



Improving Resource Utilization Efficiency and Productivity in Rice-wheat Cropping System through Cutting Edge Technologies: An Overview

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Authors' contributions

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ABSTRACT

Rice-wheat cropping system is one of the major cropping system practiced in South Asia on 13.5 m hectares area, 10.3 million hectares of which are in the Indo-Gangetic Plains (IGP). The Indian Rice-Wheat Cropping System (RWCS) accounts for more than 70% of the country's total grain production which is essential for ensuring national food security. Widely used RCT known as Zero Tillage (ZT) in which wheat is directly sown into the undisturbed soil after rice harvested. The Adoption of Furrow Irrigated Raised Bed System (FIRBS) in wheat production saves 30-40% water, seed use by 25-30% and nutrients use by 25% without reducing yield. The RCTs involve residue management (mainly residue retention), crop diversification and no- or minimum tillage with direct

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seeding and bed planting. AWD in rice save water by 10 to 30% while reducing seepage and deep drainage losses and Brown manuring is highly beneficial for weed control, water and soil conservation and nutrient supplementation. The cultivation of aerobic rice is a new system of growing in non-flooded, non-puddled soils, with high external inputs using innovative technique of aerobic rice that require less water than transplanted rice. A simple and inexpensive diagnostic tool leaf colour chart can be used for monitoring the relative greenness as a measure of the plant N status. Thus, it can be concluded that RCT adoption improving soil health, water use efficiency and nutrient use efficiency with higher sustained yields which leads to sustainable improvements in RWCS. By saving on labour, time, diesel, fertilisers, pesticides, and farm power, resource conservation technologies lower the cost of farming and also lessen environmental pollution.

Keywords: Rice; wheat; zero tillage; LCC; RCTs.

1. INTRODUCTION

“There are four countries in the Indo-Gangetic Plains (IGP): India, Pakistan, Bangladesh and Nepal. These South Asian countries have a geographical area of 401.72 million hectares and they are hold nearly half of the world population of 3.1 billion people” [1]. “In South Asia, there are about 240 million people who consume rice or wheat produced in RW system” [2].

“RWCS occupies 26 million ha (M ha) of SE Asia to supply the food needs of rapidly expanding world population. Rice-wheat sequence systems provides livelihoods and food security for millions of people. In the Indo-Gangetic Plains (IGP) of South Asia, RWCS alone occupy 13.5 million hectares” [3], or about 32% of the total rice area and 42% of the total wheat area in four IGP countries. “In Indo-Gangetic Plains countries, it is covering around 12.3 m ha in India, 2.2 m ha in Pakistan, 0.8 m ha in Bangladesh and 0.5 m ha in Nepal, and about 85% of this region falling within the IGP” [1,4].

“The Indian RWCS is essential for national food security which accounts for more than 70% of total cereal production in India” [5]. The IGP region of India has RWCS spread over a vast area expanding from Punjab in the NW to East UP to West Bengal. The Indian states falling under this region, viz. U. P., Bihar, Punjab, Haryana, West Bengal and Himachal Pradesh are also the major rice and wheat growing states spread over the country. The area under rice-wheat cropping system in special Indian states is shown in Table 1.

The productivity and sustainability of the RWCS in the IGPs is threatened due to:

1. Resources scarcity, especially water and labour, and the resulting changes in land use.
2. Climate change.
3. The efficiency of current production practices.
4. Socio-economic changes.

Table 1. The area under rice-wheat cropping system in particular states in India

States	Area (million hectares)
Uttar Pradesh + Uttarakhand	4.52
Bihar + Jharkhand	1.93
Punjab	1.61
MP + Chhattisgarh	1.06
Haryana	0.46
West Bengal (WB)	0.27
Jammu & Kashmir	0.22
Assam	0.18
Himachal Pradesh (HP)	0.09
Orissa and Andhra Pradesh	0.04
Total	>10.5

Source: RWCCIMMYT [6] and Rice-Wheat Consortium (RWC) [7]

The agricultural production boom in this region has been able to keep up with the country's population demand for food for more than 30 years thanks to the adoption of green revolution technology, which caused yield growth and was followed by area expansion. This possibility is fast disappearing due to the limited potential for improving the availability of natural resources and arable land. The conservation of the resources of land and water for sustainability of agriculture within the Indo-Gangetic plains is the other issue. Resources conservation and production increase by adopting of new crop establishment techniques, changing management practices and inclusion of new crops in the rice-wheat system.

A decline in the productivity of land of the Rice-Wheat Cropping System (RWCS) has been observed over the past few years because of prolonged usage of cereal-cereal cropping system. Concerning issues include the depleting of groundwater, status of soil organic carbon, declining soil fertility and reduced factor productivity [8]. These evidences suggest that RWCS has damaged the sustainability of the natural resource base. By adopting Resource Conservation Technologies (RCTs) in RWCS, efforts must be targeted on reversing the trend in the degradation of natural resource in order to obtain sustainable higher productivity.

"The RWCS is source of employment, livelihood, and provides income for hundreds of millions of rural poor and urban poor of South Asia" [9]. It is the predominant cropping system in India as both rice and wheat are main staple food for the people of the country. It is water-intensive, labor-intensive, energy-intensive and capital-intensive, it has become less profitable as the availability of these resources diminished. This could be exacerbated by declining underground, lower land and water productivity, deteriorating soil structure which ultimately are threat in front of profit and sustain RWCS in the region.

Threat to sustainable food production has resulted because of ongoing adoption of an exhaustive RWCS. That allows you to deal with problems including increasing production prices, stagnant productivity, a receding water table, deteriorating resource quality and increasing environmental issues alternative technologies are the key factors. For sustaining and enhancing higher yields, there are many effective technologies that can be used in RW system.

As a part of this strategy, RCTs are a key role in increasing productivity, enhancing and sustaining the productivity of the RWCS while reducing production cost and to conserve natural resources.

"The RCTs bring many possible advantages including decreased energy use (electricity and fossil fuels) and water, reduced soil erosion, GHG emissions and degradation of natural resource base, as well as increased farm incomes and yields" [10].

The experts recommended using several RCTs for improving the profits, yield benefits to the farmers and promote sustainability. RCTs is anticipated to increased productivity, water use efficiency, nutrient use efficiency, saving costs of irrigation, labour input saving, energy saving, reduced losses from soil erosion, reduced pumping of groundwater and adoption of new crop rotations.

Various RCTs are being promoted in the rice-wheat belt of the IGPs are System of Rice Intensification (SRI), Leaf Color Chart (LCC), Direct-Seeded Rice (DSR), brown manuring, laser land-levelling, rice ratooning, site specific nutrient management, precision nutrient management, artificial intelligence by use of drone, Furrow Irrigated Raised Bed System (FIRBS), Zero Tillage (ZT), minimum tillage, System of Wheat Intensification (SWI), surface seeding, bed planting system, crop residue management etc. For these RCTs require a period of three to five years for significant impact on water and crop productivity [11]. "These RCTs provide a wide range of benefits including as improved yield, reduced costs of production, increased irrigation WUE, improved NUE, effective management of insect pests and reduced GHGs emissions" [11,12].

Continuous use of conventional agricultural methods like tillage and crop residue burning has exacerbated soil depletion and depleted the soil resource base, resulting in decreasing in crop productivity. Furthermore, effective resource management in agriculture is required due to growing fuel prices, fertiliser costs, and other input costs. In order to improve and sustain greater yields, this review of the literature focuses on a variety of practical, resource-saving, yet effective technologies that can be used in RW systems. However,, adopting conservation tillage techniques can significantly increase the systems productivity by using

improving SOC pools and it assist directly in building-up of soil organic carbon, labile organic carbon fractions and improving soil fertility, production of soil and sustainability in RW system.

The main causes of the declining yield trend and productivity plateauing of the RW system are the increasing exploitation of natural resource bases and changing climate conditions. Farmers on a broad scale embraced alternative tillage and crop establishment techniques that are based on conservation agriculture and are efficient and environmentally friendly. To simulate the special tillage and crop establishment, a few tools have been developed. The Info RCT, an excel based model integrating agronomic, biophysical, and socioeconomic information to establish input-output relationships related to water, fertilizer, biocide residue in soil, biocide uses and labor, GHG emissions and nitrogen fluxes in the RW system has been demonstrated for farmer participatory practices. According to the assessment showed that double no-till system enhanced the farmer's income, whereas raised-bed systems decreased it in comparison with the traditional system. The Info RCT simulated the water use, yield, biocide residue and net income fairly well. The model has the potential to provide assessments of various cultural practices below different scenarios of soil, climate and crop management on a local scale.

Sustainability of RWCS system has been questioned with declining underground water table [13,14], yield stagnation [4,15], soil degradation [16], unattended intervening periods [17-19] and atmospheric pollutants [20].

Although considerable debate is currently going on these topics, that these technologies are site-specific and before selecting any particular RCTs for a particular region, agro-climatic conditions and soil texture must be considered. Additionally, in the absence of specific information, the challenging for policymakers and planners find it difficult to make suitable policies for increased/popularization adoption of RCTs. A solitary method or RCT might not be powerful to solve the approaching trouble of producing more food grains with insufficient land and water availability.

Continuing adoption of exhaustive RWCS has resulted in declined factor productivity and hence poses a serious threat to produce sustainable food production. Issues with stagnant

productivity, deteriorating resource quality, increasing costs of production, lowering water table and increasing environmental challenges are the fundamental drivers to search for alternative technologies that could address a majority of these problems. This article focuses on various resource saving yet efficient technologies that can be adopted in RWCS for improve and sustain higher yields.

System of Rice Intensification (SRI): In order to solve the problem of rice cultivation in primarily acidic soils in Madagascar, an island nation off the southern coast of Africa, Father Henri de Laulanie, a Jesuit priest, developed the System of Rice Intensification (SRI) in close cooperation with farmers during the 1980s. This improved method of rice cultivation was created to increase productivity of rice for resource-poor producers. "Currently, system of rice intensification methods has been adopted in about 50 countries, including major rice-producing nations such as India, Philippines, China and the Vietnam" [21]. "SRI is a system of growing rice that involves principles that are at times radically different from traditional ways of growing rice. SRI is feasible and more labor-intensive than traditional techniques, but it requires less seeds, fertilizer, water, pesticide and production costs. SRI produce higher yields with less water and seeds" [21].

- 8-12 days old young seedlings are transplanted and 2 leaved seedlings of 8-12 days age in aman and of 15-18 days age in summer are planted.
- Seed required: 5-7 kg/hectare.
- Population: 16 hills m².
- SRI involves 1-2 seedlings transplantation of young seedlings.
- Weed infestation is more.
- Chemical and brown manuring is more effective.
- Benefits of SRI 47% Yield increase.

Direct Seeded Rice (DSR): Rice can be sown directly by seeding on dry or by wet sowing. Direct seeded rice is an alternative option to puddle transplanting rice to saving in labor, fuel, time and water. Which are given similar yield to puddled transplanted rice if weeds were controlled with judicious use of herbicides. Soil health is maintained or improved, and fertilizer and water use efficiencies are higher in direct seeded rice (saving of water 35-40%). Gangwar et al, [22] reported that relative equivalent yields (REY) of different cropping system in term of

Table 2. Effect of different establishment techniques on yield and yield attributes of rice crop

Treatments	Plant height (cm)	Productive 2 tillers / m	Panicle length (cm)	Number of grains / panicles	1000 grain wt.(g)	Paddy yield (t/ha)
Double Zero Tillage	136.1	219.0	27.93	96.50	23.17	4.80
Direct seeding Brown	126.6	231.7	25.23	72.67	22.17	3.36
Manuring	128.2	186.3	27.67	93.83	22.83	4.23
Bed planting	129.2	206.7	27.93	95.73	23.17	4.43
Conventional Planting	130.2	200.2	27.93	98.57	23.50	4.72
LSD at α : 0.05	2.782	26.65	0.9019	8.851	0.9676	0.2844

Source: Akhter et al. [25]

Table 3. Effect of laser land levelling and planting techniques on growth and yield of wheat

Treatment	Plant height at harvest (cm)		Productive –2 tillers m (No.)		Length of spike (cm)		Grains / spike (No.)		Grain yield –1 (t· ha)		Straw yield –1 (t· ha)	
	2002-2003	2003-2004	2002-2003	2003-2004	2002-2003	2003-2004	2002-2003	2003-2004	2002-2003	2003-2004	2002-2003	2003-2004
T1	99.9a	101.7a	311a	316a	9.9	10.15a	44.2a	46.43a	5.00a	5.19a	6.00a	6.23a
T2	87.9c	90.1b	282c	285b	9.7	9.90ab	41.4c	43.45b	4.60b	4.74b	5.30b	5.44b
T3	95.5b	97.5c	300b	305c	9.8	9.93ab	43.0b	45.07c	4.60b	4.78b	5.20b	5.41b
T4	87.4c	88.4d	264d	268d	9.6	9.73b	41.1c	43.35b	4.30b	4.42c	4.50c	4.60c
T5	76.1d	75.7e	231e	229e	9.1	8.93c	39.2d	38.82c	2.70c	2.64d	2.90d	2.88d
SE \pm	0.76	0.56	3.06	2.42	0.21	0.138	0.383	0.328	0.165	0.111	0.184	0.102

Source: Jat, et al. [27]

(T1) Precision Levelling with Raised Bed Planting (PLRB) with recommended amount of balanced nutrients such as NPK (120:26:50) kg/ha.

(T2) Traditional Levelling with Raised Beds (TLRB) with N120 + P26 + K50.

(T3) Precision Levelling with Flat Beds (PLFB) with N120 + P26 + K50.

(T4) Traditional Levelling with Flat bEds (TLFB) with N120 + P26 + K50.

(T5) Traditional Levelling with Flat Beds (TLFB) with o fertilizer application (N0 + P0 + K0)

system productivity are highest in drum seedling followed by direct- seedling under rice – wheat cropping system.

“The shortages of labor and water, and soil fertility issues are causing increasing interest in shifting from puddling and transplanting to DSR. Low wages and adequate availability of water favour transplanting, whereas, high wages and low water availability favour DSR. The recent shift from transplanting to DSR in Southeast Asian countries has been caused by labor shortages and rising wages. DSR can reduce the labor requirement by 50% compared with transplanting” [23]. “The DSR system provides incentives for saving water” [13]. “In Northwest India, about 35– 57% water savings have been reported in research experiments in DSR sown into unpuddled soils” [24]. Direct-seeded and transplanted rice grown on raised beds decreased water use by 12–60% when compared with flooded, transplanted rice in the IGP.

Akhter et al. [25] “at Shalimar, Srinagar reported that among the different stand establishment techniques double zero tillage technique attained the highest plant height (136.1 cm) over direct seeding of rice, brown manuring of rice, transplanting on beds and conventional transplanting. The productive tillers per unit area (m^2) were recorded highest in direct seeding ($231.7 m^2$) followed by double zero tillage and bed planting”. Panicle length (cm) were recorded highest in double zero tillage, beds planting and conventional planting (27.93 cm) which was at par with brown manuring and significantly higher over rest of the treatments. The number of grains/panicle and 1000 grain wt. (g) were recorded highest in conventional planting which was at par with double zero tillage, brown manuring and beds planting and significantly higher over rest of the treatments. Paddy yield (t/ha) were recorded highest in double zero tillage (4.80 t/ha) (Table 2).

Laser Land Levelling (LLL): A Laser land levelling levels dikes and dikes within the field and ensures even distribution of irrigation water covering more area in much less time. It is estimated that a significant amount of irrigation water can be saved by using the laser land levelling without any adverse impact on crop yield [26]. It is a precision land levelling, so known as laser land levelling. A field that has been leveled by an animal or tractor drawn leveler results in over irrigation, poor crop

growth, and uneven conveyance because of unevenness. The components of a laser land leveller are a laser (transmitter) source that delivers a parallel laser beam to a laser receiver mounted to a scraper bucket behind a tractor. A hydraulic jack in a control box moves the scraper bucket vertically to level the field. Through the employment of services, the use of laser-guided equipment for the levelling of surface-irrigated fields has become economically feasible and accessible even to farmers with lesser incomes. For surface-irrigated areas, a properly levelled surface with the required inclination according to the irrigation method is absolutely essential. Traditional farmers’ technique for levelling by means of eyesight, mainly on larger plots, aren’t accurate enough and unless water consumption, lead to extended irrigation times, and inefficient water use.

A field experiment was conducted by Jat, et al. [27] at Modipuram (U.P) to quantify the benefits of precision land levelling and crop establishment technique and it was observed that Precision Levelling with Raised Bed Planting (PLRB) with recommended amount of balanced nutrients such as $120 kg N ha^{-1}$; $26 kg P ha^{-1}$ and $50 kg K ha^{-1}$ ($N120 + P26 + K50$) gives higher plant height at harvest (cm), productive tillers m^{-2} (no.), length of spike (cm), grains/spike (no.), grain yield (t/ha) and straw yield (t/ha) than other treatments (Table 3).

Jat et al. [27] conducted a field experiment during 2002-2004 at Modipuram reported that “Grain yield of wheat varied significantly due to PLRB techniques and significantly higher yield levels of 5.0 and $5.19 t ha^{-1}$ was recorded under PLRB during yr. 1 and yr. 2, respectively compared to other treatments”. The increase in grain yield with PLRB was 8.0% and 8.7% during yr. 1 and yr. 2, respectively whereas the corresponding increase under flatbed planting was recorded at 6.5% and 7.5%. The yield under TLRB and PLFB did not varied significantly during both the years. The total irrigation water use was about 20% higher in yr. 1 than yr. 2. Raised bed planting helped in saving of 25% and 29% irrigation water during yr. 1 and yr. 2 compared to flat planting under precision land leveling. Whereas, the corresponding water saving under traditional leveling was recorded at 38% and 33% (Table 7). Jat et al. [27] also revealed that “the saving in irrigation water with raised bed planting technique was more under traditional leveling as in this technique water moves in furrows only. The water productivity of precision

Table 4. Effect of laser land leveling and planting techniques on yield of wheat

Treatment	Grain yield (t /ha)		Irrigation water use (m ³ ·ha ⁻¹)		Irrigation water productivity	
	02-03	03-04	02-03	03-04	02-03	03-04
PLRB with recommended Fertilizers (N120 + P26 + K50)						
TLRB with N120 + P26 + K50	5.00a	5.19a	2635d	2170a	1.90a	2.39a
PLFB with N120 + P26 + K50	4.60b	4.74b	3335c	2870b	1.38b	1.65b
TLFB with N120 + P26 + K50	4.60b	4.78b	3525b	3060c	1.31b	1.56c
TLFB with no fertilizer application (N0 + P0 + K0)	4.30b	4.42c	5270a	4309d	0.82c	1.03d
SE ±	2.70c	2.64d	5270a	4309d	0.51d	0.61e

Source: Jat et al. [27]

Means with the same letters are not significantly different at P = 0.05.

IWP: kg·grain·m⁻³ water

PLRB & PLFB: Precision Levelling with Raised Beds & Flat Beds

TLRB & TLFB: Traditional Levelling with Raised Beds & Flat Beds

leveling with raised beds was 31% and 35% higher yr. 1 and yr. 2, i.e., 1.90 (kg·grain·m⁻³ irrigation water) and 2.39 (kg·grain·m⁻³ irrigation water) respectively compared to precision leveling with flat sowing and the corresponding increase in WP under traditional leveling with raised beds over traditional leveling with flat planting was 40% and 37%” (Table 4).

“Despite the fact that laser land levelling has several benefits, its lack of widespread adoption by small- and medium-scale farmers is due to the high cost of the machinery. Furthermore, the equipment needs a skilled operator to set, adjust and regulate laser settings and operate the tractor. The equipment is restricted only to the regularly shaped fields and less efficient in small-sized and irregular fields” [11]. “With laser levelling, the unevenness of the field is reduced to about ±2 cm, resulting in better water application and better fertilizer efficiency, improved water productivity, reduced weed pressure and distribution efficiency. The Laser land levelling has capacity to save electricity by ~25%. Water savings of up to 68% have been reported in wheat and 50% in wheat” [28]. The losses of water by way of evaporation, percolation, and seepage can be reduced by using adopting this technology. It increases 2-3% area owing to fewer requirement of channels and bunds. It increases yields of transplanting and direct-seeded rice by 12% and 6% respectively and result in average water saving [29]. “The IWP for laser leveled rice fields was increased by means of ~39%, comparison with the

conventionally flooded field. Except, there was also a saving in operational time of farm machinery and increase in the net sown area because of the removal of channels and bunds after the use of the Laser land levelling uniform water distribution reduced weed infestation in rice fields, and thereby reducing ~13% herbicide cost than the farmers’ practice of weed management. The Laser land levelling technology has enormous potential for optimizing water use efficiency in rice without any yield loss” [11].

Leaf Colour Chart (LCC): “Leaf colour chart is a fairly indicator of the nitrogen status of plant. The Leaf Colour Chart (LCC) is a great eco-friendly cheap device within the hands of small farmers to about optimize N use, irrespective of the supply of N applied organic fertilizers, bio-fertilizers or chemical fertilizers. LCC is an easy to use and inexpensive diagnostic tool for tracking the relative greenness of a rice leaf as an indicator of the plant N status” [30]. Leaf N status of rice is closely associated with photosynthetic rate and biomass production. Nitrogen use can be optimized by using matching its supply to the crop demand as determined through change in the leaf chlorophyll content and leaf colour. Use of LCC is simple, straightforward, easy and reasonably-priced underneath all conditions. LCC has four green strips, with color ranging from yellow green to dark green. “The Leaf Colour Chart (LCC) developed by International Rice Research Institute (IRRI), Philippines can assist the

farmers due to the fact the leaf colour intensity relates to leaf nitrogen status in rice plant. It costs approximately US\$1 per piece. It's far being introduced to farmers via field researchers, private sector agencies and extension group of workers. The research suggest that nitrogen can be saved from 10 to 15 percent using the LCC” [31]. A field experiment was conducted by Singh and his co-workers during 2008. The results revealed that (T4) 30 kg N/ha at LCC < 3 (at 25 and 50 DAS) with 20 kg N/ha at 0 DAS recorded significantly more grain yield (t/ha) as compared to rest of treatments. “The N uptake (kg/ha) was recorded higher in (T4) 30 kg N/ha at LCC < 3 (at 25 and 50 DAS) with 20 kg N/ha at 0 DAS (127 kg/ha) which was at par with (T3) 120 kg N/ha at 0, 20, 40 and 60 DAS (124 kg/ha) and significantly higher over rest of the treatments. The RE (%) and AE (kg grain/kg N applied) was significantly higher in (T4) 30 kg N/ha at LCC < 3 (at 25 and 50 DAS) with 20 kg N/ha at 0 DAS (73.8%) and (28.9 kg grain/kg N applied) respectively” (Singh et al. 2008).

The way to use the LCC:

- Randomly pick at least 10 disease-free rice plants or hills in an area with uniform plant population.
- Choose the topmost completely expanded leaf from every hill or plant. Place the center part of the leaf on a chart and examine the leaf color with the color panels of the LCC. Do now not detach or ruin the
- leaf.
- Measure the leaf color under the shade of your body, due to the fact direct daylight affects leaf color readings. If viable, the

same person must take LCC readings at the identical time of the day whenever.

- Determine the average LCC reading for the chosen leaves.
- Use the LCC once every 7–10 days starting from the beginning of tillering (14 DAT).
- Continue this technique up to 5–10 days after panicle initiation.

Advantages:

- LCC saves almost 26% fertilizer N.
- Helps to synchronize N supply, crop demand and enhance N use efficiency.
- It was observed that 74 percent of the farmers obtained equal or higher yields.

Brown manuring: Dhaincha (*Sesbania aculeata*) is sown during mid-may for brown manuring purposes of green manuring. It is then incorporated 45 days after sowing before the rice crop is transplanted. However, the majority of rice farmers are not capable to increase the green manure crop due to a lack of irrigation water throughout the summer.

“Brown manuring is a new innovative modern approach where both rice and sesbania crops are seeded collectively. Sesbania is then knocked down by spraying 2, 4-D (0.5 kg ha⁻¹) at 25-30 days after sowing. It exerts smothering effect on weed species and is able of reducing weed population by means of nearly half without any adverse effect on rice yield. This practice can be followed in crops like sorghum, maize and pearl millet. In broad level crops like soyabean 2,4D can't be used but sesbania can be cut manually and spread as mulch between crop

Table 5. Effect of Leaf Colour Chart (LCC) based N management in direct -seeded rice

Treatment	Grain yield (t/ha)	N uptake (kg/ha)	RE (%)	AE (kg grain/ kg N applied)
(T1) Control	3.05	68	-	-
(T2) 80 kg N/ha at 0, 20, 40 and 60 DAS	4.63	111	53.8	19.8
(T3) 120 kg N/ha at 0, 20, 40 and 60 DAS	4.72	124	46.7	13.9
(T4) 30 kg N/ha at LCC < 3 (at 25 and 50 DAS) with 20 kg N/ha at 0 DAS	5.36	127	73.8	28.9
(T5) 30 kg N/ha at LCC < 4 (at 25 and 41 DAS) with 20 kg N/ha at 0 DAS	5.23	121	66.2	27.3
CD at 5%	0.39	12.1	2.7	5.2

rows for controlling weeds and conservation of nutrients and moisture. Use of 2, 4-D in addition enhances the weed suppressive impact as 2, 4-D is effective against broad leaf weeds and sedges. *Sesbania* grows rapidly and suppresses weed. *Sesbania* surface mulch decomposes very fast to supply N. As a legume, it also fixes atmospheric nitrogen into the soil but is of lesser significance because of shorter of growth duration. Brown manuring is extraordinarily beneficial for weed manage, soil and water conservation and nutrient supplementation. In direct seeded rice with brown manuring, zero till wheat + rice residue gives superior crop productiveness and water productiveness compared to transplanted rice-conventional wheat system" [32].

Rice ratooning: Ratoon cropping is the cultivation of the rice crop from the crop's regrowth after the harvest of crop or management for next crop cultivation from the regrowth of the stubbles. Rice ratooning is one practical method to increase production of rice per unit area and time. Rice ratooning is practiced in Karnataka, Assam, Andhra Pradesh, Tamil Nadu, Kerala, Bihar, Orissa, West Bengal and Uttar Pradesh. 15-20 days manual weeding with rack weeder.

Aerobic rice: "International Rice Research Institute (IRRI) developed the aerobic rice technology to address the water disaster hassle in tropical agriculture. In aerobic rice technology, rice is grown like an upland crop with adequate inputs and supplementary irrigation when rainfall is inadequate" [33]. Aerobic rice is a production system wherein we save water losses by reducing percolation, evaporation and seepage. Aerobic rice is a new production system in which specially developed, input response rice varieties with "aerobic adaptation" are grown in non-puddled, non-flooded, well-drained and aerobic soils below irrigation with high external inputs that require much less water than transplanted rice with a management system aiming at yield levels ranges of 4-6 t ha⁻¹. A no saturated soil is also referred to as an "aerobic soil".

"The new concept of aerobic rice may be an alternate strategy, which combines the characteristics of rice varieties adopted in irrigated with high response to inputs and upland with less water requirement. Numerous technologies have been developed to increase the water productivity and reduce water loss of the rice crop. They are alternate wetting and drying" [34,35], saturated soil culture [36], system

of rice intensification [21] and ground cover systems [37]. Aerobic rice is high yielding rice grown under non-flooded conditions in non-puddled and unsaturated (aerobic) soil. It is reported that these rice are responsive to tolerates (occasional) flooding and high inputs [38]. "Nitrogen is key input in nutrient management and its application determines the yield of aerobic rice. Successful aerobic rice systems will largely depend on adoption of integrated weed management. Direct weed management methods include physical, chemical and biological practices of weed control while indirect methods include weed prevention, crop rotation, land preparation, selection of cultivar, fertilizer management and irrigation. Both post-emergence herbicides and pre-emergence herbicides can be used in aerobic rice fields, and are effective if they are properly used" (Baltazar and De Datta, 1996). "Aerobic rice cultivation results in saving of 60% water and 80-85% lesser methane emission" [39].

Site Specific Nutrient Management (SSNM): The source of nutrient in rice plant is the soil, however supply of nutrients is generally inadequate to meet the nutrient requirements for high rice yields. In Northwest India, site-specific nutrient management of macronutrients increased yield of rice and wheat crop yields by 12% and 17% respectively and profitability by of 14% and 13%. The greater fertilizer use is eventually crucial to fill the gap between the crop's need for nutrients and the supply of available organic inputs. Increased nutrient uptake and NUE across a wide range of rice-growing areas with different climatic conditions have been linked with the effects of improved N management and balanced nutrition. According to Abdurachman [40], "the consequences of 45 rice trials carried out in several countries of South Asia, revealed that the use of SSNM, fertilizer N have been reduced i.e., via 10-20% at the experimental sites in China, Vietnam and Indonesia. In North Vietnam Red River Delta, Hanoi, the P requirement have been reduce by 20% and K requirement has been also reduced by 15%. Results suggest that further increases in yield can simplest be expected when farmers exploit the synergy that occurs when all aspects of crop, nutrient and pest management are improved simultaneously. Procedures to further dissemination must be associated with prevailing site-specific conditions".

Furrow Irrigated Raised Bed System (FIRBS): "Furrow Irrigated Raised Bed System (FIRBS)

involves planting of crop is done on raised beds while irrigation is applied in the adjoining furrows and this method can save a substantial quantity of irrigation water, fuel and other agricultural inputs. FIRBs involves preparation of a furrow of 45 cm and sowing of crop at a row spacing of 30 cm. This method has been evolved to save cash irrigation water in which raised beds are prepared to accommodate with 2 or 3 rows of wheat between two furrows. The irrigation is done only in furrows. For that reason, approximately half of the irrigation required may be saved by this approach without any loss to the productivity of wheat grain. This is also profitable, eco-friendly and sustainable. A machine has been developed to make raised bed and sowing of wheat simultaneously. This technique helps in economizing water required through the crop besides giving better germination. After it's a success stint in wheat production in IGP, evaluation of this method on rice production is recently going on at different parts of north-western IGP. FIRBs system reduces seed as well as nitrogen requirement by around 25%, brings down use of irrigation water by up to 40%" [41]. "A few forms of precision farming are attempted in this technology through placing the right quantities of seeds and fertilizer at the right place; the furrow between tor rows facilitates better aeration and photosynthesis is improved that ultimately results improved tillering. This FIRBs became very much advantageous within the wheat-sugarcane intercropping system for both the crops without hampering the time of sowing and yield of wheat. Adoption of FIRBSs of wheat saves 25-30% seed, 30-40% water and 25% nutrients without affecting the yield" [41].

Zero tillage: Indian Society of Agronomy (1996) was defined 'Zero Tillage', also known as 'No Tillage' as the extreme form of conservation tillage, in which the new crop is planted directly into the residue of the previous crop without any prior soil or seed bed preparation. This method is typically feasible when all weeds are eliminated using herbicides.

In this approach, there is no prior tillage (ploughing, harrowing, planking), yet there is some minor soil disturbance necessary to make a small slit for seeding. The traditional approaches of ploughing which include 3-4 tillage operations are absolutely skipped. As a result, manufacturing costs are decreased and crop planting is ensured on schedule. Zero tillage has been established as yield boosting, price saving, and environmentally friendly resource

conservation technologies and also to reduce soil disturbance, energy use and to increase profitability in the entire IGP (Indo-Gangetic Plains). In more than 1 million ha of land in the Indo-Gangetic Plains, zero tillage has successfully reduced the demand for water in rice-wheat cropping systems. In the Indo-Gangetic plains in India this technology has been found most successful and appropriate particularly for timely sowing of wheat after rice with numerous advantages over traditional method of seeding. Vincent and Quirke [42] argued that "the Indian economy would benefit about US\$1400 million over the subsequent 30 years from the adoption of zero tillage in Northwestern India's rice-weed system because of savings in herbicide and labor costs and higher yields of wheat". "The possible water savings through zero-tillage vary depending on the cropping system and climatic conditions. Other benefits of zero tillage include better soil quality, 75% fuel savings, and a higher degree of organic carbon. ZT can save US \$40–50/ha compared with CT" [43]. Studies reported that "typically zero tillage save irrigation water in the range of 20–35% in the wheat crop compared to Conventional Tillage (CT), reducing water usage by about 10 cm ha⁻¹, or approximately 1 million liters ha⁻¹" [44]. "Zero tillage typically improves soil quality in various dimensions, including soil organic carbon, soil structure, higher stability of soil aggregates, soil fertility and soil biological properties" [45]. Under zero-tillage, the mineralization of soil organic matter can be reduced to levels inferior to the input converting the soil into a carbon sink.

Minimum tillage / Reduced tillage: Reduced-till system combines the tillage done by a rotovator with seeding. Planting is done in a single pass. Reduced tilling and seeding may be carried out each via the 2-wheel and 4-wheel tractors. In this system the entire swath of soil is rotovated while in others some of the rotovator blades are removed and only a strip is cultivated and planted. Sustained production of food and agriculture in an agriculturally important country, like India, is a ought to for alleviating hunger and poverty, specifically in rural areas and for achieving assured livelihood security and equitable economic growth. The minimum or reduced tillage system reduces the possibilities of soil crusting and soil erosion because of much less soil disturbance. Minimum tillage is highly effective practice in soil and water conservation when in comparison with conventional tillage systems. Advanced infiltration and reduced

evaporation caused more water conservation consumptive use of water by wheat crop became highest under reduced tillage followed by zero tillage and conventional tillage. But the water use efficiency was highest under conventional tillage followed by zero and reduced tillage. There was not much difference in water use efficiency and water use under zero and conventional tillage. The direct drilling equipment including no-till drill, roto-till drill and strip-till drill for wheat after rice had been in comparison with conventional tillage sowing as practiced by farmers. The result showed that no-tillage drilling was the maximum time, energy and cost effective for 70%, 67% and 6% respectively over the conventional practice. Raised bed planting has proven saving of 55%, 42%, and 44% in time, energy and price of operation over conventional system on fresh beds. On permanent beds, these are 63%, 56% and 57%, respectively. Equipment that helps conserve and save inputs like expensive seeds, fertilisers, and timely harvest the crop to save from weather and pests are available in addition to tillage and water conservation tools and machinery. These tools and machinery include inclined plate planters, power weeders, high-capacity multi-crop threshers, grain combines, self-propelled rice and vegetable transplanters, and plastic mulch laying machines. By removing system restrictions, RT wheat has a number of benefits in rice-wheat systems, including earlier wheat planting, lower costs, and water conservation. The "cost saving effect" is mostly attributable to the significant decrease in tractor time and fuel required for wheat establishment and field preparation.

System of Wheat Intensification (SWI): The system of wheat intensification technology has strong potentiality for provide high wheat yield per drop of water and per kg of agricultural inputs (seed and fertilizer) as well as application of other SRI principle to wheat crop. SWI is feasible and can prove to a boon for marginal communities and poor in eastern IGP, where the average productivity is low. This method is more labor-intensive than traditional techniques, but it requires less water, seeds, fertilizer and pesticide. Sowing seeds at proper spacing, lower seed rates, hoeing for weed control, good water management in the crop field, a higher ratio of tillers to mother seedlings and increased number of effective tillers/hills are some of the modified methods used in SWI.

Surface Seeding: Surface seeding is the simplest zero-tillage practice being followed,

which involves placement of wheat seed on to a saturated soil surface without any soil or land disturbance.

This is a traditional farming method for legume, wheat and other crops in eastern India and Bangladesh. Wheat seed is broadcasted before (relay planting) or after the rice crop harvested. Mulching prevents the weed growth in surface seeded crops, keep the soil surface moist for long time and delays nitrogen application. Depending on the soil moisture, the treated seed (2.5 9 kg of Vitavax seed) can be sown either before or after the rice harvest. In Surface seeding no costly equipment required. Using of a drum or simple seeder for line sowing. Fine-textured soils are more suitable. Suitable for regions where preparation of land is very difficult.

Precautions:

- Correct soil moisture at seeding is essential for success.
- Inadequate moisture causes poor germination, and excessive moisture can cause seed rotting.
- Rice straw mulch applied after seeding promotes better germination

Bed planting system: The basic principle behind bed planting is basically sowing of wheat or other crops on ridges or beds rather than on flat surface and applying inputs, irrigation water is applied in furrows between the beds. In this approach, the land is prepared conventionally, furrows and raised bed are prepared using an either raised bed planting machine or with manually. Row crops commonly use this method, but not for small grain crops like rice and wheat. Bed planting in RWCS may be a approach for enhancing the yield and resource use efficiency.

"This technique also provides an opportunity for crop diversity through feasibility of inter- or relay-cropping as well as inclusion of different crops, thereby opening avenues for generating alternate sources of productivity growth through efficient resource use. This technique has increased significantly in the last ten years or so in the irrigated, high-yielding and wheat-growing region of NW Mexico" [46,47]. The Bed-planting system is widely adopted in the IGPs, proven to be an effective conservation technology. Akbar et al. [48] reported "about 10% saving of water for narrow-beds and a 36% for broad-beds compared to flat sowing, and 33% increase maize grain yield and 6% wheat grain yield".

Crop Residue Management in RWCS: The fraction of a crop or plant is left in the field after the harvesting can be used as crop residue for protection and enhancement of the soil. About 25% of N and P, 50% of S and 75% of K uptake by cereal crops they retain in crop residues, making them excellent nutrient sources. The crop residue, when chopped into pieces and spread over the field followed by incorporation or thorough mixing with the soil exhibits following key positive effects.

“Crop residue retention whether semi-permanent or permanent, on the dead mulch and soil, is essential for protection of soil’s physical properties from the sun, wind and rain as well as for feeding soil biota that take over the nutrient balance and tillage function. Incorporation of crop residues into soil increases crop production and improves soil fertility” [24]. Sharma et al. (1998) evaluated the “impact of crop residue management on productivity of RWCS. According to the study finding’s the incorporated crop residue of rice resulted highest grain yield by 4.47 (t/ha) over removed, but it remained at par with burnt residue 4.14 (t/ha)”. Incorporated crop residue of wheat gives highest grain yield 4.57 (t/ha) as compared to other treatments (Table 6).

The crop residue added plant nutrients and organic matter like 0.5-1.5% N, 0.2-1.0% P and 0.8-1.0% K [49]. “Application of 15-20 kg N

hectares⁻¹ as starter dose together with straw incorporation increases yields of wheat and rice comparison to either burning straw or its incorporation into the soil. Zero-tillage and crop planting avoids burning of straw about 10 tonnes/ha which lowers the release of 13–14 tonnes of CO₂” [50].

“The RCTs involving no-tillage or minimum-tillage with direct seeding and bed planting, innovations in residue control to keep avoid straw burning, and crop diversification” [51] “are being advocated as options to the traditional RW system for improving productivity and sustainability and these ability for improving soil quality, mainly through the accumulation of soil organic matter (SOM)” [52,53] (Barclay, 2006).

There is a need for larger scale to checking out of these innovative technologies for water, labour, and energy efficiency in farmers-controlled trails. Long-term field trials to investigate these efficiencies will be expensive, time-consuming and a number of the parameters which include nitrogen flux, biocide residue, and GHGs is difficult to measure, hence a modeling approach is preferred for the quantitative evaluation of RCTs [54-56]. RCTs are the methods, when observed consequences in energy saving, costs and also minimize the environmental pollution over the conventional methods [57,58].

Table 6. Impact of residue management of crop on the productivity of RWCS

Treatments	Grain yield (tonnes / hectares)		
	Rice	Wheat	Total
Removed	4.02	4.09	8.11
Burnt	4.14	4.14	8.24
Incorporated	4.47	4.57	9.04
CD (P=0.05)	0.44	0.40	0.487

Source: Sharma et al. (1998)

Table 7. Resource-conservation technologies for Rice and Wheat

Resource conservation technologies for Rice	Resource conservation technologies for Wheat
System of Rice Intensification (SRI)	Furrow-Irrigated Raised-Bed System (FIRBs)
Direct Seeded Rice (DSR)	Zero Tillage (ZT)
Laser Land Levelling (LLL)	Minimum Tillage / Reduced Tillage
Leaf Color Chart (LCC)	System of Wheat Intensification (SWI)
Brown Manuring	Surface Seeding
Rice Ratooning	Bed Planting System
Aerobic Rice	Crop Residue Management
Site Specific Nutrient Management (SSNM)	

2. CONCLUSION

The Adoption of various RCTs like System of Rice Intensification (SRI), Direct-Seeded Rice (DSR), Leaf Color Chart (LCC), brown manuring, laser land levelling, rice ratooning, aerobic rice, site-specific nutrient management, real time N management, precision nutrient management, artificial intelligence by use of drone, Furrow Irrigated Raised Bed System (FIRBS), Zero-Tillage (ZT), minimum tillage, system of Wheat Intensification (SWI), surface seeding, bed planting system, crop residue management etc. has significant impact in increasing rice-wheat productivity and leads to sustainable improvements in rice wheat cropping system by water use efficiency and nutrient use efficiency with higher yields and improving soil health. RCTs improves livelihoods of farmers and the efficiency of natural resources, all of which ultimate help in alleviating poverty. In addition, it reduces environmental pollution and also reduce the cultivation cost by saving of time, cost, energy, labour, fertilizers and pesticides.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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