaya, Secretary, ICAR & Additional Secretary, DARE to RCTs farmers' field on 17th February 2007

Table 15. Effect of crop establishment methods on yield and economics of wheat in canal irrigated area of Patna

Technology/Method of wheat crop establishment	No. of sites	Sowing periods	Wheat variety used	Grain yield range (t/ha)	Mean grain yield (t/ha)	Savings in tillage (₹/ha)	Yield gain over control (t/ha)	Gross benefit (₹/ha)
Rotary disc drill establishment in rice residue after ZT DSR	20	03.12.04 to 04.01.05	HD-2733 PBW-343 UP-262	2.17-4.92	3.55	1,520	1.12	8,495
Double Zero till practice for wheat establishment	07	03.12.04 to 31.12.04	HD-2733 PBW-343	2.47-3.92	3.20	1,720	0.77	6,500
Paired row wheat sowing after ZTDSR	18	26.12.04 to 06.01.05	HD-2733 PBW-343 UP-262 HUW-234	1.11-4.41	2.67	1,720	0.25	3,239
Equal row wheat sowing after ZTDSR	22	06.12.04 to 29.12.04	UP-2338 UP-262 HD-2733 Kundan PBW-343	1.11-4.27	2.70	1,720	0.26	3,363
Conventional wheat after conventional rice (control)	05	14.12.05 to 01.01.05	Lok – 1 Kundan UP – 262 PBW-343	1.22-3.63	2.45	-	-	-

Effect of double Zero Tillage in RW system

ZT wheat grown after ZT direct seeded rice was more productive over conventional R-W system. There was more than 150 % yield increase in wheat under double zero tillage over conventional method. Yield gain was 1.61 t/ha (Table 16).

Table 16. Yield of wheat in double zero till practice

Technology	No. of sites	Wheat yield (t/ha)	Increase in yield over conventional practice (%)
ZT wheat in Zero tilled in direct seeded rice field	07	2.65	154.8
Conventional Wheat in transplanted puddled rice field	03	1.04	-

Refinement of surface seeding of wheat

Wheat is broadcast in standing crop under excess moisture conditions (lowland moist field) before 15-20 days of rice harvest. This facilitates timely seeding of wheat and reduces tillage and irrigation cost. Due to this practice, delay in wheat sowing is avoided and the cost of cultivation is minimized. Due to timely planting, higher yields are achieved. Farmers rarely irrigate surface seeded wheat in south Bihar due to presence of high soil moisture for at least a month after sowing extending beyond the crown root initiation stage. The crop was sown timely (20-25 days early). The surface seeding practices saved water by 35-40%. This reduces the irrigation requirement in early phase and there is about 45% less water requirement in the first irrigation. Farmers were more responsive in lowland area and used only nitrogen (70-80 kg/ha) fertilizer in basal and top dressing mode. However, after the interventions of ICAR, farmers started using potash @ 40 kg/ha at basal and only 35 kg N at basal after rice harvesting. Further, urea top dressing was standardized for split doses at the time of tillering and panicle initiation (65 kg N/ha), against farmer's practice (70-80 : 0-37 : 0 NPK). Presence of *Phalaris minor* was observed to be less. Herbicide (2,4-D) was used for broad leaved weeds. The yield was 2.6-3.0 t/ha and B:C ratio was higher due to less expenditure in crop establishment.

Broadcasting of wheat seeds in standing rice crop

Broadcasted wheat seeds

Soil moisture sampling at the time of surface seeding of wheat

Surface seeded wheat crop

Effect of balanced nutrient management in surface seeded wheat

Surface seeding is done in low lands where excess soil moisture does not allow tillage operation till the end of December. Seed @ 160 kg/ha is broadcast in standing rice crop before 10 – 12 days of harvesting. Sometimes, immediate sowing before harvesting is done. No basal fertilizer is applied. Only N is applied as top dressing. There was net benefit of ₹ 4,780/ha due to application of balanced fertilizer (Table 17).

Table 17. Effect of balanced NPK on yield gain and net benefit in surface seeded wheat

Technology/method of wheat crop establishment	No. of sites	Sowing period	Wheat variety used	Grain yield range (t/ha)	Mean grain yield (t/ha)	Yield gain over control (t/ha)	Gross benefit (₹/ha)
Surface seeded wheat with balance NPK after conventional rice	35	01.12.04 to 29.12.04	PBW-343 Lok-1 Kundan	2.10-4.02	2.78	1.12	4,780
Surface seeded wheat with only N application (conv.)	05	01.12.04 to 24.12.04	UP 262 RR 21	1.42-1.83	1.66	–	–

Effect of varieties and sowing method on grain yield of wheat in south Bihar

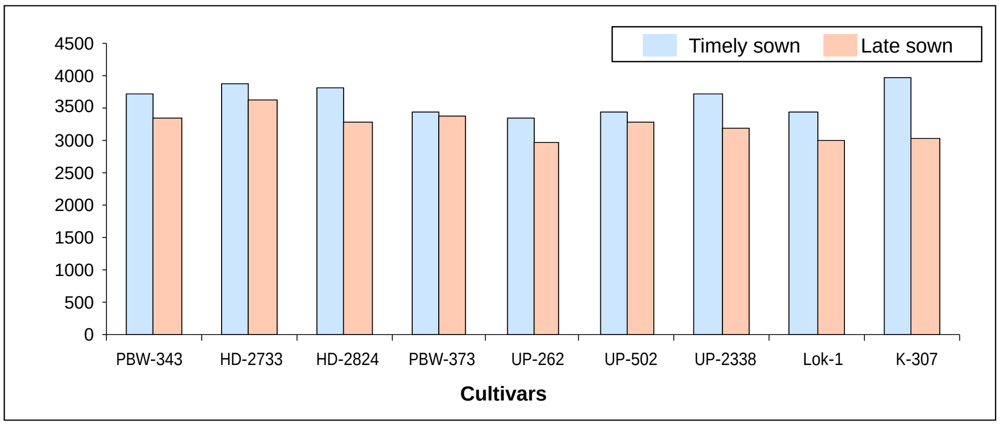
PBW 343 was highest yielder in ZT equal row (3.23 t/ha) and ZT control traffic (3.07 t/ha) whereas in ZT paired row, HUW 234 gave the highest yield (2.91 t/ha). In double disc ZT, HD 2733 was the highest yielder (3.49 t/ha). In surface seeding, local popular RR 21 was the highest yielder (2.65 t/ha), followed by PBW 343 (2.44 t/ha). In conventional method, the prevailing popular variety UP 262 has given the highest yield of 2.49 t/ha (Table 18).

Table 18. Effect of varieties on grain yield (t/ha) under various methods

Variety	ZT equal	ZT paired	ZT control traffic	Double disc ZT	Surface seeding	Conventional
HD 2733	2.98	2.17	2.80	3.49	–	–
PBW 343	3.22	–	3.07	2.93	2.44	1.12
UP 262	2.26	1.40	2.95	–	2.35	2.49
HUW 234	1.75	2.91	–	–	–	–
PBW 373	2.16	2.66	2.92	–	–	–
Kundan	–	–	–	–	2.40	1.25
Lok – 1	–	–	–	–	2.17	1.12
RR 21	–	–	–	–	2.65	–
Average	2.47	2.28	2.94	3.21	2.40	1.49

Cultivar choice for wheat

Recently several leading high yielding wheat varieties were tested under timely and late sown condition in EIGP. Varietal performance under difference dates of sowing indicated yield reduction under late sown conditions in all the varieties and timely planting emerged one of the important factors for improving wheat productivity (Fig. 4). However, in rice wheat system, sowing of wheat is delayed due to long duration rice cultivars. Wheat varieties like PBW 343, HD 2733, HD 2824 and K 307 performed better in zero-till condition and seemed flexible for different dates of sowing than other varieties under timely as well as late sown conditions. However, wheat variety PBW 343 was found susceptible to foliar diseases in several farmers' participatory trials.



Source: Singh et al. (2010)

Fig. 4. Response of wheat varieties in zero tillage planting system under timely and late plating conditions

Role of RCTs for Enhancing Water Productivity

Efficient water use in wheat for higher productivity

Soil moisture status of silty clay loam soil of north Bihar under conventional and Zero tillage for wheat crop is presented in Table 19. It was observed that sowing of wheat in conventional tillage is generally done at 60 to 65 per cent of field capacity of soil, whereas sowing can be done at 85-90% of field capacity in zero tillage. This facilitates about 10 to 12 per cent additional utilization of residual soil moisture. The normal time taken to irrigate one-hectare field of conventional tilled wheat field is 20 to 21 hrs with 5 HP pump whereas, it took only 14 to 15 hrs in zero tillage. Thus there is a net saving of 5 hrs of pumping, which reduces the use of energy and irrigation cost for zero tilled wheat crop.

Zero till sowing of wheat also captures advantages of earlier sowing like low temperature for longer period and time for more tillering in wheat. It also reduces loss of soil moisture due to lesser potential evapo - transpiration in the month of December and January. Zero till seed drill sowing of wheat done at higher moisture content enhances the sowing of wheat by 15 to 20 days. This facilitates the crop to escape terminal heat losses due to earlier flowering and grain setting in wheat and from westerly winds in summer months.

It has been observed that 15 to 20% losses occur due to terminal heat in wheat. As compared to conventional tillage, wheat sowing in low lying area with zero till seed drill requires less number of irrigations. It is because of the fact that the initial soil moisture is excessive at sowing in zero till on the one hand and the low potential evaporation losses in the month of December and January on the other. Better utilization of initial soil moisture and profile water storage for longer period together with reduced depth of each irrigation application contributes to higher water use efficiency in zero tillage. The above factors also help the crop in escaping temporary water stress and results in 10 to 15 per cent higher grain yield with less depth of irrigation which ultimately gives higher water use efficiency in zero till sown wheat in low lying areas. Generally, low lying areas are blessed with heavy textured soils with high organic carbon (> 0.5%) content, which also helps in increasing water retention of soil.

Wheat establishment under zero tillage system saved up to 30% water in first irrigation. Due to wheat sowing just after rice harvest at residual moisture, the pre-sowing irrigation water requirement is reduced by about 10 cm–ha water. Saving in water is due to faster advancement of irrigation water in untilled soil compared to a tilled soil implying farmers can apply irrigation much faster. Heavy irrigation is avoided in ZT during February-March in order to avoid lodging due to high-velocity winds, particularly in northwestern areas of the country.

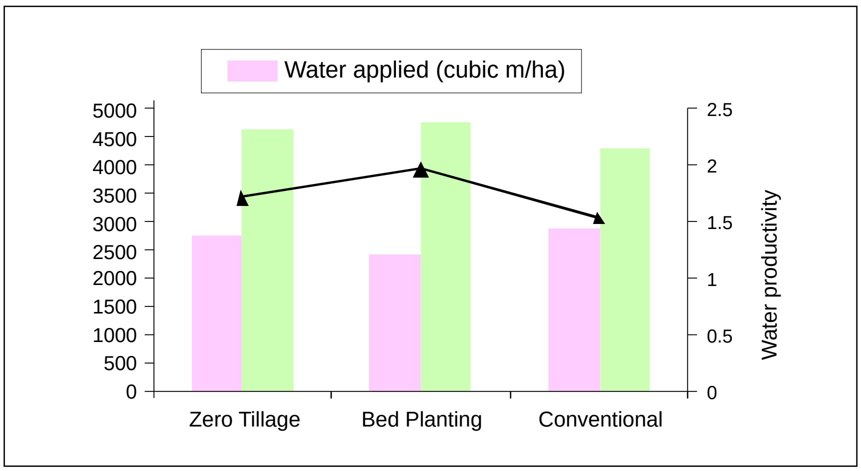
Table 19. Soil moisture status of wheat under different tillage observations in silty clay loam soil of north Bihar

Particulars	Conventional Tillage	Zero Tillage	Higher moisture content/ saving in ZT over CT
Soil moisture status at sowing time (%)	23.67	33.57	9.8
Time taken by 5 HP diesel pump (oil charge – 12 liters) for irrigating one hectare area (hr)	20.60	14.50	29.5
Depth of applied irrigation water (cm)	8.90	6.30	29.5
Charges of each irrigation (₹/ha)	1236.00	870.00	367.20
Total water applied (cm)	17.80	12.50	29.8
Yield (t/ha)	3.69	4.21	14.1
Water use efficiency (kg/ha cm)	207.30	336.80	62.4

Source : Reconstituted from report of ADB Project, RAU, Pusa/RWC-CIMMYT India

Furrow irrigated raised beds (FIRBs) for planting wheat

Significant improvement in the water productivity has been found in bed planting of wheat (Fig. 5) but the success of this technology will depend on the type of soil and source of irrigation (Anonymous, 2005). The average use of water in zero-till, raised bed and conventional planting practices in wheat, for the Pabnawa Minor canal in Kurukshetra irrigation circle of Bhakra canal system of northwest India were (14.7 cm) in raised bed planting (BP) compared to Zero tillage (24.8 cm) and conventional tillage (30.3 cm). Nearly 18 % and 50 %, water saving was recorded in zero tillage and bed planting systems (Chandra *et al.*, 2007)



Source: Mallick (2010)

Fig. 5. Grain yield and water productivity of wheat under different crop establishment techniques.

Direct dry sowing using zero-till seed drill and use of permanent furrow irrigated raised beds (FIRBs) for planting wheat can reduce the cost and save time in land preparation. It also saves irrigation water for crop growth. Field trials were conducted in participatory mode using the RCTs like permanent FIRBs planting with two/three rows and zero tilled along with conventional sowing in clay loam soil and loamy soils to study the irrigation efficiency and economics of wheat production. Two/three irrigations were given in the entire cropping period of wheat in this region. FIRBs planting has resulted in 1.0-1.1 t/ha higher wheat grain yield in north Bihar and 0.84 t/ha in south Bihar. Wheat with 2 rows on FIRBs was better yielder than 3 rows. Maximum gain of ₹ 8,415/ha was found with 2 rows on FIRBs in north Bihar. Gain in south Bihar was comparatively less (₹ 6,660/ha) due to low yield owing to the increased terminal heat (hot wind) at milking stage during March (Table 20). Water productivity and grain yield of wheat under different sowing methods are presented in Fig. 6.

Table 20. Effect of FIRB planting on yield and economics of wheat (average of 10 farmers fields)

Treatment	Yield (t/ha)		Yield gain over conventional tillage, (t/ha)		Total gain through saving in irrigation and additional yield (₹/ha)	
	North Bihar	South Bihar	North Bihar	South Bihar	North Bihar	South Bihar
FIRB planting with 2 row	3.85	2.64	1.10	0.84	8, 415	6,660
FIRB planting with 3 row	3.71	-	0.96	-	7,470	-
Conventional	2.75	0.18	-	-	-	-

Source: Singh, *et al*. (2006)

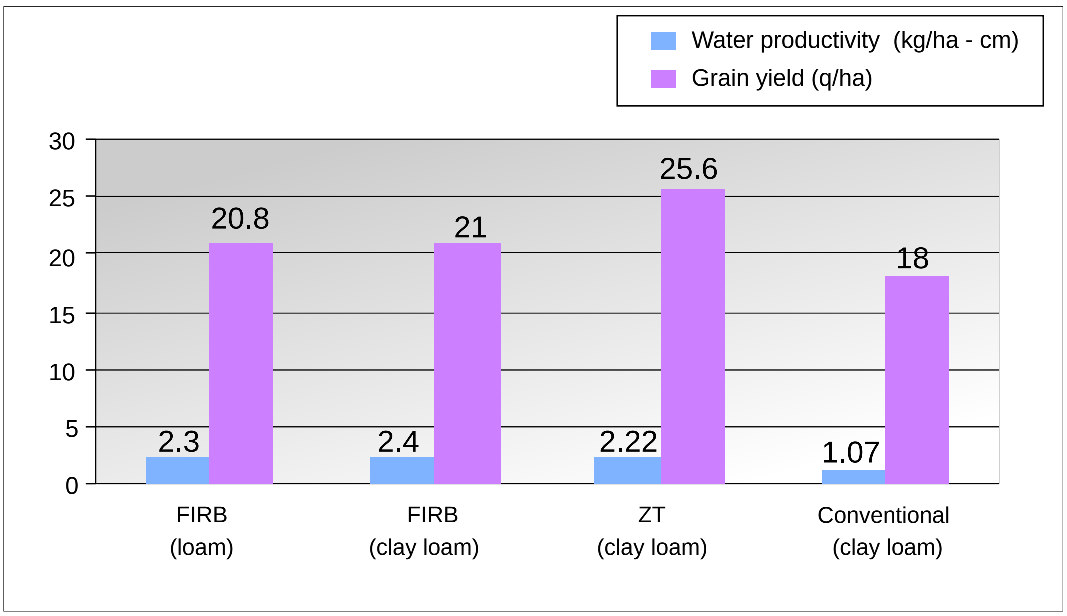


Fig. 6. Water productivity and grain yield of wheat under different sowing methods

Saving in the cost of irrigation in different agro-climatic zone of eastern U P is presented in Table 21. On an average, saving of ₹ 562/ha under ZT wheat was found in north eastern plane zone. The maximum saving of ₹ 656/ha was in eastern plain zone and only ₹ 312/ha was reported in Vindhyan Zone. Zero tillage technology saves more than 90 per cent diesel, which comes to 61 liters/ha compared to conventional system. This proves eco-friendly wheat cultivation by reducing 135 kg CO_2/ha (assuming 2.6 CO_2 production/liter of CO_2 diesel burnt), which is one of the major causes for global warming (Chauhan *et al.*, 2001)

Furrow irrigated raised beds (FIRBs) planting

Table 21. Saving in irrigation (₹/ha) over conventional tillage in different agro-climatic zones of eastern Uttar Pradesh for two wheat seasons

Agro climatic zone	Saving in irrigation (₹/ha)		Mean
	2001-2002	2002-2003	(₹/ha)
North eastern plane zone	625	500	562
Eastern plain zone	750	563	656
Vindhyan Zone	250	375	312

Source : Eastern UP marching forwards ZT Technology, Directorate of Extension, NDUAT, Faizabad

Economics and participatory budgeting of wheat cultivation

The economic gains due to RCTs were ₹ 6,146/ha and ₹ 3,634/ha in ZT and surface seeded wheat, respectively. The details of the gross economic gains are presented in the Table 22. Participatory budgeting with farmers is presented in Table 23.

Table 22. Economic gains of wheat cultivation due to RCTs (2006)

Resource	Benefit over conventional sown (₹/ha)		Total saving in covered area* (Rs)		Gross saving (Rs)
	ZT	Surface Seeded	ZT	Surface Seeded	
Land preparation cost including sowing	900	1,500	4,374	7,290	11,664
Saving in the cost of seed	600	-	2,916	-	2,916
Saving in first irrigation	480	1440	2,332	6,998	9,330
Saving in weeding	-	-	-	-	-
Increase income due to additional yield	4,166	694	20,246	3,372	23,618
Total gains	6,146	3,634	29,868	17,660	47,528

Remark : Cost of diesel in sowing is included under the cost of land preparation and sowing

Table 23. Participatory budgeting with farmers on wheat cultivation

	Participants				Non Participatnts				Control Koriyawan
	Taret	Nahar pura	Azad nagar	All	Taret	Nahar pura	Azad nagar	All	
Seed (₹)	1680	960	960		1240	1280	1280		1280
MOP (₹)	200	200	200		100	100	200		150
DAP (₹)	1560	1560	1560		2000	1560	1560		1560
Urea (₹)	832	832	832		832	624	832		832
Pesticides (₹)	425	425	0		00	00	00		0
Tractor and field preparations (₹)	600	600	600		1500	1500	1500		1500
Labour in weeding & intercultural operations (₹)	400	300	250		400	300	250		250
Harvesting (₹)	3157	3213	3088	3166	3396	3422	1548	2800	1929
Others	200	200	100		200	200	100		150
Total	9054	8290	7590	8310	9668	8986	7270	8641	7651
Yield t/ha	2.25	2.29	2.25	2.26	2.43	2.44	1.11	2.0	1.38
Return ₹/ha	16985	17315	16640	17030	18282	18400	8340	15100	10345

All participants/non-participants are from villages of Patna district.

Laser land leveling

Effective land leveling is meant to optimize water-use efficiency, improve crop establishment and reduce the irrigation time etc. Land leveling is a precursor to good agronomic, soil and crop management practices. RCTs perform better on well-leveled and laid-out fields for farming activities. Traditional farmers' methods for leveling

Scientists from different countries visited RCTs field in Patna during February 2005

by eye sight are not sufficiently accurate (particularly on larger plots), and resulting in extended irrigation times, unnecessary water consumption and inefficient water use. Precision land leveling with laser leveler is the basic requirement for uniform crop stand. Laser leveling helps to overcome the above listed inefficiency and reduces water requirement through transmission losses and uniformity in moisture distribution.

Benefits of laser land leveling

- More level and smooth soil surface,
- Reduction in time and water required to irrigate the field,
- Reduces weed problems and improves weed control efficiency,
- Improved efficiency of applied fertilizer and herbicides,
- Reduction in salinity problems,
- Increase in water application efficiency up to 50 per cent,

- More uniform distribution of water in the field,
- Improved crop establishment,
- Increase in cultivable area by 3 to 5 per cent,
- More uniform moisture environment for crops,
- More uniform germination and growth of crops,
- Reduction in seeds, fertilizer, chemicals and fuel used in cultural operations
- Easy farm operation due uniform tilth,
- Increase crop yields by 10%,
- Improved field traffic ability for subsequent operations.

However, the limitations of laser land leveling include the following

- High cost of the equipment/laser instrument,
- Need for skilled operator to set/ adjust laser settings and operate the tractor,
- Need of regularly sized and shaped fields.

Laser leveling reduces the unevenness of the field to about ±2 cm with a slope of 0 to 0.2 %, resulting in better water application and distribution efficiency, improved water productivity, increased fertilizer efficiency and reduced weed pressure. Savings of up to 50 per cent in wheat and 68 per cent in rice have been reported (Jat *et al.*, 2006). A comparison of conventionally leveled and laser leveled fields is given in Table 24. The use of laser leveler would help farmers to make better use of furrow irrigated bed planting system based intercropping. Comparison of different RCTs with normal planting established that RCTs provided better water productivity compared with traditional systems.

Laser aided land leveling in the field
Source: Jat *et al.* (2006)

Dr. B.P. Bhatt, Director, ICAR-RCER discussing about Laser Leveling equipment with the QRT members

Table 24. Wheat yield and water productivity in conventional and laser leveling

Parameters	Conventional leveling	Laser leveling
Leveling index (cm)	>1.5	>1.5
Irrigation depth (cm)		
Paddy	110-115	90-95
Wheat	30-35	20-25
Pumping requirement per irrigation (hr/ha)		
Paddy	25-27	20-22
Wheat	15-17	9-11
Water productivity (kg/m^3)		
Paddy	0.37	0.47
Wheat	1.50	2.44

Source: Ambast *et al.* (2006)

In EIGP, irrigation to the crops is becoming very costly due to ever increasing energy prices and poor electricity supply. Need of the hour is, therefore, to introduce a technology that can save water and improve water use efficiency. In a study conducted on effect of laser land leveling in different districts of Bihar revealed that average savings in cost of irrigation ranged from ₹ 550 to ₹ 1600/ha in rice and ₹ 700 to 2200/ha in wheat due to laser assisted precision land leveling (Table 25).

Table 25. Savings in irrigation costs in different crops under laser land leveling compared with traditional leveling in different districts of Bihar

Districts	Savings in cost of irrigation (₹/ha)	
	Rice*	Wheat
Vaishali	-	2200±200 (07)
Muzzafarpur	900 (01)	-
Samastipur	-	700±250 (07)
Begusarai	1100±450 (05)	1100±400 (11)
Jamuai	-	1100±450 (03)
Purnea	1600±250 (03)	-
East Champaran	550±150 (02)	900±350 (03)
Mean	1040±440 (11)	1275±645 (38)

Source: Singh *et al.*, 2010

*Figures in parentheses indicate number of participatory field trials.
± Standard deviation, - = no data available

Crop Residue Management

Crop residues can be recycled and utilized in soil by different methods, such as (i) *in situ* incorporation, (ii) *in situ* burning, (iii) application as surface mulch, (iv) compositing, and (v) use for biogas production.

In situ incorporation of crop reduces

Organic materials of different crops left after their harvest can be directly incorporated into the soil before sowing of the following crop. The period allowed for decomposition of the crop residues is important so as to ensure mineralization of nutrients. However, decomposition of crop residues in soil, which depends upon carbon to nitrogen (C/N) ratio, also varies with soil properties, temperature and soil moisture regimes. Leguminous plant materials with narrow C/N ratio (< 30) decompose faster. About 40 % of carbon added though green manure gets decomposed within 7-15 days. Cereal crop residues having wider C/N ratio (>100) decompose rather slowly.

Use of crop residues as mulch

Soil nutrients are depleted heavily due to RW cropping system. According to one estimate, yields of 7 t/ha of rice and 4 t/ha of wheat removes more than 300 kg N, 30 kg P, and 300 kg K per ha from the soil in RW cropping sequence. Hence, field management of crop residues can be done very effectively through mulching on the surface of the soil. The heat reflective properties and water transmission characteristics of mulches are quite different from those of bare soil. Covering the soil surface with crop residues can help in checking soil loss through erosion and change its energy balance, which affects soil environment through its influence on hydrothermal regime. Organic mulch also suppressed the surface temperature and it served as temperature moderator (Khan *et al.,* 2000).

In situ burning of crop residues

Large quantities of crop residues remain in the fields after mechanical harvesting of crops. Removal of mechanically harvested left over residues from the field is rather difficult. It can either be incorporated into the soil or burnt *in situ*. After combine harvesting of rice, the residues are normally burnt prior to establishing wheat (Gajri *et al*., 2002). Approximately 16 m tonnes of rice straw is currently burnt each year in Punjab alone (Singh *et al*., 2008). Combined harvesting has


Mulched wheat crop

started very recently in south-west Bihar and approximately 5 m tonnes of rice straw is burnt in Bihar alone. Farmers burn the residues because many tillage passes are required for incorporation, coupled with the need to allow time for the straw to decompose sufficiently so as to avoid N immobilization at the time of sowing. Thus, incorporation of rice straw delays wheat sowing beyond the optimum date for maximum yield. Managing heavy crop stubbles (7-10 t/ha) is a major problem. Burning of stubbles is, therefore, a rapid and cheap option. Recently, Govt. of Bihar is taking steps for residue management through turbo seeder and has extended the subsidy on purchase of such equipments.

Effects of Straw Burning

Burning of rice residues is a major source of air pollution in the region. Burning crop residues destroys organic matter and results in large nutrient losses. On an average, all of the C, 90% of the N, 60% of the S, and 20–25% of the P and K in the rice straw is lost through burning. On the other hand, addition of crop residue on a long-term basis helps in improving physico-chemical and biological properties of the soil and can be expected to prove beneficial in improving soil productivity. It is only the wider C:N ratio of the material added that results in immobilization of nutrients and in lower crop yields under incorporation treatments.

Turbo Seeder

Now in India, many RCTs machines like Turbo/Happy seeder and rotary drill disk etc are available for planting rice, wheat and other crops directly in presence of residue. Development of a residue/trash handling zero tillage sowing implement, the 'Turbo Seeder' provides the capability of direct drilling wheat in rice residues (Sidhu *et al.,* 2007; 2008). The technology is now recommended to the farmers. The Turbo Seeder simultaneously cuts and removes the straw in front of the sowing tynes, and spreads the straw on the surface as mulch behind the tynes. Studies on the effect of rice residue on ZT wheat in manually rice harvested field having around 4 t/ha residue is presented in Table 26. Impacts of the RCT on the environment are depicted in Table 26.



Residue burning

Table 26: Yield of wheat as influenced by rice residue retention in Patna (2007)

Technology	No. of sites	Wheat yield (t/ha)	Increase yield over conv. (%)	Remarks
ZT wheat in rice residue (4 t/ha)	08	4.4	142	Leaving long rice residue is drudgery while sitting in field for harvesting. Small rice straw is difficult for drying, bundling and thresh-ing.
Conventional wheat without rice residue	12	3.1	-	

Turbo seeder

Rotary till drill disk

Cultivation of wheat with residue

Impact of RCTs on Environment

RCTs impact the environment by :

- Reducing the need for applying herbicides.
- Reducing the amount of N that "leaks" into the environment.
- Providing environmentally friendly options for managing crop residues.
- Reducing soil compaction.
- Improving soil physical properties over time.
- Reducing the production of CO_2, CO, SO_2 .
- Carbon sequestration thus reduces CO_2 emissions significantly.
- Saving of 20-30% of water which would also help save 80 KWh of electricity and 160 kg of CO_2.
- It has been estimated that CO_2 equivalent emissions from a high input conventionally tilled cropping system with residue burning and organic amendments would be equal to 29 Mg CO_2 per year from 1 m ha. It can be reduced to emissions of 14 Mg CO_2 from no-till residue retention system with low input from an equivalent area.
- Under resource conserving agricultural practices, soil erosion is less as compared to soil builds up process resulting in about one mm of soil builds up per year due to accumulation of soil organic matter.
- Adoption of zero tillage systems on 1 ha of land would save up to 100 liters of diesel and approximately 1 m liters of irrigation water. Using a conversion factor of 2.6 kg of CO_2 per liter of diesel burned, this represents a quarter ton less emission per ha of CO_2, a principal contributor to global warming (Gupta *et. al.*, 2003).
- Zero-tillage even on one million hectares of rice-wheat system area would save one billion cubic meters of water each year. About 100 million liters of saving in diesel every year will help reduce CO_2 emissions by 0.26 m tons every year.

Crop Diversification

Diversification of crop is a shift towards high-value crops. Diversification in the rainfed and marginal environments is an insurance scheme that diffuses risk, arrests resource degradation, and reduces biotic and abiotic losses. Diversification of agriculture in favor of commercial crops leads to greater market orientation of farm production and progressive substitution of non-traded inputs in favor of purchased inputs.

Substitution of RW cropping system through introduction of diverse nature of crops like potato, maize, pulses (green gram) may be a good alternative to break the monotony of the traditional RW cropping system and help to sustain the productivity through soil fertility maintenance in the long run.

ZT Lentil

Lentil, which is an important rabi pulse crop, is sown through zero till drill machine and the farmers are encouraged to adopt this practice in south Bihar.


Lentil crop sown through ZT machine

Diversification of Potato + Maize on Raised Bed through RCTs

Potato - Diversification of potato + maize on raised bed in RW system through RCTs was undertaken after the harvest of rice. Potato crop was sown in the end of November and harvested by the middle to end of February. Potato yield ranged from 22.5 - 38.4 t/ha. (Table 27). The control yield was much less, ranging between 15.2 to 19.2 t/ha. The normal basal dose of NPK was recommended with three irrigations.


Potato and Maize cultivation

Maize - Potato was sown on beds at a distance of 15 cm and maize at the slope of the bed, which was 5 cm above the furrow and distance between the seed to seed was 20 cm (Fig. 7). The seed rate was 20 kg/ha. It was observed that growing of maize in the southern part of Bihar during *rabi* is also possible with good yield. The introduction of QPM alongwith potato in the month of November (first week) is profitable proposition because apart from the potato, farmers could get good yield of maize.

Table 27. Effect of wheat crop diversification through maize + potato and the gross benefit obtained

Technology / Method of wheat crop establishment	No. of sites	Range of Sowing date	Variety	Grain yield range (t/ha)	Mean yield (t/ha)	Saving in tillage (₹/ha)	Gain over control (t/ha)	Gross benefit (₹/ha)
Potato on raised bed through RCTs	50	13.11.04 to 05.12.04	Kufri Ashoka	9.33 – 38.4	23.86	25,599	2.88	42,909
Maize on raised bed through RCTs	41	16.11.04 to 10.12.04	Shaktiman-1 (QPM)	1.0 – 5.44	3.22	1,184	0.36	3,344

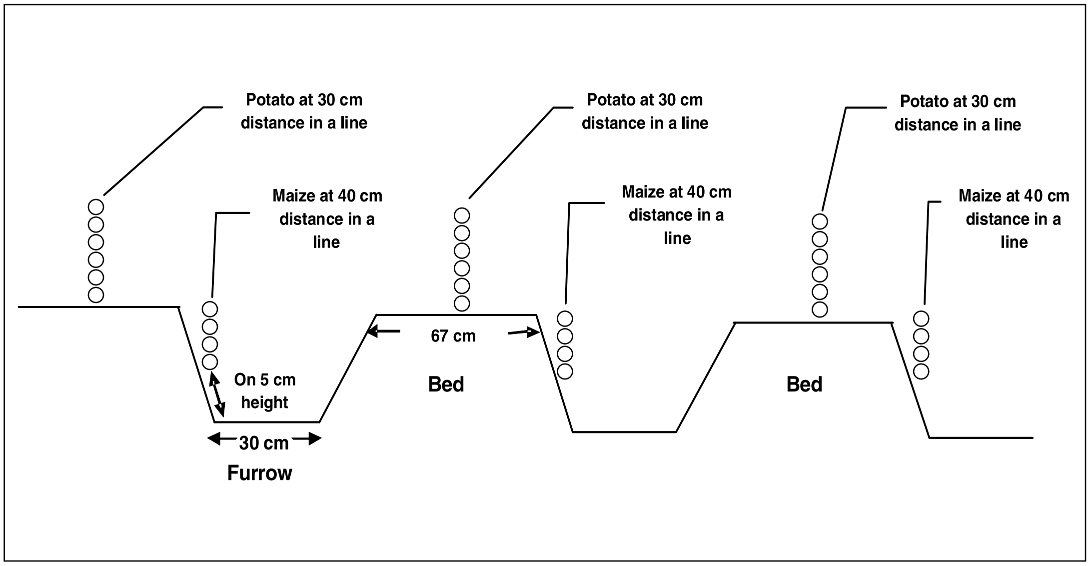


Fig. 7. Sketch of raised bed and furrow for potato + maize cultivation

Crop Intensification of RW Cropping System

Extra early Pigeon Pea (ICPL 88039). For intensification and diversification of the cropping system, extra early short duration pigeon pea (ICPL 88039) of 150 days duration was introduced during *kharif* season with a purpose to introduce winter wheat after its harvesting. The crop was harvested by the end of November or early of December with yield range of 1.02-1.3 t/ha. Farmers' responses was very positive as they could take wheat crop also. Summer pulses were also introduced for crop intensification in RW system. Both the crops improved the soil health through fixation of atmospheric N.

Extra early Pigeon Pea (ICPL 88039) in the field

Green gram: Summer moong bean was grown through ZT after the harvest of wheat and also as a relay crop in standing wheat crop. This crop mature in 60-65 days and is harvested by the end of May before the ZTDSR (Table 28). This crop has increased the cropping intensity and income of the farmers apart from fixation of atmospheric nitrogen and improvement in soil properties.

Cultivation of Cowpea: Cowpea was introduced during spring in south Bihar. Being a new vegetable crop for the region, only few farmers had sown it through Zero till machine (Table 28).

Table 28. Yield of summer crops at Patna during 2011

Crop	Number of sites	Sowing date/period	Seed rate (kg/ha)	Yield (t/ha)
Moongbean	29	Feb 28, 2011-March 25, 2011	20.00	0.56 - 0.80
Cowpea	05	March 13 – 20 , 2011	20.00	2.0 – 20.6
Spring Maize	07	March 02 -15, 2011	20.00	4.75 - 9.25

Green gram in rice-wheat system

Cowpea crop sown in the farmer's field

Bill & Melinda Gates Foundation Team and CIMMYT Scientists visiting cowpea fields on 15th April 2010

Cultivation of Spring Maize: The spring maize was also introduced in south Bihar. No tillage operation was done. Sowing was done by *khurpi* (scud). The yield was recorded in the range of 4.75 to 9.25 t/ha (Table 28).

Spring maize cultivation in south Bihar

Sugarcane with vegetables

Vegetables are grown in early sugarcane fields which fetch good price to the farmers through the sale of vegetables.

Sugarcane with vegetables

Comparative Studies of RCT Methods on Yield, Saving in Cost of Cultivation and Net Benefit

The comparative studies of different RCT methods are presented in Table 29. From the perusal of the table, it can be inferred that potato on raised bed through RCTs gave the maximum benefit, followed by wheat establishment in the presence of residue of rice crop after ZTDSR with traffic control. Other RCT practices have edge in profit over conventional methods. Evaluation of cropping system in south Bihar is presented in Table 30.

Rice-Maize Cropping System through RCTs

Maize cultivation is dominent in north Bihar, but is being introduced in south Bihar and other parts of EIGP. The agro-climatic condition of EIGP during winters is more favorable for maize than wheat. Winter maize is, therefore, gaining popularity in this region due to sustainable high yields, less insect pest infestation and assured marketing. High soil moisture, warm climate and customary intensive tillage after rice harvest delays wheat sowing thereby affecting wheat yields

Punch Planter

Table 29. Effect of crop establishment methods on yield of rabi crops

Technology / Method of crop establishment	Sowing period	Grain yield range (t/ha)	Mean grain yield t/ha (₹/ha)	Saving in crop establishment	Yield gain over control (t/ha)	Gross benefit (₹/ha)
Sowing by Rotary disk drill for wheat establishment in presence of residues of rice cropafter ZTDSR with traffic control (08 sites) Var.- HD-2285, PBW-343	04.12.05 to 15.12.05	3.01 – 4.18	3.59	1,480	1.35	10,958
Double Zero till practice for wheat establishment (07 sites) Var.- HD-2733, PBW-343,PBW 373	06.12.05 to 21.12.05	2.75 – 3.96	3.34	1,560	1.10	9,288
Paired row wheat sowing after ZTDSR(35 sites) Var.- HD-2733, PBW-343, Lok -1, UP-262	03.12.05 to 30.12.05	2.29 – 4.01	3.15	1,560	0.92	8,000
Equal row wheat sowing after ZTDSR(54 sites) Var.- PBW 343, DS 2285, UP 262, HUW 234, Lok–1, HD 2733	30.11.05 to 05.01.06	1.84 – 4.32	3.08	1,560	0.84	7,468
Surface seeded Wheat with balance NPK after conven-tional rice(10 sites) Var.- UP-262, Lok-1, PBW-343, HD 2733	23.11.05 to 22.12.05	2.09 – 3.31	2.71	3,300	0.47	6,583
Conventional wheat after conventional rice (control) (07 sites) Var.- UP-262, PBW 154, Lok-1, PBW-343 PBW 373	11.12.05 to 01.01.06	2.04 – 2.43	2.23	-	-	-
Potato on raised bed through RCTs (07 sites) Var.- KufriAshoka	15.10.05 to 20.10.05	19.2 – 28.5	23.1	26,490	7.29	73,875
Maize on raised bed through RCTs(07 sites) Var.- S3(QPM)	28.11.05 to 29.11.05	2.66 – 4.06	3.36	1,975	0.92	7,495
Crop intensification through Green gram (Moong) in Double Zero till field (06 sites) Var.- Vishal	18.04.06 to 28.04.06	0.75 – 0.97	0.86	700	0.16	3,100

Table 30. Evaluation of cropping systems in south Bihar

Cropping system	Varieties	Mean economic yield of different crops (t/ha)	Wheat equivalent yield (t/ha)	Net return (₹/ha)	Increase in net return over control (%)
DSR - Potato + Maize	Rajendra 1-K. Ashoka +SM 1	5.00 – 23.86 – 3.22	4.03–23.09 + 2.68	1,12,377	731
Transplanted Rice - Potato + Maize	MTU 7029 - K. Ashoka + SM 1	3.25–23.86 + 3.22	2.62 – 23.09 + 2.68	1,00,387	642
DSR - Wheat - Moong	R 1-PBW 343-Vishal	5.00 – 3.02 – 0.85	4.03–3.02–2.05	37,271	176
DSR - Wheat (ZT)	R 1-PBW 343	5.00–3.02	4.03 – 3.02	29,998	122
DSR - Wheat (Conventional)	R 1-Lok 1	5.00 – 0.60	4.03 – 0.60	13,736	2
Transplanted Rice-Wheat (Control)	MTU 7029-Lok 1	3.25 – 2.50	2.62 – 2.50	13,526	-

due to terminal heat stress at grain filling stage. Higher relative humidity coupled with relatively warm atmosphere makes wheat more susceptible to foliar diseases and, therefore, average wheat productivity in EIGP is much lower than the national average. It provides scope for maize cultivation during winters in South Bihar. Maize being C_4 crop exhibits many desirable agronomic traits, high photosynthesis rate, faster growth and high water and input use efficiency. Rice- maize system is, therefore, emerging as one of the important cropping systems in Bihar

Zero till maize: Multi-crop ZT fertilizer cum seed drill with inclined plate seed metering can be used to plant maize. Row to row distance (60-65 cm) can be fixed by adjusting tynes. Plant to plant distance and seeding depth is kept same as in bed planting. Punch planter can also be used to plant maize in ZT situations

Bed planting: Beds are prepared at 67 cm width (37 cm ridge and 30 cm furrow) with the help of bed planter. Bed planter with inclined plate seed metering system can precisely place the maize seed at required depth (3-4cm). On permanent beds, punch planter can be used to plant maize. One line of maize on each bed is desirable when sole crop of maize is planted keeping seed to seed spacing of 20 cm. Plant density of 75,000-87,500 nos./ha is generally maintained for potentials hybrids. The rice-maize productivity under different establishment system is presented in Table 31.

Rating of Different Technologies with Respect to Conventional Technique

Rating of different cultivation technologies namely, ZT wheat, ZTDSR, bed planting, surface seeding, leaf colour chart, brown manuring etc. were done on the basis of farmers' opinion (Table 32). The benefit achieved by the farmers due to different RCTs is stated below. The direct benefits to the farmers are from cost savings in

Dr. Olaf Erenstein, Agro-Economist, CIMMYT-India is discussing with scientists and farmers the rating of different technologies

cultivation through savings in tillage, seeds, labour, time, energy and improved use efficiency. It reduces the degradation of natural resources and improves the soil health, biological activities and sustainability through efficient use of nutrients and water.

Table 31. Effect of tillage/establishment techniques on productivity of rice-maize system

Tillage/establishment options		Yield (t/ha)		
Rice	Maize	Rice	Maize	Rice-Maize System
Conventional Till	Conventional Till	5.63	3.04	8.67
Zero-till	Zero Till	5.02	5.11	10.13
Permanent Beds	Permanent Beds	3.81	5.29	9.10
Permanent Beds + Residues	Permanent Beds + Residues	4.04	6.21	10.25

Source: Singh *et al.*, 2010

Table 32. Farmers' opinion on different technologies

ZT Wheat	Bed planting wheat	Surface seeded wheat	Direct seeded rice (Zero tillage)	Leaf color chart (LCC based N management)	Green/brown manuring (*Sesbania* co-culture)	Potato-maize inter crop
Labour saving	Water saving	Low cost	Low cost	Less cost of fertilizers	Less cost of fertilizers	Less Rotting of tuber
Cost reduction	Less weed infestation	Less labour requirement	Less labour requirement	Less lodging	Increase in yield	Two crops in place of one
Water saving	More	Suitable for low land	More	Less pest attack	Less weed infestation	Less water needed

Livelihood Improvement

Evaluation and acceleration of RCTs and alternate livelihoods support systems through new institutional arrangements was found to improve various livelihoods indicators as described below:

Livelihood indicators/capitals	Small farmers/ land owners/share croppers
Financial	Resource saving in operation cost, irrigation and plant protection. More income due to resource saving
Human	Capacity building around new knowledge on seed treatment and RCTs. Better understanding of working around new crop management practices.
Natural	Water saving, improved physical and chemical properties of soil, reduced pest incidence, organic matter build up, use of residue for cultivation
Physical	Better institutional arrangement through new service delivery system on new practices.
Social	Reduced conflict in water management and increased social interaction

Mr. Bill Gates and Melinda Gates are discussing with scientists and RCTs' farmers at ICAR-RCER, Patna

Problem faced by farmers

There are few problems in adopting RCTS (Table 33). Farmers are discouraged for bed planting because of higher cost of the machines and availability of *sesbania* seed was the problem. In the use of LCC, they have to visit frequently to the field for taking observations and they are reluctant to adopt this practice.

Table 33. Farmers' opinion about problems of RCTs.

ZT Wheat	Bed planting wheat	Surface seeded wheat	Direct seeded rice (Zero tillage)	Leaf color Leaf color (LCC based N management)	Green/ brown manuring (*Sesbania* co-culture)	Potato maize inter crop
Presence of moisture	More time taking in land preparation	More pest problem	More weed infestation	Frequent visits to field	Seed availability	Suitable to uplands only
Timely non-availability of machine	High Cost of the machine	Less yield	Dependent on weather	-	-	Non-availability of bed planter
--	--	--	Not suitable to uplands	-	-	-

Service Providers

Different service providers were selected and trained at ICAR-RCER, Patna and sent to different organizations through traveling workshops for their exposure to RCTs. Their activities have been continuously monitored and few third generation RCT machines have also been provided.

Dignitaries discussing with the service providers

For diffusion of project impact and up-scaling of technologies, activities were taken with the help of service providers, SHG members, unemployed landless rural youths, marginal and progressive farmers, share croppers and interest groups on different aspects of RCTs. The service providers are the best ambassador for up-scaling resource conserving technologies in EIGB.

Training and Availability of Machines and Spare Parts

ICAR-RCER is extending regular technical support through training for repair of zero tillage machines at the institute workshop. By now, spare parts are also available in few shops of Patna, Begusarai and Samastipur. Hence, repair of the ZT machines is possible locally.

Training to the farmers and service providers being imparted at Institute level

Subsidy by State Government

Recently, Govt. of Bihar has taken a decision in favour of farmers to purchase RCT machines on subsidy, so that larger area could be brought under CA. Government has declared the following subsidy for the year 2011-12 (vide O.O. no. IPRD-6614 S (Agri) 11-12 Table 34).

Table 34. List of RCT equipments and rate of subsidy by Government of Bihar

Equipment	Per unit subsidy (₹)	Total physical target (no.) for 2011-12
Laser Land leveler	50% or Max. ₹ 2,50,000	104
Raised Bed Planter	80% or Max. ₹ 40,000	293
Zero Tillage Drill	80% or Max. ₹ 40,000	620
Happy Seeder	80% or Max. ₹ 40,000	200
Multi Crop Planter	80% or Max. ₹ 40,000	112
Paddy Transplanter	50% or Max. ₹ 80,000	151
Dibbler	50% or Max. ₹ 2,000	11968
Potato Planter	50% or Max. ₹ 30,000	270
Potato Digger	50% or Max. ₹ 30,000	268
Power Weeder	50% or Max. ₹ 30,000	89
Reaper	50% or Max. ₹ 80,000	965
Maize Sheller	50% or Max. ₹ 4,000	397
Combined Harvester	50% or Max. ₹ 5,00,000	125
Seed Treating Drum	50% or Max. ₹ 1,600	980

Crop and resource Management Practices for Sustainable Future Cereal based Systems

Two projects on Cereal System Initiative for South Asia (CSISA), sponsored by Bill & Melinda Gates Foundation and USAID, were started as Platform Research and Delivery & Rolling out CA based RCTs at the institute since June 2009. CSISA objective 1 on Delivery and rolling out conservation agriculture is being conducted through farmers' participatory trials and adaptive trials on farmers' fields in Patna.

Dr. A.K. Singh, DDG (NRM) visiting CSISA Research Platform along with Dr. B.P. Bhatt, Director & Scientists of ICAR-RCER, Patna & IRRI.

The objective 2 of CSISA project is on Platform Research, which is conducted at the research farm of ICAR-RCER, Patna for strategic experimental research for future cereal systems with focus on RW system, its intensification and future diversification for high cereal production with sustainable natural resource management.

Technical Programme/activities include (i) Participatory adaptation of new crop and resource management technologies for CA system, (ii) New generation of resource-efficient, high-yielding cereal systems, and (iii) Operation in technology delivery hubs and other selected areas and interactions with breeding programs.

Four scenarios of cropping with different residue management have been developed as shown in Table 35.

Among the different scenarios, grain yield of wheat during 2009-10 under CA (Scenario 3: zero tillage and keeping one third residue of the previous crop rice) was 40 per cent higher than conventional practice by farmers (Scenario 1) (Fig 7). The conventional practice was determined by benchmark survey of

Fig. 7. Wheat grain yield (t/ha) during 2009-10 in different scenarios
Source: Annual Report 2010-11, ICAR-RCER, Patna

Table 35. Crop production scenarios and management practices

Scenarios	Drivers of change	Crop rotations	Crop management (CM)	Tillage systems	Residue management	Crop health	Nutrient management
1	Business as usual	Rice-wheat (current)	Farmers practice	CT-CT	Removal	As usual	As usual
2	Increasing food demand	Rice-wheat-mungbean	Best Available	CT-ZT-CT	Anchored-removal-in-corporation	Best Available	Best Available
3	Increasing food demand, Degrading natural resources, energy and labor crises	Rice-wheat-Mungbean	Conservation Agriculture	ZT-ZT-ZT	Retention anchored retention	Best management	SSNM Based
4	Food and nutritional security, Intensification and Diversification, farmprofitability	Rice-Potato +Maize-Mungbean	Best practice	ZT-CT-ZT	Retention-anchored-retention	Best management	SSNM Based

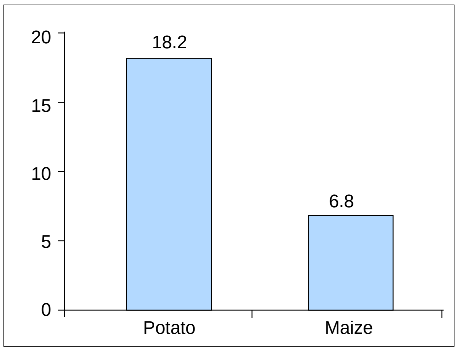
Source: Annual Report 2010-11, ICAR-RCER, Patna

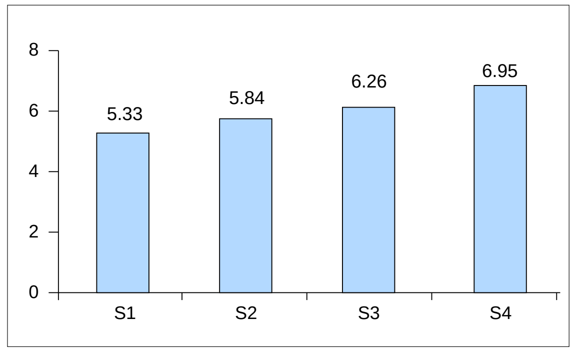
30 farmers in the vicinity of the experimental area within 25-30 km. Higher grain yield was also reflected in higher yield attributing characteristics of wheat in scenario 3. Under future cereal system (Scenario 4), potato and maize intercropping was considered for intensification and diversification (Fig. 8). In these plots, 18.2 t/ha of potato and 6.8 t/ha of maize yield was obtained. The cost of different components for wheat production was calculated and it was observed that net incomes were 233 and 444% higher in scenario 3 and 4, respectively, as compared to scenario 1. On average, conservation agriculture (Fig. 9) practice could save 17% irrigation water in comparison to conventional practice in scenario 1. One third crop residue of wheat was retained for cowpea and entire cowpea residue was recycled in rice in scenario 3 by zero tillage (Table 36).

The biomass of potato after harvesting of tubers was incorporated for earthing up of maize and one third maize residue was retained for rice-cowpea cultivation. Again cowpea residue was retained for rice in S4. Moongbean residue was incorporated for rice cultivation in S2. Thus 18.90 t/ha of crop residue was added/recycled in S4 and 8.09 t/ha in S3 as compared to 4.96 t/ha in S2.

Table 36. Amount of crop residue recycled in different scenarios

Scenario	Crop residue (t/ha) added in different scenarios			
	Rice in wheat/ potato +maize	Wheat in green gram/ cowpea	Green gram/ cowpea in rice	Total
S1	Removed	Removed	Fallow	-
S2	1.95	1.42	1.59	4.96
S3	2.09	2.80	3.20	8.09
S4	2.32	13.50	3.08	18.90





Source: Annual Report 2010-11, ICAR-RCER, Patna

Fig. 8. S4 (intensification and diversification): Potato and maize yields (t ha^{-1})

Fig. 9. Rice yield (t/ha) in different scenarios

Constraints and Challenges in Adopting RCTs

Proven benefits are achieved by the farmers through CA based RCTs. In spite of the benefits these practices are not being adopted by a wide range of farmers. The cost of equipments and herbicide often diminishes the attractiveness of CA adoption. In general, the following factors limit the adoption of RCTs:

- Availability of quality machines and spare parts,
- Most of the third generation resource conserving machines need more than 50 hp tractors,
- Custom hiring is not very common,
- Bullock ploughing is still in practice,
- Small resource poor farmer face constraints in adopting CA due to financial constraints,
- Service providers are lacking entrepreneurship,
- Availability of Govt. subsidy to resource poor farmers is difficult,
- Use of herbicides for weed control is costly and spurious materials are available in the market,

- Weed control in direct seeded rice is a deterrent for wider adoption of this technology,
- Attitude of the farmers in favour of puddled transplanted rice,
- Time available for ZTDSR is limited whereas puddled transplanted rice can be taken till the middle of August,
- Due to rain, sowing through ZT direct seeded rice in time is difficult,
- Since, farmers are using straw as animal feed and for other uses, retaining residues in crop fields is becoming difficult.
- Combine harvesters leave straw in the field and farmers are compelled to burn it due to non-availability of turbo seeder for sowing with residue,
- The mind set of farmers for intensive tillage,
- Small and fragmented land holdings ,
- Social conflicts,
- Non-availability of quality seed, and
- Release of canal water is unpredictable.

Other Researchable Issues

- Increasing the infiltration/percolation of water under continuous ZT, where no residue is retained in the fields due to manual harvesting (combine harvester is not used) especially in heavy soils of Bihar and in fragmented small holdings.
- Optimum moisture status of field under surface seeded wheat just after rice harvest for efficient use of applied fertilizer.
- Time of first irrigation in zero tilled wheat sown under excess soil moisture. Under normal condition, first irrigation is recommended at 15-16 days after sowing.
- How to optimize the RCTs in conjunction with deep summer ploughing for enhancing the water, land and nutrient efficiency, especially in the areas where residues are not retained.
- Detailed scientific study (using field experimentation supported with modeling) on water balance components under system of RCTs in eastern region.
- Long term implication of large scale adoption of RCTs on runoff and ground water recharge under different soil conditions. Research on water-use efficiency requires accurate measurement of water applied from the source to the field.
- Effect on soil, ground water and environment due to herbicide application in ZT rice/wheat for weed management.
- Effect of herbicide application on microbial populations and micro flora in soil environment.
- Scope of the frequency of deep tillage in long-term zero tilled adopted fields with manual harvesting (without residue) to enhance the water requirement, crop health and soil environment.
- There is a need to investigate alternate tillage operations (including zero and reduce tillage) for better root growth to achieve improved water and nutrient use efficiency and crop productivity through minimum energy expenditure.
- Quantification of integrated plant nutrient management, tillage and water interactions in the R-W cropping system.
- Indentification /development of suitable varieties suited for various tillage systems.
- Quantification of emission of GHG's (including N_2O, CH_4 and CO_2) under various production systems.

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