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

ABSTRACT

Rice-wheat cropping system is one of the major agricultural production cropping system practiced on 13.5 m ha area in South Asia, out of which 10.3 m ha is in the Indo-Gangetic plains (IGP) of India. The rice-wheat cropping system (RWCS) of India is vital for national food security contributing more than 70% of total cereal production in India. Zero tillage (ZT) is a widely used RCT in which wheat is directly seeded in to the undisturbed soil after rice harvesting. Adoption of furrow irrigated raised bed system (FIRBS) of wheat saves 30-40% water, 25-30% seed and 25% nutrients without affecting the yield. The RCTs involving no- or minimum tillage with direct seeding and bed planting, residue management (mainly residue retention) and crop diversification. Alternative wetting and drying (AWD) in rice reduce seepage, deep drainage losses and save water by 10 to 30%. Brown manuring is highly beneficial for soil and water conservation, weed control and nutrient supplementation. Aerobic rice is a new system of growing rice in non-puddled, non-flooded, aerobic soils under irrigation with high external inputs that require less water than transplanted rice. Leaf Colour Chart is an easy-to-use and inexpensive diagnostic tool for monitoring the relative greenness of a rice leaf as an indicator of the plant N status. Thus, it can be concluded that adoption of RCTs leads to sustainable improvements in RWCS by improving soil health, nutrient and water use efficiency with higher sustained yields. Resource Conservation Technologies reduce cost of cultivation by saving in labour, diesel, time, fertilizers, pesticides and farm power and also reduce environmental pollution.

INTRODUCTION

The Rice-wheat cropping system (RWCS) is the world's major agricultural production systems in four Indo-Gangetic Plains (IGP) countries: India, Pakistan, Bangladesh and Nepal of South Asian countries with a geographical area of 401.72 million ha, hold nearly half of the world population of 3.1 billion **(Timsina and Connor, 2001).** Approximately 240 million people in South Asia consume rice or/and wheat produced in rice-wheat system **(Benites, 2001).** Rice-wheat cropping system (RWCS) occupies 26 million ha (M ha) of South and East Asia to meet the food demand of rapidly expanding human population. Rice-wheat sequence systems provides food security and livelihoods for millions of people. Rice-wheat cropping systems alone occupy 13.5 million hectares in the Indo-Gangetic Plains (IGP) of South Asia **(Gupta and Seth, 2007),** about 32% of the total rice area and 42% of the total wheat area in four Indo-Gangetic Plains (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 around

85 percent of this area falls in Indo-Gangetic plains (IGP) **(Ladha et al., 2003; Timsina & Connor 2001).** The rice-wheat cropping system (RWCS) of India is vital for national food security contributing more than 70% of total cereal production in India **(Singh and Kaur, 2012).** The Indo-Gangetic plains (IGP) region of India has rice-wheat cropping system (RWCS) spread over a vast area spanning from Punjab in the Northwest to East up to West Bengal. The states of India falling under this region, viz. Uttar Pradesh, Bihar, Punjab, Haryana, West Bengal and Himachal Pradesh, are also the major rice-wheat growing states spread over the country. Area under rice – wheat cropping system in special states in India is shown in Table:1.

The sustainability and productivity of the Rice-Wheat cropping system (RWCS) in the Indo-Gangetic Plains is threatened because of

1. the scarcity of resources, especially labour and water, and associated changes in land use;
2. climate change;
3. the efficiency of current production practices;
4. socio-economic changes.

Table 1: Area under rice – wheat cropping system in special states in India [Source: RWCCIMMYT, (2003) and Rice–Wheat Consortium (RWC), (2005).]

State	Area (m ha)
U.P & Uttarakhand	4.522
Bihar & Jharkhand	1.936
Punjab	1.614
MP + Chhattisgarh	1.064
Haryana	0.462
West Bengal	0.274
Jammu & Kashmir	0.228
Assam	0.183
Himachal Pradesh	0.093
Orissa and AP	0.042
Total	>10.5

All through the beyond 30 years, agricultural production boom in this location has been able to keep pace with population demand for food in the country specifically due to adoption of green revolution technologies inducing yield growth, followed by area expansion. But this possibility is ceasing very rapid due to limited scope for increasing the availability of natural sources and arable land. The other issue is the conservation of the fundamental resources of land and water for sustainability of agriculture within the Indo-Gangetic plains. Adoption or development of new crop establishment methods, changing management practices and inclusion of new crops in the rice-wheat system may be some very important ways of maintaining resource conservation and increasing productivity.

A decline in land productivity of Rice-Wheat cropping system (RWCS) has been observed over the last few years because of continued cereal-cereal cropping system. Depleting ground water, soil organic carbon status, decreasing soil fertility and reduced factor productivity are other issues of concern **(Prasad, 2005**). These evidences suggest that RWCS has weakened the natural resource base and its sustainability. To obtained sustainable higher productivity, efforts must be targeted on reversing the trend in natural resource degradation via adopting resource conservation technologies (RCTs) in Rice-Wheat cropping system (RCWS).

Rice-wheat (RW) cropping system is source of livelihood, employment and income for hundreds of millions of rural and urban poor of South Asia **(Ladha *et al.,* 2003).** It is the pre-dominant cropping system in India as both rice and wheat are main staple food for the people of the country. It is labor-intensive, water-intensive, capital-intensive and energy-intensive, and it has become less profitable as the availability of these resources diminished. This could be exacerbated by declining underground, lower land and water productivity, deterioration of soil structure which ultimately are threat in front of profitable and sustainable RWCS in the region. Threat to sustainable food production has resulted because of the continuing adoption of exhaustive rice-wheat cropping system. That allows you to deal with problems like increasing production costs, stagnant productivity, receding water table, declining resource quality and increasing environmental troubles alternative technologies are the fundamental drivers. For enhancing and sustaining higher yields there are various efficient technologies that can be followed in rice wheat system.

As a part of this strategy, resource conserving technologies (RCTs) play a major role in sustaining, increasing productivity, and enhancing the productivity of the rice-wheat cropping system at a reducing cost of production and to conserve natural resources.

The Resource conservation technologies (RCTs) bring many possible benefits including decreased energy use (fossil fuels and electricity) and water, decreased soil erosion, greenhouse gas (GHG) emissions and degradation of the natural resource base, increased farm incomes and yields, and reduced bondager shortages **(Pandey *et al.,* 2012).**

The scientists recommended the adoption of different resource conservation technologies (RCTs) for improving the profits, yield benefits to the farmers and sustainability. Resource conservation technologies (RCTs) is anticipated to increased productivity, increased water use efficiency, increased nutrient use efficiency, saving of irrigation costs, saving on labour input, saving of energy, reduced losses due to soil erosion, reduced pumping of groundwater and adoption of new crop rotations.

Various resource conservation technologies (RCTs) that are being promoted in the rice-wheat belt of the Indo-Gangetic Plains are system of rice intensification (SRI), direct seeded rice (DSR), leaf color chart (LCC), 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. These RCTs require a period of 3–5 years for significant effects on crop and water productivity **(Bhatt *et al.,* 2019).** These RCTs provide a wide range of advantages including improved yield, reduced production costs, increased irrigation WUE, improved nutrient use efficiency, efficient control of insect pests and reduced GHGs emissions **(Rehman *et al.,* 2015; Bhatt *et al.,* 2020).**

Furthermore, continuous use of conventional agricultural practices such as tillage and crop residue burning has exacerbated soil depletion and depleted the soil resource base, resulting in a reduction in crop production. Moreover, rising fuel, fertilizer, and other input charges necessitate efficient resource management in agriculture. This collected overview literature focuses on numerous useful resources saving yet efficient technologies that may be adopted in rice-wheat system for enhancing and sustaining higher yields. But, adoption of conservation tillage practices can significantly enhance the systems productivity by using improving SOC pools and it assist directly in building–up of soil organic carbon, labile organic carbon fractions and improve the fertility status of soil, production of soil and sustainability in RW system.

The excessive usage of natural resource bases and changing climate are main to the negative yield trend and plateauing of Rice-wheat (RW) system productivity. The conservation agriculture based efficient and environmentally friendly alternative tillage and crop establishment practices were adopted through farmers on large scale. A few tools have been advanced to simulate the special tillage and crop establishment. The Info RCT (Information on Use of Resource Conserving Technologies), a excel based model integrating agronomic, biophysical, and socioeconomic information to establish input-output relationships associated fertilizer, water, biocide uses and labor; biocide residue in soil; greenhouse gas (GHG) emissions; and Nitrogen (N) fluxes in the rice-wheat system has been demonstrated for farmer participatory practices. The assessment showed that double no-till system increased 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 potential to provide assessments of various cultural practices below different scenarios of climate, soil, and crop control on a local scale.

Sustainability of RWCS system has been questioned with declining underground water table **(Humphreys *et al.,* 2010; Hira *et al.,* 2004)**, yield stagnation **(Ladha *et al.,* 2003; Busari *et al.,* 2015)**, soil degradation **(Bhandari *et al.,* 2002)**, unattended intervening periods **(Bhatt and Kukal 2014a; Bhatt and Kukal 2015a, b**), and atmospheric pollutants **(Bijay *et al.,* 2008)**.

Although considerable debate is currently going on these issues, 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. Also, in the absence of specific information, the policymakers and planners find it difficult to make suitable policies for increased/popularization adoption of RCTs. A solitary method/RCT might not be powerful to solve the approaching trouble of producing more food grains with inadequate available land and water.

The continuing adoption of exhaustive rice-wheat cropping system has resulted in declined factor productivity and thus poses a serious threat to sustainable food production. Issues of stagnant productivity, declining resource quality, increasing production costs, receding water table and increasing environmental problems are the fundamental drivers to search for alternative technologies that could address a majority of these problems. This article focuses on different resource saving yet efficient technologies that can be adopted in rice-wheat cropping system for improving and sustaining higher yields.

System of Rice Intensification (SRI)

The principles of System of Rice Intensification (SRI) are an improved method of rice cultivation developed through participatory on-farm research by Father Henri de Laulanie, a Jesuit priest in close collaboration with farmers to overcome the problem of rice cultivation in predominantly acidic soils in Madagascar, an island nation off the southern coast of Africa during 1980s to improve rice productivity for resource-poor producers. At present, system of rice intensification methods has been adopted in almost 50 countries, including major rice-producing nations such as India, China, Philippines and the Vietnam **(Uphoff, 2002).** System of Rice Intensification is a system of growing rice that involves principles that are at times radically different from traditional ways of growing rice. System of rice intensification is feasible and more labor-intensive than traditional techniques, but it requires less seeds, water, fertilizer, pesticide and cost of production. SRI produce higher yields with less seeds and water. **(Stoop *et al.,* 2002**).

- Young seedlings are transplanted at 8-12 days old 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 m^{-2}
- SRI involves 1-2 seedlings transplantation of young seedlings with shallow depth 1-2 cm into soils that are not flooded.
- Weed infestation is more.
- Chemical and brown manuring is more effective.
- Benefits of SRI 47% Yield increase.

System of Rice Intensification practices enhance the rice plants growing conditions by:

1. Optimizing soil and water conditions
2. Reducing the recovery time seedlings need after transplanting
3. Reducing competition and crowding

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,* (2009)** reported that relative equivalent yields (REY) of different cropping system in term of 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. The DSR system provides incentives for saving water **(Humphreys *et al.,* 2010).** In Northwest India, about 35– 57% water savings have been reported in research experiments in DSR sown into unpuddled soils **(Singh *et al.,* 2002).** Direct-seeded and transplanted rice grown on raised beds decreased water use by 12–60% when compared with flooded, transplanted rice in the IGP.

Table 2: Effect of different Establishment Techniques on Yield and yield Attributes of Rice crop [Source: Akhter *et al.,* (2016)]

Treatments	Plant height (cm)	Productive tillers/m^2	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	126.6	231.7	25.23	72.67	22.17	3.36
Brown 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*

Akhter *et al.,* (2016) 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 dukes 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 **(Bhatt and Sharma 2010).** 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. Laser land leveller consists of a laser (transmitter) source which emits a parallel laser beam to a laser receiver attached to a scraper bucket behind a tractor and the vertical movement of scraper bucket is controlled by a hydraulic jack in a control box for levelling the field. The use of laser-guided equipment for the levelling of surface-irrigated fields has come to be economically possible and, through hiring services, come to accessible even to lower-earning farmers. 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.

Table 3: Effect of Laser Land Levelling and Planting Techniques on Growth and Yield of Wheat [Source: Jat, *et al.,* (2011)]

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 ±	*0.76*	*0.56*	*3.06*	*2.42*	*0.21*	*0.138*	*0.383*	*0.328*	*0.165*	*0.111*	*0.184*	*0.102*

(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)

A field experiment was conducted by Jat, *et al.,* (2011) 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)

Table 4: Effect of laser land leveling and planting techniques on yield of wheat [Source: Jat *et al*., (2011)]

Treatment	Grain yield (t /ha)		Irrigation water use ($m^3 \cdot ha^{-1}$)		Irrigation water productivity	
PLRB with recommended Fertilizers (N120 + P26 + K50)	02-03	03-04	02-03	03-04	02-03	03-04
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*

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

Jat *et al*., (2011) 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). The results 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 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 **(Bhatt *et al.,* 2020).** 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 **(Jat *et al.,* 2006).** 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 fever 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 **(Jat *et al.,* 2009).** 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 **(Bhatt *et al.,* 2020).**

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 **(Alam *et al.,* 2005).** 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$l 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 **(Sharma *et al.,* 2008).** 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)**

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*

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

Traditionally, in brown manuring dhaincha (Sesbania aculeata) is sown during mid-May for the purpose of green manuring and is incorporated 45 days after sowing before transplanting of rice crop. However, due to dearth of irrigation water during summer, majority of the rice farmers are not capable to increase the green manure crop.

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 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 **(Das *et al.,* 2013).**

Rice Ratooning

Ratoon cropping is defined as cultivation of the re-growth of rice crop from the stubbles after the harvest of crop or managed for next crop cultivation from the re-growth of the stubbles. Rice ratooning is one practical way to increase rice production per unit area and per unit time. Rice ratooning is practiced in Karnataka, Andhra Pradesh, Assam Bihar, Kerala, Orissa, Tamil Nadu, Uttar Pradesh and West Bengal. Manual weeding with rack weeder at 15-20 days.

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 **(Bouman 2001).** 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 **(Li 2001; Tabbal *et al.*, 2002),** saturated soil culture **(Borell *et al.,* 1997),** system of rice intensification **(Stoop et al. 2002)** and ground cover systems **(Lin *et al.,* 2002).** 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 **(Bouman and Tuong 2001).** 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 **(Pal *et al.,* 2012).**

Site specific nutrient management (SSNM)

Soil is the source of nutrient in rice plant but, supply of nutrients is generally inadequate to meet the nutrient requirements for high rice yields. Site specific nutrient management of macronutrients increased yields of rice and wheat crops by 12% and 17% and profitability by way of 14% and 13%, respectively, in Northwest India. The greater use of fertilizer is eventually crucial to fill the gap between the crop needs nutrients and available organic inputs. SSNM may be used anywhere fertilizers are applied. Increased nutrient uptake and N use efficiency across a wide range of rice-growing environments with various climatic situations have been relate with the effects of improved N management and balanced nutrition. **Abdulrachman (2002)** mentioned that the consequences of 45 trials carried out on rice in different countries of South Asia, found that with SSNM, fertilizer N have been reduced significantly i.e., via 10-20% at the experimental sites in China, Indonesia and Vietnam. Reduction in P requirement have been 20%; reduction in K requirement was also found in 15% Hanoi in the Red River Delta of North Vietnam. Results suggest that further increases in yield can simplest be expected when farmers exploit the synergy that occurs when all aspects of nutrient, crop, 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 %. 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 **(Jat *et al.,* 2012).**

Zero Tillage

Indian Society of Agronomy (1996) defined 'Zero Tillage', additionally in another way termed as 'No Tillage', as the extreme in conservation tillage, wherein, the new crop is planted within the residue of the previous crop without any prior soil tillage or seed bed preparation and is generally possible when all weeds are controlled by way of the usage of herbicides.

In this system, no preparatory tillage (ploughing, harrowing, planking) is performed and there are slight soil disturbances associated with creating a narrow slit for planting seeds. The traditional approaches of ploughing which include 3-4 tillage operations are absolutely skipped. Hence, cost of production is reduced and timely planting of crop is ensured. 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 (2002)** 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 **(Malik *et al.,* 2002).** 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 **(Mehla *et al.,* 2000).** 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 **(Chauhan *et al.,* 2002).** 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. Besides tillage and water conservation tools and machines, there are equipment which help to preserve and save inputs like costly seeds, fertilizers and timely harvest the crop to save from weather and pests. Some such equipment and machines are plastic mulch laying machine, inclined plate planter, self-propelled rice and vegetable transplanters, power weeders, high-capacity multi-crop threshers and grain combines. RT wheat has a number of advantages in rice wheat systems by alleviating system constraints: earlier wheat planting, reducing costs and saving water. The ‘cost saving effect’ primarily reflects the drastic reduction in tractor time and fuel for land preparation and wheat establishment.

System of Wheat Intensification (SWI)

The technology which has high potentiality to provide high wheat yield per drop of water and per kg of agricultural inputs (fertilizer, seed etc.) and application of other SRI principle to wheat crop, is known as system of wheat intensification. SWI is feasible and can prove to a boon for poor and marginal community eastern IGP, where average productivity is low. This method is more labor-intensive than traditional techniques, but it requires less seeds, water, pesticide and fertilizer. Modified practices adopted in SWI are lower seed rate, sowing of seeds at proper spacing, good control of water in the crop field, hoeing for weed control, higher ratio of tillers to mother seedlings and increased number of effective tillers/hills. Moisture availability in soil is required when the germinated seeds are sown @ 2 seeds hill^{-1}.

Surface Seeding

Surface seeding is the simplest zero-tillage system being followed which involves placement of wheat seed on to a saturated soil surface without any land or soil disturbance. Its simplest of all crop establishment options. This is a traditional farmer practice for wheat, legume and other crops in eastern India and Bangladesh. Wheat seed is either broadcasted before (relay planting) or after the harvest of the rice crop. Mulching of surface seeded crops deters weed growth; keep the soil surface moist for long and delaying nitrogen application. The treated seed (with Vitavax, 2.5 9 kg-l seed) can be sown before or after the rice harvest depending on the soil moisture. In Surface seeding no costly equipment is needed. The use of a drum or simple seeder for line sowing. Fine-textured soils are more suitable. Suitable for areas where land preparation is very difficult.

Precautions

- Key to success is correct soil moisture at seeding
- To little moisture results in poor germination and too much moisture can cause rotting of seeds
- Rice straw mulch after seeding ensures better germination

Bed Planting System:

The basic principle of bed planting is basically sowing of wheat or other crops on ridges or beds instead of on the flat surface and applying inputs, irrigation water is applied in furrows between the beds. In this system, the land is prepared conventionally and raised bed and furrows are prepared using a raised bed planting machine or manually. This is a common practice for row crops, but not for small grain crops such as wheat and rice. Bed planting in RWCS may be a technique for increasing the yield and improving 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 use of resource base. This practice has increased dramatically in the last decade or so in the irrigated, high-yielding and wheat-growing area of N-W Mexico **(Meisner *et al.,* 1992; Sayre and Moreno Ramos, 1997).** Bed-planting system is widely adopted in the IGPs, proved to be a successful conservation technology. **Akbar *et al.,* (2007)** reported about 10% water saving for narrow-beds and 36% for broad-beds compared to flat sowing, and 33% increased grain yield of maize and 6% of wheat. The reasons for adopting bed planting system:

1. Bed planting facilitates irrigation before seeding and thus provides an opportunity for weed control prior to planting.
2. Weeds can be controlled mechanically, between the beds, early in the crop cycle.
3. Herbicide dependence is reduced, and hand-weeding and roguing are easier.
4. Reduced seed rate and improved fertilizer efficiency.
5. Management of irrigation water is improved because reduced evaporation surface and efficiency in distribution.
6. Water savings compared to flat surfaces of 42% for transplanted rice and 26% for wheat.
7. Less lodging occurs.
8. Plant stands are better.
9. The aeration of the bed zone is better than with flat planting.
10. After wheat is harvested and straw is burnt, the beds are reshaped for planting the succeeding soybean crop. Burning can also be eliminated.
11. Yield increases, easiness in interculturing (RWC-CIMMYT 2003).

Crop Residue Management in Rice-Wheat Cropping System

The portion of a crop or plant left in the field after the harvest can be used as crop residue for protection and improvement of the soil. About 25% of N and P, 50% of S and 75% of K uptake by cereal crops are retained in crop residues, making them valuable nutrient sources. The crop residue, when chopped into pieces and spread over the field followed by incorporation or well mixing with the soil exhibits following main positive effects. Crop residue retention either semi-permanent or permanent on the dead mulch and soil, which play crucial role for protection of soil physical properties from sun, rain and wind and to feed soil biota that take over the nutrient balancing and tillage function. Incorporation of crop residues in to soil increases crop yield and improves soil fertility **(Singh *et al.,* 2001). Sharma *et al.,* (1998)** evaluated the effect of crop residue management on the productivity of rice-wheat cropping system. The results of study indicated that incorporated crop residue of rice resulted higher 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 higher grain yield 4.57 (t/ha) than other treatments (Table 6).

Table 6: Effect of crop residue management on the productivity of rice-wheat cropping system [Source: Sharma *et al.,* (1998)]

Treatment	**Grain yield (t/ha)**		
	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*

The crop residue added organic matter and plant nutrients like 0.5-1.5 %N, 0.2-1.0 % P and 0.8-1.0% K **(Mongkol and Anan 2006).** Application of 15 to 20 kg N ha-1 as starter dose with straw incorporation increases yields of wheat and rice compared to either burning of straw or its incorporation in the soil. Crop planting and zero-tillage avoids burning of straw of about 10 t/ha which reduces release of 13–14 tons of CO_2 **(Gupta *et al.,* 2004).**

The RCTs concerning no- or minimum-tillage with direct seeding, and bed planting, innovations in residue control to keep away from straw burning, and crop diversification **(Gupta and Sayre, 2007)** are being advocated as options to the conventional RW system for sustainability and improving productivity **(Sharma *et al.,* 2002; Barclay, 2006, Ladha *et al.,* 2009)** and ability for improving productivity and soil quality, mainly through soil organic matter (SOM) build-up.

There is a need for wider scale to checking out of these new technologies for labour, water and energy efficiency in farmers-controlled trails. Long-term field trials to study these efficiencies will be costly, time consuming and a number of the parameters which include biocide residue, nitrogen flux and greenhouse gases are difficult to measure, hence modeling method is desirable for quantitative assessment of RCTs. Resource conservation technologies (RCTs) are the practices, when observed consequences in saving of energy, price and also reduces the environmental pollutants over the conventional practices.

Table 7: Resource-conservation technologies (RCTs) for Rice and wheat

Resource-conservation technologies (RCTs) for Rice	**Resource-conservation technologies (RCTs) for Wheat**
System of Rice Intensification (SRI)	Furrow Irrigated Raised Bed System (FIRBs)
Direct Seeded Rice (DSR)	Zero Tillage
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	

Conclusion

The Adoption of various resource conservation technologies (RCTs) such as 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 nitrogen 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 RWCS by nutrient and water use efficiency with higher sustained yields and improving soil health. Resource conservation technologies (RCTs) improves livelihoods of farmers and the efficiency of natural resources, all of which ultimately help in alleviating poverty. In addition, it reduces environmental pollution and also reduce cost of cultivation by saving of cost, time, energy, labour, pesticides, fertilizers and farm power.

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