# Rice (*Oryza sativa* L.)–Wheat (*Triticum aestivum* L.) Cropping System in Response to Conservation Tillage and Residue Management

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**Abstract**

This paper provides a comprehensive review of literature related to introduction of conservation agriculture practices and their consequences on Rice-Wheat cropping system's (RWCS) productivity. This system of cultivation is feeding almost the whole world. However, challenges farmers are facing in conventional system are increased cost of production, energy and labor scarcity, loss of soil fertility, irregular weather events, loss of water quality, decreased farm income and degraded soil profile are of considerable importance. These problems are being addressed through conservation tillage system. Conservation tillage and residue retention practices assist reclamation of degraded soil, less cost of production, labor and energy efficient system, conserve water resources, manage weeds and allows timely planting of subsequent crop thus enhance yield of rice-wheat cropping system which ultimately boost revenue and food security while bolstering the natural resources.

**Keywords:** conservation tillage (CT), residue management (RM), burning of residues, surface reservation of crop residue, residue incorporation, RWCS, Indo Gangetic Plains (IGP)

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## 1. Introduction

Major food source for the whole world is Rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.). Rice belongs to grass family and about half of the world's population feed on it. It contains

high nutritious significance as it provides 21% energy per capita and 15% per capita protein. Global production of rice is 496 million metric tons (2019-2020). China is the leading producer of rice where its cultivation takes place on an area of 10 million ha (Sharma and Bhushan, 2001). Other regions are India, Bangladesh, Pakistan, Indonesia and Nepal.
Wheat also belongs to grass family, a worldwide staple food which is cultivated for its seed called grain. One fifth of a fully grown individual's daily calorie requirement is fulfilled by wheat. According to Isitor et al., 1990; Langer and Hill, 1991; Olabanji et al., 2004, it is an immensely grown cereal crop covering 237 m ha area and yielding 420 MMT annually.
Rice and wheat crop rotation system is the oldest and leading cropping system worldwide. In IGP of South Asia it covers a cultivation land of 13.5 m ha (Gupta and Seth, 2007) which is providing food to 20% population of world (Chauhan et al., 2012). So, it is imperatively important for food security, rural development, income generation, employment and livelihood for millions of people (Gupta et al., 2003; Ladha et al., 2003). Although rice-wheat is the oldest and most common cropping system worldwide, meanwhile, current conventional farming system (CFS) is deteriorating the natural resources of soil and water. Frequent puddling over the years in rice under wet conditions has two major issues with physiochemical properties of soil under RWCS which is degradation of soil structure and exhaustion of soil carbon status and aggregation of subsurface soil layer. The structural degradation through puddle-transplanting of rice has serious consequence to the following crop of wheat (Kukal and Aggarwal 2003). This accompanied with loss in soil carbon (Singh et al. 2014, Mondal et al. 2016) cause worsening impact on soil physical condition. Moreover, sub-surface soil compaction is of foremost concern in rice-wheat system in IGP (Aggarwal et al., 2006; Kumar et al., 2014) and elsewhere. The capacity of this system is declining (Bajpai and Tripathi, 2000), the main cause of this stagnation is puddle rice (Mohanty et al., 2006). Puddling causes soil particles compaction, low bulk density and decreased porosity so it is not encouraging for flourishing subsequent wheat crop (Bajpai and Tripathi, 2000). Moreover, deeply tilled soil is also linked with condensed root mass in the next crop (Pagliai et al., 2004). Puddling and compacted root density also decreases the nitrogen use efficiency by the crop.
To mitigate the problems prevailing in conventional RWCS, conservation tillage is a marvelous alternative which is water, labor and capital and energy exhaustive system. Moreover, soil health is being deteriorated with the passage of time because of the repeated ploughing of field in wet condition (puddle rice) (Seema et al., 2019). Compared to conservation tillage system, conventional farming system delays the wheat crop which causes 8-9% yield reduction (Kumar and Ladha, 2011). While conservation tillage is energy effective, improves water productivity, reduce production cost, reduce erosion of all kinds and stabilizes the crop (Hobbs, 2007; Bhushan et al., 2007; Jat et al., 2009; Malik et al., 2014). Conservation tillage also enriches the soil organic matter, organic carbon content, increases microbial activity and improves overall soil health (Gathala et al., 2011b; Kienzler et al., 2012). Along with economic part of crops, residue is also generated which is not a waste until we waste it (Amit Anil Shahane and Y. A. shbir Singh

Shivay, 2016). The problem of residue management is of crucial importance due to trivial gap between rice reaping and wheat planting. Efficient utilization of residue for fruitful purpose is chiefly important in all major cereal growing areas.

This review is aimed at addressing that how the needs of the world and food security could be ensured by minimizing production cost, soil disturbance and conserving natural resources through conservation tillage and effective residue management system by amplifying the capacity of RWCS.

## 2. Conservation tillage-definition and concept

Conservation tillage as the main principle of the conservation agriculture is defined as:

Any tillage sequence, the objective of which is to minimize or reduce loss of soil and water; operationally, a combination of tillage and planting that leaves a 30% or greater cover of crop residue on the surface (SSSA, 2017).

### i. Merits of conservation tillage

- Reduces soil disturbance caused by traditional tillage
- Maintains soil cover
- Reduces wind, soil and water erosion (95%) significantly
- Minimize soil particles compaction
- Better water infiltration as compared to conventional tillage
- Enhances biological health of soil by accelerating microbial activity in top soil
- Increases soil organic carbon content
- Reduces production cost
- Energy effective system as it reduces fuel consumption by 3.5 gallons/acre in no-till practice
- Conserves soil moisture for next crop use by minimizing the evaporation as the soil is not tilled
- Enhances water productivity by increasing proportion of plant available water
- Reclaims degraded soil structure

### ii. Demerits of conservation tillage

- Conservation tillage requires intensive field account control compared to conventional methods
- Higher demands for management and crop production (crop variety selection, crop rotation, residue management etc.)

### iii. Techniques used for conservation tillage in RWCS

Conservation tillage methods include three main techniques viz., no-tillage, strip-tillage, and mulch-tillage. Each method requires equipment and management practices. In no-tillage system the crop is directly planted into previous crop residues without any tillage practice. While in strip-till, the crop is planted in narrow tilled strips while rest of the field is left undisturbed. In mulch-tillage conservation practice the topsoil remains covered with previous crop residue. Other techniques are minimum till, zero till, ridge till and chisel plow. Studies from India and China evaluated considerable water savings 20-90% when wheat straw was used as mulch in rice field (Shen and Yangchun 2003). Direct seeding of rice can be performed with happy seeder to attain possible benefits from wheat residue mulching (Gathala et al. 2013).

Equipment used for cultivation in conservation tillage are: seed furrow openers, coulters, row cleaners and seed covers, chisel plough, direct seeder, happy seeder, sub-soiler and rippers. Happy seeder implementation in rice-wheat cropping system can lead to wider options for residue management (Sidhuet al., 2007), as it can be used for direct drilling of seeds in loose as well as standing and makes their homogeneous dispersion throughout the field.

3. **Residue-definition and concept**

Any plant part remained after the separation of economic part of plant is called crop residue.

**Crop residue is divided into two categories:**

a. The left-over parts of crop in field after harvesting i.e. stalks and stubbles in case of cereals.
b. The material left after the processing of crop into useable forms i.e. husk or hull in case of cereals and bagasse and molasses in case of sugarcane.

Residue is also referred as 'economic product of second order due to its precious uses such as: energy generation, conservation, mulching, animal feed, carbon sources and sink and many others. Bearing in mind the efficiency of residue it is understood that agriculture does not only possess the capability of achieving food security through its main products i.e. grains, fruits and vegetables but it may also prove a solution to other issues like declining fertility, erosion and global warming through efficient cop residue management.

i. **Residue administration in RWCS**

Crop remnants i.e. (straw, stubbles) have various competing and valuable uses thus these should not be considered as waste (Lal, 2004). Suggested by Y. Singh and H. S. Sidhu, 2013, residue incorporation should be carefully performed to avoid any negative effects such as greenhouse gas emission, intrusion with planting of crops and N immobilization.

**On farm execution of crop residue can be obtained through four ways:**

a. Incorporation of residue
b. Retention of residue on surface
c. In-situ burning of residue
d. Removal of residue

I. **Incorporation of residue**

Depending upon the method of farming, crop residues incorporation might be complete or partial. The most effective method considered for residue incorporation is ploughing. Integration of rice residues in field before wheat sowing is troublesome due to low heat and short turnaround period between rice harvesting and wheat sowing (Mandal et al., 2004). Continuous incorporation of crop residues for two years in R-W and R-W-M cropping systems results in an increase of 30.2 and 37.5 t ha$^{-1}$ in total dry matter production of both cropping systems respectively after two years (Table 1) (Dawari et al., 2012). This incorporation of residue accounts for 188.9 kg ha$^{-1}$ N, 20.4 kg ha$^{-1}$ P and 445.5 kg ha$^{-1}$ K addition to the soil after two years which indicates the potential of crop residue to reclaim soil fertility and sustainability. Gupta et al., 2004, suggested that residue incorporation is considered to give best output in rice-wheat cropping system.

**Table 1: crop residue integration impacts on recycling of total dry matter accumulation, O.C, N, P, and K in R-W and R-W-M cropping systems (2007-08).**

| Cropping system | Dry matter (t ha$^{-1}$) | C (t ha$^{-1}$) | N (kg ha$^{-1}$) | P (kg ha$^{-1}$) | K (kg ha$^{-1}$) |
|---|---|---|---|---|---|
| **2006-07** | | | | | |
| **R-W-M system** | 17.8 | 7.1 | 114.9 | 12.4 | 228.7 |
| **R-W system** | 14.2 | 5.7 | 61.7 | 8.5 | 213.1 |
| **Mean** | 16.0 | 6.4 | 88.3 | 10.5 | 220.9 |
| **2007-08** | | | | | |
| **R-W-M system** | 19.7 | 8.0 | 128.2 | 14.0 | 233.0 |
| **R-W system** | 16.0 | 6.5 | 72.9 | 5.9 | 216.6 |
| **Mean** | 17.9 | 7.3 | 100.6 | 11.8 | 224.8 |
| **Mean of two-years** | | | | | |
| **R-W-M system** | 37.5 | 15.1 | 243.1 | 26.4 | 461.7 |
| **R-W system** | 30.2 | 12.2 | 143.6 | 14.4 | 429.7 |
| **Mean** | 33.9 | 13.7 | 188.9 | 20.4 | 445.7 |

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Amit Anil Shahane and Yashbir Singh Shivay, 2016.
O.C: organic carbon
R-W: Rice-Wheat
R-W-M: Rice-Wheat-Mung bean

The disadvantage of cereal crop straw incorporation is that it causes immobilization of inorganic nitrogen which results in N deficiency (Mandal et al., 2004). Incorporation of rice straw after harvesting slow down the decomposition and immobilization of soil nitrate and the outcome is N deficiency which adversely affects about 40% yield of the following wheat crop (Bacon, 1987; Sidhu and Beri, 1989). Proper fertilizer application practices can manage the N deficiency. Four rules should be considered while fertilization application viz.

a. Appropriate method of application
b. Right time of application
c. Right place
d. Rate of fertilizer used

## II. Surface retention of residue

It is another form of on farm residue management. This idea emerged with the concept of conservation agriculture. It is one of the important components of three components of conservation agriculture, viz., less disturbance to soil, surface retention of residue and crop rotation. Other name for residue retention is "crop residue mulching" (CRM) in zero tillage which is defined as:

"A technology by which at the time of crop emergence at least 30% of soil surface remain covered by organic residue of the previous crop."

Erenstein, 1999, said that crop residue mulching must not be confused with other mulching techniques as it constitutes of organic mulch from prior crop. This mulch possesses conservation and productivity effects. It conserves the soil and soil moisture by protecting from soil and water erosion and evaporation as it is present on the surface soil as protective layer. Conservation effect of residue retention also reduces soil erosion due to its enviable effect on soil physiochemical properties such as increased infiltration rate, decreasing bulk density, enhancing cation exchange capacity (Reddy et al., 2002) and reducing runoff (Nalatwadmath et al., 2006). In its productivity potential, first it tends to stabilize the mulch then occasionally enhance the crop yield (Erenstein, 2012). Properties such as increasing water infiltration and amount of water stable aggregate, decreasing bulk density (Reddy et al., 2002) and reducing runoff (Nalatwadmath et al., 2006). Crop residue also provides a favorable and readily available food source which enhances the activity of biota which ultimately results in better crop growth (Carsky et al., 1998).

**III. Burning of crop residue**

Burning of crop residue is primarily practiced in intensive cereal based cropping systems. In CT system, residue burning is usually adopted because there is less turnaround time after the harvesting of rice and before wheat planting. The other reasons are, field clearance, soil fertility augmentation, weeds/pests' control and other personal interests (Erenstein, 1999). Residue burning causes short term availability of P and K but reduces soil acidity and loss of N and S (Akobundu, 1987). Consequently, deleterious effects of residue burning on soil's natural profile are a warning for sustainability of RWCS in IGP (Abrol et al., 2000; Timsina and Connor, 2001).

## 4. Wheat straw mulching and management in rice

A joint study was conducted in India and china to estimate the effect of wheat straw mulching in rice. As a consequence, 20-90% water saving was observed as compared to conventional rice planting (puddle rice) (Shen and Yangchun, 2003). The management of residues should be vigilantly observed to assure irrefutable effects and avoiding negative results on crop and soil such as: N immobilization, greenhouse gases emission, and interference with planting crops. Most of the farmers in North West state of IGP assemble wheat crop remnants for their use after harvesting, leaving behind 20-25% (1.5-2.0 t $ha^{-1}$) of crop remnants which are latterly burned to prepare the land for rice crop. A common discernment of farmers is that stubbles of wheat will influence rice yield negatively. In this background Department of soil Science, PAU Ludhiana, conducted a field experiment for three years. It was suggested that partial crop residues integration does not pose any inauspicious effects on rice productivity instead favors positive impacts on soil and crop. Xuet al., 2009, reported 2.65% increased rice grain yield with wheat straw amalgamation in contrast to no mulching.

## 5. Rice straw mulching and management in Wheat

Burning of rice crop residues to prepare soil for wheat plantation causes severe soil, crop and ecological problems. To mitigate these issues in an effective way an emerging solution of crop residue management is the mulching of rice remnants by incorporating them manually or with combine harvester (BijaySinghet al., 2008; Sidhu et al., 2010). Conservational benefits to soil and increase in crop yield is gradually attained by surface maintenance of crop residues. In semiarid environments evaporation causes 50% of total soil water loss. By mulching practices evapotranspiration can be reduced by minimizing evaporative losses (Prihar et al., 2010). All above benefits are lost by wasting or using all crop residues as animal feed. However, sustainable crop production and soil fertility is possible by alternative crop residue management implementations viz., reservation of partial residues, growing forage crops (alfalfa, mung bean, Jantar) which can provide mulch and organic matter to the soil. Erenstein and Laxmi, 2008; Ladhaet al., 2009, reported that in RWCS, zero-till wheat plantation is being practiced on large vicinity having favorable impacts on crop yield, soil fertility and economic prosperity. Rice straw mulch increases water use efficiency (25%) as compared to no mulching. During 2007-10, data from several on-farm trials under different tillage practices from different districts of Punjab was collected which revealed that standard wheat productivity of plots treated with Happy seeder (HS) was significantly higher (3.24%) than the traditionally planted wheat (Table 2).

**Table 2: Effect of happy seeder used for wheat plantation in rice-wheat field (2007-2010).**

| Year | No. of experiments | Grain yield (t $ha^{-1}$) | | Increase in yield (%) |
|---|---|---|---|---|
| | | Happy Seeder (HS) | Conventional tillage (CT) over Conservational tillage (CT) | |
| **2007-08** | 46 | 4.59 | 4.50 | 2.0 |
| **2008-09** | 14 | 4.54 | 4.34 | 4.6 |
| **2009-10** | 94 | 4.42 | 4.30 | 2.8 |
| **Mean** | 154 | 4.56 | 4.42 | 3.24 |

6. **Influence of CT and residue management (RM) practices on RWCS**

Conservation tillage includes the retention of at least 30% surface retention of crop residues. Along with facilitating timely sowing of next crop, conservation tillage also influence the soil physiochemical properties as well as crop physiology and yield attributes. It also has positive effect on environment. Keeping in view its impacts on soil and crop conservation tillage is now being adopted in many areas of the world. Here are some impacts of conservation tillage on crop yield attributes of rice-wheat cropping system:

**i. Crop growth rate**

Conventional farming delays the planting of subsequent crop which negatively affects the crop growth rate and productivity. In IGP of South Asia a sequence of experimental approaches was carried out for the assessment of crop growth rate of rice and wheat under conservation and conventional tillage methods in RWCS, which depicts that conservation tillage has slow crop growth rate than conventional system during early years of experiments. Whereas, conservation tillage practices in RWCS demonstrate higher crop growth rate, biomass accumulation, availability of plant nutrients through improved soil nutrient status and organic carbon accumulation by decomposition of crop remnants during lateral years of experiments (Venkatesh et al., 2013). Higher biomass accumulation under conservation tillage system is associated with large number of tillers production and their individual growth (Jat et al., 2014). Similarly, the trend of crop growth rate for wheat crop was similar to the rice crop. In fact, line sowing of wheat by drill is the main reason of improved growth rate as compared to that of broadcasting in conventional tillage practices. Moreover, in zero-till conservation technique with residue retention on surface suppresses the weeds or delays their germination and allows crop establishment without any expected damage from weeds which ultimately enhances crop yield (Nath et al., 2015).

### ii. Wheat grain yield

Combination of field experiments conducted in different regions and sites show that conservation tillage and residue management practices have advantages over conventional tillage practices. According to a seven years study of Raj Kumar Jat et al., 2014, in IGP in which conservational techniques were compared with conventional ones. The conclusion of study revealed that yield is usually low during initial years of CT practices however; increase with increased time duration. It is a common consideration that 33% residue retention enhances wheat grain and straw yield by 8.69-9.90% (Raghubar Sahu et al., 2019). Seema et al., 2019, concluded that higher grain yield (4.31 t $ha^{-1}$) might be achieved by zero tillage with surface retention of rice residue over no residue retention.

### iii. Wheat yield attributes

Numerous studies show that in RWCS, CT practices favors healthier wheat crop in terms of yield and yield attributes. As the soil natural profile degrades with continuous conventional tillage (residue burning and puddle transplanted rice), thus in earlier periods the success rate of conservation tillage practices is slow because it takes time to reclaim soil's natural resources, however; after consistent conservation practices positive impacts on crops i.e. increased yield, 1000-grain weight, no. of spikelets, no. of productive tillers, might be achieved (Raj Kumar Jat et al., 2014).

### iv. Wheat nutrients uptake in RWCS under CT and RM

Residue retention as mulch in soil provides nutrients to reclaim the fertility of soil. To compare soil nutrient status, uptake of nutrients by crops and yield capacity of RWCS in conservational and conventional tillage, a field study was conducted in China. For this rice residue was used as mulch. It was observed that before anthesis and at maturity wheat sown by conventional tillage system followed by puddle transplanted rice had lower K concentration than wheat planted under conservation tillage system. Wheat N conc. did not differ at jointing and anthesis stage however, in conservation tillage treatments wheat N conc. was higher in both grains and vegetative parts. Soil P observed to increase till maturity (Chaosu et al., 2019). Thus, wheat planted under conservation tillage practice has advantage in nutrients uptake over conventional tillage due to better crop growth.

**Table 3. Evaluation of longterm tillage treatments' impacts on N, P, and K % conc. at different wheat growth stages.**

| Sampling time | Nutrient | CTW-CTR | ZTW-CTR | ZTW-CTRs | ZTW-ZTR | ZTW-ZTR/B |
|---|---|---|---|---|---|---|
| Tillering | N | 4.50 ab | 4.34 ab | 4.46 ab | 4.55 a | 4.25 b |
| | P | 0.48 a | 0.46 a | 0.45 a | 0.47 a | 0.46 a |
| | K | 2.11 b | 2.92 a | 3.17 a | 3.18 a | 3.25 a |
| Stem elongation | N | 4.91 a | 4.98 a | 4.58 a | 4.60 a | 4.76 a |
| | P | 0.50 b | 0.50 b | 0.50 b | 0.58 a | 0.56 a |
| | K | 2.07 c | 3.38 ab | 3.87 ab | 4.51 a | 4.29 ab |
| Anthesis | N | 1.64 a | 1.71 a | 1.71 a | 1.67 a | 1.71 a |
| | P | 0.22 a | 0.26 a | 0.26 a | 0.23 a | 0.24 a |
| | K | 1.14 b | 1.63 a | 1.89 a | 1.80 a | 1.90 a |
| Maturity straw | N | 0.46 b | 0.55 ab | 0.52 ab | 0.58 a | 0.62 a |
| | P | 0.03 b | 0.04 a | 0.04 ab | 0.05 a | 0.04 ab |
| | K | 1.23 b | 1.52 ab | 1.54 ab | 1.60 a | 1.80 a |
| Maturity grain | N | 1.95 ab | 1.83 b | 1.95 ab | 1.97 ab | 2.07 a |
| | P | 0.30 b | 0.32 ab | 0.32 ab | 0.35 a | 0.29 b |
| | K | 0.37 b | 0.40 ab | 0.39 ab | 0.40 a | 0.37 b |

(Chaosu Li et al., 2019)
(n = 3)
($P < 0.05$)
Values at each growth stage are mean of three replicates of each nutrient.
CTW-CTR: Conventional tilled wheat *fb* conventional transplanted rice.
CTW-ZTR: Conventional tilled wheat *fb* zero-tilled rice (residue mulching).
CTW-ZTRs: Conventional tilled wheat *fb* zero-tilled rice (residue incorporation).
ZTW-ZTR: Zero tilled wheat *fb* zero tilled rice (residue mulching).
ZTW-ZTR/B: Zero-tilled wheat *fb* zero tilled rice with residue mulching on raised beds.

### v. Rice grain yield

Likewise, in case of rice grain yield does not increase in initial phase of conservation tillage implementation. However, with time similarly like wheat, significant effect of conservation tillage practices can be observed in grain yield and other yield attributes of rice. In rice-wheat system 9.4-9.7% improved rice grain yield resulted in conservation tillage and residue retention, however; no significant increase was observed in 1000-grain weight of rice (Raj Kumar Jat et al., 2014).

## vi. Rice yield attributes

Numerous studies show that more no. of panicles high grain yield is achieved in CT system which might be associated with higher no. of tillers. Enhanced rice yield and soil profile with residue integration in RWCS was reported by Choudhury et al., (2014) and Laik et al., (2014). In one study yield attributes i.e. no. of panicles, grains per panicle, productive tillers/ $m^2$as well as ear length was recorded considerably higher in rice-wheat crop system with 33% residue retention. Raj Kumar Jat et al., 2014, reported that no. of panicles/$m^2$ notably higher in CT practices but no. of grains per panicle were recorded higher in conventionally puddle transplanted rice.

## vii. Rice nutrients uptake in RWCS under CT and RM

In numerous studies it has been observed that the effect of tillage practice mainly manifests during early growth stages. Macronutrients accumulation is proportional to the total dry matter produced particularly in early growth stages. At active tillering stage conventional puddle rice has higher concentration of N and P as compare to rice planted in conservation tillage. However, this difference of nutrients accumulation between two tillage practices diminishes after anthesis and increases in conservation direct seeded rice at reproductive stage (Chaosu et al., 2019).

**Table 4. Evaluation of longterm tillage treatments' impacts on N, P, K % conc. at different rice growth stages.**

| Time of sampling | Nutrients | CTW-CTR | ZTW-CTR | ZTW-CTRs | ZTW-ZTR | ZTW-ZTR/B |
|---|---|---|---|---|---|---|
| Tillering | N | 3.11 a | 2.95 a | 3.25 a | 2.30 b | 2.31 b |
| | P | 0.38 a | 0.32 ab | 0.40 a | 0.22 b | 0.22 b |
| | K | 2.81 a | 2.72 a | 3.03 a | 3.03 a | 2.32 a |
| Stem elongation | N | 2.14 a | 1.75 b | 1.83 ab | 1.95 ab | 2.11 ab |
| | P | 0.33 a | 0.34 a | 0.32 a | 0.24 b | 0.26 b |
| | K | 3.11 a | 3.20 a | 3.29 a | 3.07 a | 3.02 a |
| Anthesis | N | 1.06 a | 0.94 a | 0.98 a | 0.97 a | 1.01 a |
| | P | 0.20 ab | 0.19 b | 0.22 a | 0.21 ab | 0.21 ab |
| | K | 1.53 b | 1.69 ab | 1.83 a | 1.79 a | 1.69 ab |
| Maturity | N | 0.62 ab | 0.56 ab | 0.51 b | 0.65 a | 0.64 a |

| | | | | | | |
|---|---|---|---|---|---|---|
| **straw** | P | 0.07 a | 0.06 a | 0.06 a | 0.05 a | 0.07 a |
| | K | 1.76 c | 1.94 c | 2.24 b | 2.45 ab | 2.71 a |
| **Maturity grain** | N | 0.92 c | 1.00 abc | 0.96 bc | 1.09 a | 1.07 ab |
| | P | 0.23 ab | 0.23 ab | 0.24 ab | 0.22 b | 0.25 a |
| | K | 0.24 ab | 0.24 ab | 0.27 a | 0.23 b | 0.26 ab |

(Chaosu Li et al., 2019)
(n = 3)
($P < 0.05$)
Values at each growth stage are mean of three replicates of each nutrient.
CTW-CTR: Conventional tilled wheat *fb* conventional transplanted rice.
CTW-ZTR: Conventional tilled wheat *fb* zero-tilled rice (residue mulching).
CTW-ZTRs: Conventional tilled wheat *fb* zero-tilled rice (residue incorporation).
ZTW-ZTR: Zero tilled wheat *fb* zero tilled rice (residue mulching).
ZTW-ZTR/B: Zero-tilled wheat *fb* zero tilled rice with residue mulching on raised beds.

### viii. Rice-wheat system productivity

Capacity of RWCS turns out to be higher under CT in terms of grain yield, tillers/m$^2$, productive tillers, net yield, straw yield, no. of panicles, no. of spikelets, grains/panicle, grains/spike, 1000-grain weight (g) of rice and wheat. Recorded increase in rice grain yield is 8.2-10.0% with 33% residue retention under CT instead of puddle transplanted rice. Likewise, wheat grain yield enhances from 8.69-9.92% with CT practices.

**Table 5. Influence of diverse tillage and residue management practices on grain yield (t ha$^{-1}$) and productivity of RWCS (t ha$^{-1}$) (2013-2015).**

| **Treatments** | **Grain yield (t ha$^{-1}$)** | | | | **RWCS productivity (REY*, t ha$^{-1}$)** | |
|---|---|---|---|---|---|---|
| | 2013-2014 | | 2014-2015 | | 2013-2014 | 2014-2015 |
| | Rice | Wheat | Rice | Wheat | | |
| **Residue management practices** | | | | | | |
| **Residue removal** | 4.61 | 5.02 | 4.43 | 5.12 | 9.63 | 9.74 |
| **Residue retention** | 5.08 | 5.29 | 4.81 | 5.66 | 10.37 | 10.68 |
| **Tillage practices** | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| PTR-CTW | 4.47 | 4.59 | 4.06 | 4.68 | 9.06 | 8.92 |
| UPTR-ZTW | 4.59 | 5.07 | 4.46 | 5.51 | 9.66 | 10.18 |
| ZTTR-ZTW | 4.94 | 5.34 | 4.75 | 5.63 | 10.28 | 10.59 |
| ZTDSR-ZTW | 5.39 | 5.62 | 5.21 | 5.73 | 11.01 | 11.15 |

(Rajiv Nandan et al., 2018)
REY: Rice equivalent yield (t $ha^{-1}$).
PTR-CTW: puddle transplanted rice *fb* conventional-tillage wheat.
UPTR-ZTW: Un-puddle transplanted rice *fb* zero-tillage wheat.
ZTTR-ZTW: Zero-tillage transplanted rice *fb* zero-tillage wheat.
ZTDSR-ZTW: Zero-tillage direct-seeded rice *fb* zero-tillage wheat.

## 7. Economics of RWCS under CT and RM

In RWCS conservation tillage and residue integration has increased water use efficiency of crops, water productivity and increased soil moisture level, which has lowered need for irrigation thus expenses. Fertility enhancement has lessened requirement of fertilizers. Moreover, timely planting of wheat improved net production. All these attributes reduced on-farm expenditures and enhanced net return, gross income and benefit cost ratio (B:C). Reduction of cost of production has ultimately increased farm income and GDP.

## 8. Conclusion and future research

A sustainable agriculture system is need of hour for attaining food security for ever increasing population. This objective should have been attained without disturbing natural resources but current conventional agriculture system has deteriorated the natural resources and moved towards artificial substitutes. Rice and wheat is main food source for the whole world population and RWCS is the leading cropping system. So, sustainability for higher productivity of RWCS is needed to feed the world. In this review, it has been revealed that CT has constructive impacts on soil fertility and crop yield attributes. However, further research is required regarding nutrient status of soil, carbon sequestration and reliable tillage systems other than zero-till and no-till in conservation tillage system.

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