

Effect of tillage, cultivars, nitrogen and residue management on crop performance and carbon sequestration in rice-wheat cropping system

By

**PARDEEP KUMAR
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CERTIFICATE - I

This is to certify that this dissertation entitled, “**Effect of tillage, cultivars, nitrogen and residue management on crop performance and carbon sequestration in rice-wheat cropping system**” submitted for the degree of **Doctor of Philosophy** in the subject of Agronomy of Chaudhary Charan Singh Haryana Agricultural University, Hisar, is a bonafide research work carried out by **Mr. Pardeep Kumar, Admn. No. 2012A6D**, under my guidance and supervision and that no part of this dissertation has been submitted for any other degree.

The assistance and help received during the course of investigations have been fully acknowledged.

Dr. Satish Kumar
Major Advisor
Professor (Agronomy)
Assoc. Dean, Post Graduate Studies
CCS Haryana Agricultural University, Hisar.

CERTIFICATE-II

This is to certify that this dissertation entitled, “**Effect of tillage, cultivars, nitrogen and residue management on crop performance and carbon sequestration in rice-wheat cropping system**” submitted by **Mr. Pardeep Kumar, Admn. No. 2012A6D** to Chaudhary Charan Singh Haryana Agricultural University, Hisar, in partial fulfillment of the requirements for the degree of **Doctor of Philosophy** in the subject of **Agronomy** has been approved by the Student’s Advisory Committee after an oral examination on the same, in collaboration with an external examiner.

MAJOR ADVISOR

EXTERNAL EXAMINER

HEAD OF THE DEPARTMENT

DEAN, POST- GRADUATE STUDIES

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ABBREVIATIONS

₹	: Indian rupee
CA	: Conservation agriculture
CCAFS	: Climate change, agriculture and food security
CGIAR	: Consultative group of international agricultural research
CGR	: Crop growth rate
CIMMYT	: International maize and wheat improvement centre
CT	: Conventional tillage
CTW	: Conventional tilled wheat
DAS	: Days after sowing
DSR – R	: Direct seeded rice without residue
DSR + R	: Direct seeded rice with residue
DSR	: Direct seeded rice
GS	: GreenSeeker
IGP	: Indo-Gangetic plains
INR	: Indian rupee
N	: Nitrogen
NDVI	: Normalized difference vegetation index
PTR	: Puddled transplanted rice
R	: Crop residue
RCTs	: Resource conservation technologies
RDN	: Recommended dose of nitrogen
RGR	: Relative growth rate
SOC	: Soil organic carbon
SOM	: Soil organic matter
TCE	: Tillage and crop establishment
ZT DSR	: Zero-till direct seeded rice
ZT	: Zero tillage
ZTW	: Zero-tilled wheat

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) is one of the major cropping system, which occupies about 18 million hectares in Asia, and provides food security and livelihood for millions of farmers and workers. In South Asia, this system undertakes nearly 13.5 million hectares across the Indo-Gangetic Plains (IGP) of Bangladesh, India, Nepal and Pakistan. Over last 30 years, this system has emerged as the region's major food production system, accounting for more than 30% of the total rice area and 40% of the total wheat area, and producing nearly one third of the region's rice and more than half of wheat to meet food requirement of more than one billion people or about 15% of the world's population (Laik *et al.*, 2014). In India, rice-wheat (RW) cropping system occupies near about 10.5 million hectare area and contributes about 40% of the country's total food basket (Sharma *et al.*, 2015; Saharawat *et al.*, 2010). Nation occupies nearly 44.1 million hectares area of rice and total production of 105.5 million tones with a productivity of 2291 kg/ha, whereas wheat undertakes 31.47 million hectares area with 86.52 million tones production and 2750 kg/ha productivity for the year 2014-15 (Anonymous, 2016).

Farmers conventionally grow rice as a lowland crop during the warm and humid/subhumid season from June to October, followed by wheat as an upland crop in the cool and dry weather from November to March/April in the rice-wheat system. Rice is mainly grown by manual transplanting seedlings into puddled soils. This practice is water, capital, labour and energy intensive, and deteriorates soil health. Puddling (wet tillage) results into complete breakdown of soil aggregates, destruction of macropores and deterioration of soil physical properties, ultimately leading to poor soil structure, suboptimal permeability in the subsurface layer, poor soil aeration and soil compaction (Pathak *et al.*, 2011; Kumar *et al.*, 2008). Repeated puddling year after year, leads to development of hard pan at shallow depths, which inhibits root elongation and thus adversely affecting the growth and performance of succeeding crop of wheat. Since rice transplanting is mainly done from mid June to mid July, which delays crop maturity upto last week of october, on even upto first or second week of November, specially under basmati cultivated area. As a result of which, fields are not in *vattar* (optimum moisture for tillage) condition for conventional wheat sowing because of high soil moisture being sandy loam to clay loam in texture coupled with low air temperature with less sunshine hours. Under these situations, conventional wheat planting delays substantially as it requires repeated tillage (5-6 times) for field preparation. Consequently, late planted wheat matures late in April often coincides with high temperatures (>34°C) during ripening. High temperature during wheat maturity suppress the current photosynthesis, inhibits starch synthesis (Sharma *et al.*, 2015), shortens grain filling duration (Tashiro and Wardlaw, 1989) and rate of grain filling (Lobell *et al.*, 2012) and all leading to shrivelled grain, poor grain quality and lower yields. Pathak *et al.* (2003) reported a yield loss of 15-60 kg ha⁻¹ day⁻¹ if wheat planting is delayed beyond mid-November in NW India.

In addition to above all, intensive tillage and crop establishment methods require a large amount of labour and water, resulting in a rise in the cost of cultivation. Water and labour scarcity is becoming major concern for the productivity and sustainability of the rice-wheat cropping system in South Asia (Saharawat *et al.*, 2010; Pathak *et al.*, 2011). The problem has further been intensified with the timely unavailability of labour and increasing labour wages. Traditionally, wheat and rice residues were removed from the fields for use as cattle feed and for other purposes. Recently, with the advent of mechanized harvesting, a large quantity of crop residues are left in the fields. Farmers have been burning (in situ) large quantities of crop residues left in the field, which can be recycled for nutrient supply. As crop residues interfere with tillage and seeding operations for the next crop, farmers often prefer to burn the residue, which causes loss of nutrients and organic matter in the soil and environmental safety. Furthermore, incorporation and decomposition of rice residue before wheat planting compared to wheat residue before rice planting is difficult due to low temperatures and the short interval between rice harvest and wheat planting. Crop residues retention has been identified as a promising management option to combat soil salinity, as it can decrease soil water evaporation, increase infiltration and regulate soil water and salt movement (Bezborodov *et al.*, 2010 and Naresh *et al.*, 2012).

In conventional RW system, fields are kept fallow during the warmer months (April to June) without surface residue retention which warrants for the problem of secondary salinization because of upward movement of salt due to high evaporative demand (Brady and Weil, 2008) and due to the use of inadequate quantities of irrigation water to leach salts that accumulate in the root zone due to evaporation (Umali, 1993) and it is being increased in the recent past with changing climate (Shannon *et al.*, 1994). The challenge of the rice-wheat cropping system is to produce more food at less cost and to improve water and labour productivity besides maintaining environmental quality. Farmers need alternatives to conventional intensive tillage and crop establishment practices to help them conserve water, labour, and energy. There is urgent need to improve input use efficiency and total factor productivity by maintaining soil health (Chauhan *et al.*, 2012) with improved management practices (Jat *et al.*, 2014b) to increase the farmers profitability. Now farmers are facing the complexity of challenges because of climate change induced extreme weather conditions (Jat *et al.*, 2016). Inefficient crop management practices (conventional tillage, puddling, residue removal etc.) in the region contributes to overexploitation of ground water resources leading to decline in ground water table (0.1-1.0 m/year), increased energy cost of pumping of water and deterioration of groundwater quality, which lead to low profits with negative environmental impacts (Saharawat *et al.*, 2010).

In RW system, conservation agriculture based management options like efficient crop rotations, zero-tillage, improved crop establishment, residue management and system intensification etc. is the need of hour to overcome the problem of delayed wheat sowing in RW system and better management of resources (water, labour, energy, residues etc). Kumar *et al.* (2008) demonstrated an

8% reduction in wheat yield when sown after puddled transplanted rice compared with wheat sown after direct sown rice (DSR) in non-puddled conditions. Therefore, adoption of CA based sustainable intensification (SI) through minimizing mechanical soil disturbance and permanent soil cover combined with appropriate crop diversification/intensification has emerged as an important management strategy to address the issues of productivity and profitability of RW system in NW India. Experimental evidences from various production environments suggests that CA based management practices can have both short-term (Jat *et al.*, 2009) and long-term benefits (Kienzler *et al.*, 2012). Moreover inclusion of short duration legumes like moongbean (*Vigna radiata*) might be used to intensify and to contribute in productivity and profitability of RW cropping system at sustainable level (Sharma *et al.*, 2015). Possibility of ZT wheat sowing in conserved moisture after rice harvest and relay seeding of moongbean before wheat harvest could provide an opportunity for sustainable intensification of existing RW cropping system in NW India.

The shift from puddled-transplanted rice and conventional intensive tilled wheat to direct drill-seeded rice (DSR) and wheat after zero-tillage on the flat or raised-bed system could affect the productivity and resource-use efficiency of the rice-wheat system (Ladha *et al.*, 2009). However, the potential benefits and constraints of alternative tillage and crop establishment methods need to be quantified on a short to long term basis to maximize yield and input-use efficiency. Zero tillage (ZT) is being widely adopted by farmers in the North western IGP of India, particularly in areas where rice is harvested late. However, to get the full benefits of ZT, both rice and wheat need to be grown with a 'double zero-tillage' system (Jat *et al.*, 2009; Bhushan *et al.*, 2007).

Soil organic carbon (SOC) is a good indicator of soil quality and conservation. It plays a vital role in maintaining soil fertility, water retention, soil tilth and crop production. SOC can increase or decrease by altering the management practices. Reducing tillage practice and increasing cropping intensity, can enhance the accumulation rate of SOC, thereby sequestering CO₂ from atmosphere (Grace *et al.*, 2012). Changes in land use and management practices are good strategies to mitigate the global greenhouse effect through soil C sequestration and also the nitrogen management and cultivar choice is equally important under such situations (Tan and Lal, 2005). One of the major problems associated to rice-wheat cropping system is reduction in organic matter content of soil, besides depletion of water resources, deteriorating water quality and groundwater reservoirs, burning of residue, reduction in productivity, quality of production and environmental pollution. Due to these reasons the sustainability of rice-wheat system is under great threat. Therefore, to achieve sustainably higher productivity, CA based management practices must be widely adopted. With due emphasis to the current consequences of low profitability in existing RW system of NW India, it was realized to collect and quantify the evidences to address aforesaid consequences through CA based agronomic management practices for achieving higher productivity.

Therefore to study the impact of précised management of tillage, crop establishment, crop residues, nitrogen management and cropping system intesification through legume integration on system productivity and profitablity to have sustained production, the present investigation entitled **“Effect of tillage, cultivars, nitrogen and residue management on crop performance and carbon sequestration in rice-wheat cropping system”** was undertaken with the following objectives:

1. To study the effect of tillage and crop establishment techniques, nitrogen and residue management on growth and yield of rice and wheat.
2. To quantify the soil carbon sequestration under different management practices in rice-wheat sequence.
3. To compute economics of different treatments

A brief resume of the research work done so far pertaining to “**Effect of tillage, cultivars, nitrogen and residue management on crop performance and carbon sequestration in rice-wheat cropping system**” has been reviewed in this chapter. Wherever necessary, the references from related crops/research area are also included to make the review more comprehensive and complete. The literature is reviewed under the following heads:

2.1 Effect of tillage and crop establishment

2.1.1 Growth and yield

Rice

Tallest plants (103.97 and 105.63 cm during 2012 and 2013, respectively) were recorded at harvest under ZT DSR treatments, while shortest plants were recorded under puddled transplanted rice (Choudhary, 2016). Ginigaddara and Ranamukhaarachchi (2009) reported higher tiller density in direct seeded rice (DSR) than transplanted rice. Aslam *et al.* (2008) reported highest number of productive tillers/m² (231.7) in direct seeding followed by double zero tillage (219), bed planting (206.7) and conventional planting (200.2), respectively. Ullah *et al.* (2007) obtained maximum mean productive tillers (367.5 m⁻²) under direct seeding, which were much higher as compared to that under transplanting. Similarly, Manjunatha *et al.* (2009) reported that direct seeded rice gave higher number of panicles, panicle length, test weight, grain yield and net returns as compared to the transplanted rice at Agricultural Research Station, Gangavathi. Mahmood *et al.* (2002) revealed that although transplanting method produced more grains/panicle and 1000-grain weight but produced statistically similar paddy yield of basmati rice to that obtained under direct sowing as numbers of panicle/m² were greater in directly sown rice. The number of effective tillers and biomass yield were significantly higher in all the direct seeded methods than transplanted rice (Tripathi *et al.*, 2004). Halder and Patra (2007) attributed higher grain yield of rice under direct seeding to more number of tillers, higher leaf area and more dry matter production as compared to transplanting. The productivity of rice has been reported to be higher with direct seeding (Subbaiah *et al.*, 2002; Sharma *et al.*, 2004; Gill, 2008; Gangwar *et al.*, 2008).

In contrast to above, Akhgari and Kaviani (2011) reported that transplanted rice yields more than DSR under different cultivars, but lesser yield is compensated by reduction in production cost. Panicle number per unit area was almost 150% higher in DSR than PTR, but grain weight per panicle was higher in the transplanted crop. This compensation of various yield components under DSR resulted in statistically similar grain yield (Hobbs *et al.*, 2002). Huang *et al.* (2012) while working at Nanxian, Hunan Province (China) with two super hybrid rice cultivars recorded no difference in terms of grain yield under no tilled direct seeding and conventional tilled transplanting. Jat *et al.* (2009)

reported that yield of conventional tilled DSR (7.5 t ha⁻¹) was at par with PTR (7.5 t ha⁻¹) but was higher than that of ZT-DSR (7.19 t ha⁻¹).

Mahajan *et al.* (2011) found similar grain yields between aerobic DSR and conventional puddled transplanted rice. Singh *et al.* (2011) found that the grain yields in the absence of weed competition were greatest (6.56 t/ha) under wet seeding (sowing pre-germinated rice seed on puddled soil), and similar to those in transplanted rice (6.17 t/ha) into puddled soil, and dry seeded rice after dry soil tillage (6.15 t/ha). Gupta *et al.* (2003) recorded 10% higher yield in DSR than flooded transplanted rice (TPR). Punia *et al.* (2005) reported that higher yield was obtained under direct seeding than puddle transplanting at Fatehabad, Haryana. Piggin *et al.* (2002) reported similar yield in direct seeded broadcast rice and puddle transplanted rice. Rice yield under conventional puddled transplanting and direct seeding system on puddled or non-puddled (no-tillage) flat bed system were similar (Bhushan *et al.*, 2007). Direct seeding of paddy with drum seeder under puddled conditions increased the grain yield by 38% as compared to line transplanting (Jagadeesha *et al.*, 2009). The yield under reduced till and zero-tillage DSR was comparable with puddle transplanted rice, but the water productivity was higher in DSR (Singh *et al.*, 2006). Whereas, Ganesh (2002) reported that transplanted rice gave significantly higher grain yield (6.3 t ha⁻¹) than direct seeded (4.8 t ha⁻¹). Similarly, Singh (2005) opined that yield in DSR is often lower than transplanting practices owing to poor crop stand and high weed infestation. DSR is both cost and labour saving, although grain yield in DSR is comparatively less than TPR (Farooq *et al.*, 2011). Transplanted rice gave significantly higher grain yield, straw yield, yield attributes and net returns than DSR both under puddle and unpuddled conditions reported by (Prasad *et al.*, 2001, Parihar, 2004; Ram *et al.*, 2006; Ehsanullah *et al.*, 2011. and Choudhary *et al.*, 2004).

Wheat

Kumar and Yadav (2005) found significantly more days were taken to attain spike initiation, anthesis, milk and physiological maturity of wheat under zero tillage than the conventional tillage. Jat (2016) after two of experimentation stated that the maximum plants height and dry matter accumulation were recorded at harvest under permanent beds, while shortest plant and least dry matter accumulation was recorded under CT.

Based on eight years studies, Yadav *et al.* (2005) realized that continuous adoption of ZT in wheat resulted not only in the similar or increased grain yield of wheat but also in reduced infestation of resistant *Phalaris minor* compared to conventional tillage (CT). However, to get the full benefits of ZT, both rice and wheat need to be grown with a double zero-tillage system (Bhushan *et al.*, 2007). Pathak *et al.* (2003) reported that puddling can also delay wheat planting which results in yield loss of 35-60 kg per day per ha in the Indo-Gangetic plains. So timely planting of wheat is crucial as yield reductions of 1-1.5% per day occur for each day delay after the optimum sowing date. Kumar *et al.*

(2008), Gathala *et al.*, (2011a) and Kumar and Ladha (2011) demonstrated 8-9% reduction in wheat yield when sown after PTR compared with wheat sown after direct sown rice (DSR) in non-puddled conditions.

Kumar and Yadav (2005) and Gupta *et al.* (2007) reported that yield performance of wheat was marginally better under ZT practices. Mishra and Singh (2009) reported that variation in tillage systems did not influence the grain yield of wheat significantly except in 2002-03, where continuous ZT yielded significantly higher (5.13 t/ha) as compared to CT rotated with ZT (4.28 t/ha). Ram *et al.* (2010) reported that grain yield of wheat could not vary significantly among various treatments (different combinations of CT/ZT; flat/bed planting; residue/without residue). Jat *et al.* (2005) reported that the productivity of wheat was higher by 7.3 and 8.6% under flat no-till (5.56 t/ha) compared to no-till FIRB (5.18 t/ha) and flat conventional till planting (5.12 t/ha), respectively.

There was 12% higher wheat yield in Dry-DSR plots than in CT-TPR in all 5 years at Pantnagar (Singh *et al.*, 2002). The lower grain yield of wheat grown after CT-TPR was due to poor root development in a suboptimal soil physical environment resulting from puddling during the previous rice crop (Aggarwal *et al.*, 2006). Ishaq *et al.* (2001) observed that subsoil compaction due to puddling resulted in a reduction in both water and nutrient use efficiency in wheat by 38% owing to decreased root length.

Rice-wheat system

Gupta and Seth (2007) reported that resource conserving technologies, improves yields, reduce water consumption and reduce negative impacts on the environmental quality in rice-wheat cropping system. DSR followed by zero or conventional tillage wheat has been reported to improve the total productivity of the rice-wheat cropping system (Yadav and Yadav (2012). DSR produced significantly higher grain and straw yield of rice and succeeding wheat crop (Tripathi *et al.*, 2000). Furthermore, Gangwar *et al.*, (2008) found that direct seeding (dry bed and unpuddled) adopted in the previous rice crop gave higher mean yield of the succeeding wheat (5.70 t ha⁻¹), chickpea (2.20 t ha⁻¹) and Indian mustard (1.86 t ha⁻¹). The pooled (4 year) analysis of yield data revealed that though the system productivity under double zero-tillage was lower (11.46 Mg ha⁻¹) than traditional tillage practice (12.51 Mg ha⁻¹), the net income was markedly higher in double zero-tillage (US \$ 948 ha⁻¹) with benefit: cost of 2.13 than traditional till practice (US \$ 871 ha⁻¹) with the ratio of 1.89 (Gathala *et al.*, 2009). Similarly Ram *et al.* (2006) and Jat *et al.* (2013) obtained higher yield of wheat followed by direct seeded rice than followed by transplanted rice but total productivity and profitability of rice and rice-wheat system was highest when rice crop in the system was raised by transplanting. Gathala *et al.* (2013) stressed that to harness the full potential of CA, not only residue will have to be used as soil surface mulch but also rice will have to be brought under zero tillage.

2.1.2 Soil N, P and K status

Increasing both pre-puddling tillage and puddling intensity played a significant role in reducing nitrate-N leaching and increasing rice yield. Optimization of pre puddling tillage and puddling is essential to increase yield of the total rice–wheat system, saving energy and increasing profitability (Dwivedi *et al.*, 2012). The increase in N in soil suggests that the N-supplying power of soil can be improved by eliminating tillage (Malhi *et al.*, 2011a). Astier *et al.* (2006) recorded significantly higher total N under zero tillage compared to conventional tillage in the highlands of Central Mexico. Govaerts *et al.* (2007) reported that concentration of NO₃ nitrogen in the conventional tillage system was larger as compared to the permanent raised bed system, total N was significantly higher under both zero tillage on the flat and permanent raised beds compared to conventional. Gosai *et al.* (2009) reported that the total nitrogen and phosphorus varied significantly across the tillage types and study sites. Adoption of reduced tillage and crop diversity can increase organic N and mineralizable N stored in the soil (Malhi *et al.*, 2009), thus improving soil fertility and nutrient supplying power of soil. No-till treatments have higher P, K and organic carbon concentrations in the superficial 0-2.5 cm soil layer and in runoff sediments than CT (Betrol *et al.*, 2007). Govaerts *et al.* (2007) reported that on the average, permanent raised beds had higher concentration of K by 1.65 and 1.43 times in the 0-5 cm and 5-20 cm layer, respectively, compared to conventional tilled raised beds. Du Preez *et al.*, (2001) found increased level of K in zero tillage compared to conventional tillage, but this effect declined with depth. However, Duiker and Beegle (2006) found no effect of tillage on available K concentrations.

2.1.3 Soil organic carbon

Soil organic carbon (SOC) is a good indicator of soil quality and conservation. It plays a vital role in maintaining soil fertility, water retention, soil tilth and crop production. Sombbrero and Benito (2010) reported that by following no tillage practice and increasing cropping intensity can enhance the accumulation rate of SOC, thereby sequestering more CO₂ from atmosphere. Similar findings were reported by Grace *et al.* (2012) and Lal (2013). No-till farming also reduces the unnecessarily repaid oxidation of soil organic matter to CO₂ which is induced by tillage (Nelson *et al.*, 2009). In similar context Gathala *et al.* (2011b) and Liu *et al.* (2010) stated that intensive tillage systems results to a decrease in soil organic matter due to acceleration of the oxidation and breakdown of organic matter and ultimately degradation of soil properties. Similarly, Gwenzi *et al.* (2009) reported lower decomposition rates of soil organic matter with minimal tillage and residue retention, consequently organic carbon content increased with time. Melero *et al.* (2009) concluded that that long-term conservation tillage slightly increases the storage of organic matter and improves biological properties, especially at 0-5 cm depth.

Machado (2011) reported that the dynamics of SOC was influenced by crop rotation, cropping intensity and tillage on long term basis. Similarly, Hutchinson *et al.* (2007) and Olsen (2013) reviewed that management practices for an increase in SOC includes; increase in cropping frequency i.e. reducing bare fallow, increasing use of forages in crop rotations, reducing tillage intensity and frequency, better crop residue management and adopting agro-forestry. Most of the comprehensive field studies have shown that zero tillage results in greater accumulation of soil organic matter in surface layers (0-20 cm) than conventional tillage (Govaerts *et al.*, 2007). Whereas, Thomas *et al.* (2007) did not find a significant difference with SOC between zero and conventional tillage. Blanco-Canqui and Lal (2008) found that some crops and crop rotations decreased SOC in zero tillage compared to conventional tillage. The mechanism that governs the balance between increased or no sequestration after conversion to zero tillage are not clear and needs further research. It is well known that reduced use of tractors and other powered equipment result in lower emissions. Organic carbon levels were significantly higher with direct drilling, compared to conventional cultivation (Chan *et al.*, 2002).

2.1.4 Inputs saving and economic analysis

Short to medium term on-station studies reported 34–46% savings in machine labor requirement in ZT-dry-DSR compared with CT-TPR (Bhushan *et al.*, 2007; Saharawat *et al.*, 2010). DSR can reduce total labor requirements from 11 to 66% depending on season, location and type of DSR compared with CT-TPR (Isvilanonda, 2002; Kumar and Ladha, 2011; Rashid *et al.*, 2009). Labor requirements for CE decreased by more than 75% with direct seeding compared with transplanting (Dawe, 2005; Pandey and Velasco, 2002). In addition to labor savings, the demand for labor is spread out over a longer period in DSR than in transplanted rice. Conventional practice (CT-TPR) requires much more labour in the critical operation of transplanting, which often results in a shortage of labor. The spread-out labor requirement helps in making full use of family labor and having less dependence on hired labor (Kumar and Ladha, 2011). Because of high labor demand at the time of transplanting, increasing labor scarcity and rising wage rates are forcing farmers to opt for a shift in method of rice establishment from transplanting, which requires 25–50 persons per day ha⁻¹, to direct seeding, which in comparison needs only about 5 person per day ha⁻¹ (Balasubramanian and Hill, 2002).

Lee *et al.* (2002) reported that the labour requirement for tillage to seeding in dry seeding was 41 man hours ha⁻¹, which was 73 and 23% lower than that of machine transplanting and wet seeding, respectively. Recently, interest has been rapidly increasing in non-ponded direct seeded rice (dry-DSR), due to increasing labour scarcity, energy constraint and rising input costs (Kumar *et al.*, 2013; Kumar and Ladha, 2011). Farooq *et al.* (2011) reported that DSR has received much attention because of its low-input demand. However, there is an urgent need to identify/develop varieties suitable under different establishment techniques in rice-wheat cropping system. Similarly

zero tillage in cereal systems have helped in saving in fuel, water, reduce cost of production, improving system productivity and soil health (Jat *et al.* 2009). In addition, Pathak *et al.* (2011) reviewed that the intensive tillage and crop establishment (CE) methods require a large amount of labour and water, resulting in a rise in the cost of cultivation.

Many farmers in the Philippines, Malaysia, Thailand and India have been encouraged to switch over from transplanted to DSR culture (Farooq *et al.*, 2011). Effective management of problems like weeds, micronutrient deficiencies, pests and diseases affecting long-term crop productivity and input use efficiency would actually decide the success and adoption of the alternative rice establishment options, particularly DSR (Malik and Yadav, 2008). Continuous pumping of groundwater over the years to meet the high water requirement of flooded rice has resulted in a drastic decline in groundwater tables (Humphreys *et al.*, 2010 and Sharma *et al.*, 2012) leading to potential reduction in water availability in the future and an increase in socio-economic instability. Pathak *et al.*, (2011) emphasized that cultivation of conventional puddled transplanted rice is facing severe constraints because of water and labour scarcity and climatic changes. DSR sown in unpuddled soils on flat or raised beds has shown 15-30% water savings compared with traditional PTR (Jat *et al.*, 2009). Low cost of cultivation, early maturity (Subbaiah *et al.*, 2002; Gill, 2008), higher net returns (Sharma *et al.*, 2004; Nasurudeen and Mahesh, 2004; Gangwar *et al.*, 2008) has been reported well under DSR.

Ali *et al.* (2006) found that dry seeding had a higher benefit: cost ratio during both wet and dry seasons. Halder and Patra (2007) also reported that direct seeded paddy furnished higher net return and benefit cost ratio than transplanted paddy. Manjunatha *et al.* (2009) and Singh and Hensel (2012) reported that gross return and net return were more in case of DSR than TPR. The economic analysis based on experimental data and farmers' interview revealed that the highest net return of 33% was achieved from drill direct seeded rice followed by zero-tillage direct seeded rice (22%) and wet seeded rice (21%) over conventional transplanted rice (Tripathi *et al.*, 2004). While considering the net monetary returns and benefit cost ratio due to different sowing method of rice, Jha *et al.* (2006) reported that direct seeding of sprouted seed with drum seeder produced higher net returns of ₹ 30,473 ha⁻¹ with benefit cost ratio of 2.37 as compared to transplanting with net returns of ₹ 28,000 ha⁻¹ and benefit cost ratio of 2.27.

Research on farmer's fields showed that direct seeded rice was profitable to farmers, giving net return of ₹ 13,350 ha⁻¹ for direct seeding and ₹ 11,592 ha⁻¹ for wet seeding compared to ₹ 10,343 ha⁻¹ for puddle transplanted rice (Yadav *et al.*, 2006). Total saving was around ₹ 3,500 ha⁻¹ due to saving in labour and paddy seed in broadcast method as compared transplanting method (Jayawardena and Abeysekera, 2006). Singh *et al.* (2006) reported higher profitability under reduced till direct seeded rice and zero-tillage rice by ₹ 2,745 and ₹ 3,139 ha⁻¹ compared to transplanted rice

in western Uttar Pradesh and Haryana, respectively. Gill (2008) reported that direct wet seeding of pre germinated rice seeds on puddle field recorded higher grain yield, better yield parameters, lower cost of cultivation and resulted in higher net returns than conventional method of transplanting.

2.2 Effect of residue management

2.2.1 Growth and yield

Residue retention provides multiple benefits, including soil moisture conservation, suppression of weeds, and improvement in soil organic matter and soil structure (Kumar *et al.*, 2013; Verhulst *et al.*, 2011). Ram *et al.* (2010) reported higher yields of wheat under ZT with residue due to the cumulative effects of higher light interception more dry matter production, low soil and canopy temperature, more soil moisture, tillers, grains/ear and 1000-grain weight than no-residue application under ZT practices, as well as CT practices. Bakht *et al.* (2009) reported that on an average, crop residue incorporation increased the wheat grain yield by 1.31 times and straw yield by 1.39 times. Sidhu *et al.* (2007) found an average 9-15% higher grain yield of wheat with Happy Seeder sowing into rice residues compared to farmers practice (convention tillage after residue burning). Based upon three year findings Dusserrea *et al.* (2012) and Sidhu *et al.* (2015) revealed that no tillage coupled with residue retention showed positive effects on initial crop growth,

Singh *et al.* (2009) reported that in sandy loam soil, recovery efficiency (RE) of applied N in wheat was lower (49%) for straw burnt-ZT than in other treatments (54–56% for straw incorporation and surface mulch under CT and ZT). In silt loam, RE was higher in straw mulch-ZT compared with straw incorporation-CT (65 vs. 58%). In sandy loam, agronomic efficiency (AE) was higher in straw burnt-CT and straw mulch-ZT compared with other treatments (straw incorporation under CT and ZT). Rahman *et al.* (2005) found larger apparent recovery of fertilizer N under mulch than no-mulch conditions.

Numerous studies showed that no-tillage practices, with crop residue left on the soil surface improve soil aggregation, and preserve the nutrients for plant and soil micro-organisms (Jacobs *et al.*, 2009; Zhang *et al.*, 2007; Rasool *et al.*, 2007). The development and rapid adoption of direct drilling of wheat into rice stubble has been a major advance in reducing production costs, increasing yields and reducing greenhouse gas emissions (Hobbs and Gupta, 2003). CA based systems was agronomically and economically superior to CT based systems for rice–wheat rotation in a smallholder production system of Eastern IGP of South Asia (Jat *et al.* 2014b)

2.2.2 Soil N, P and K status

Crop residue provide a source of organic matter, so when returned to soil the residues increase the storage of organic C and N in soil, whereas their removal results in a substantial loss of organic C and N from the soil system (Malhi and Lemke, 2007). The increase in N in soil suggests that the N-supplying power of soil can be improved by returning straw to the soil (Malhi *et al.*, 2011a;

Atreya *et al.*, 2006). Similarly Govaerts *et al.* (2007) reported that increasing the amount of straw retention under permanent raised beds resulted an increased per cent of total N. Shafi *et al.* (2007) and Bakht *et al.* (2009) were also reported that significant increase in N content of soil due to crop residue incorporation. Positive effect of returning crop residue in improving P fertility of soil and thus increasing potential for long-term sustainability of soil productivity was reported by Malhi *et al.* (2011b). Verhulst *et al.* (2009) reported that most macronutrients (P, Ca, Mg, K) were not affected by tillage-straw management, probably because the soil was rich in those nutrients (Ca, Mg, K) or adequate amounts of P fertilizer were applied

2.2.3 Soil organic carbon/ Carbon sequestration

Grace *et al.* (2012) reported that by following no tillage practice and increasing cropping intensity can enhance the accumulation rate of soil organic carbon (SOC), thereby sequestering CO₂ from atmosphere. Similarly Hutchinson *et al.* (2007) and Olsen (2013) reviewed that SOC can be increased through better crop residue management and adopting agro-forestry. Numerous studies showed that no-tillage practices, with crop residue left on the soil surface increase SOC and preserve the nutrients for plant and soil micro-organisms (Jacobs *et al.*, 2009; Lal, 2004; Lal 2013).

Crop residues retention on soil surface was associated with an increase in SOC concentration (Dolan *et al.*, 2006). The use of no-tillage management together with a moderate amount of crop residue (33%) rapidly improved the soil organic carbon (Roldan *et al.*, 2003). Govaerts *et al.* (2007) reported that permanent raised beds with full residue retention increased soil organic matter content about 1.4 times in the 0-5 cm layer compared to conventionally tilled raised beds with straw incorporated and it increased significantly with increasing amounts of residue retained on the soil surface for permanent raised beds. It can be hypothesized that conventional tillage with all plant residues incorporated by disking is actually a system that rapidly breaks down the organic carbon inputs, while carbon coming from roots in permanent raised beds with all residues removed maintains some carbon in the soil. Similar findings were also reported by Sarkar and Kar (2011).

High-residue producing crops may sequester more C than crops with low residue input. Intensification of cropping systems such as increased number of crops per year, double cropping, and addition of cover crops can result in increased soil C storage under NT (West and Post, 2002). Choudhury *et al.* 2014 stated that DSR and wheat in zero tillage coupled with residue retention is a suitable management practice for enhancing soil C sequestration and sustainable yield increment even in reclaimed sodic soil of hot semi-arid zone of Indian subcontinent. This has a potential to increase total SOC content by 33.6% and macro-aggregate associated C by 20.8% over conventional tillage with transplanted rice after five years of continuous rice-wheat cropping.

2.3 Effect of nitrogen management

2.3.1 Growth and yield

No-till system often exhibit suppressed yields because of lesser N availability due to slower soil N mineralization, and greater immobilization, denitrification and NH₃ volatilization, particularly in early part of growing season compared with conventional-till systems (Patra *et al.*, 2004). Majumdar *et al.* (2011) opined that computer based 'nutrient expert' (decision support tool) for wheat fertilization recommendation recorded higher wheat grain yield of 4436/ha compared with farmers practice of 3504 kg/ha. In an other study, robust relationship were observed in-season GreenSeeker optical sensor based estimates of yield at 5-6 and 7-8 weeks growth stages and actual wheat yield. Sensor guided N application resulted in higher yield levels and N use efficiency (Singh *et al.*, 2011). GreenSeeker guided N applications helped to achieve grain yields of wheat similar to the blanket recommendations of 150 Kg N/ha but with total application to the extent of almost 50%.

Mahapatra *et al.* (2012) conducted a field experiment and reported that there was significant increase in grain yield of basmati rice with increase in nitrogen levels up to 40 Kg N/ha. Similarly, Singh (2004) reported that grain and straw yield of basmati rice increased with increment of nitrogen upto 40 Kg N/ha in sandy loam soils but it was at par with 60 kg N /ha. Chopra and Chopra (2000) reported a significant increase in plant height and straw yields with increase in N levels in aromatic rice variety Pusa Basmati-1. Singh and Singh (2000) found that the number of tillers were significantly higher in the fertilizer treatment (120 N + 60 K₂O kg ha⁻¹) over the control.

Gadade *et al.* (2004) studied that the response of basmati rice (cv. Basmati 370, Basmati 385, Tarori Basmati and Pak Basmati) to different fertilizer levels under upland irrigated conditions and reported that Basmati 370 showed the highest growth, panicle length, grains and test weight followed by Basmati 385. Rice grain was superior with the application of 125% of recommended dose of fertilizers. Manzoor *et al.* (2006) reported that plant height, number of productive tillers per hill, panicle length, number of grains per panicle, 1000 grain weight and grains yield of cv. Super Basmati increased with increase in nitrogen level up to 175 kg/ha. The yield parameters including paddy yield, number of grains per panicle and 1000 grain weight started declining at 200 kg N/ha level and above. Haque *et al.* (2004) reported that the tiller and dry matter increased proportionally with the increase in nitrogen levels. Khan *et al.* (2010) reported that the plant height showed the increasing trend up to 120 kg N and 90 kg P₂O₅ ha⁻¹.

2.3.2 Soil N, P and K status

When nitrogen was applied in three splits in zero till wheat, total N uptake (144.6 kg/ha) was lower than corresponding conventionally tilled wheat (184.4 kg/ha) with crop residues removed (Pasricha *et al.*, 2006). Several studies have shown that starter fertilizer was critical for maintaining early-season crop growth and ultimately yields in no-till (Singh *et al.*, 2014 ; Jat *et al.*, 2014a). The

build-up of the soil organic matter and increased in readily mineralized organic soil N with residue recycling suggest the potential for reducing fertilizer N rates for optimal yield of following crop after several years of residue incorporation (Thuy *et al.*, 2008).

2.3.3 Soil organic carbon/ Carbon sequestration

N fertilizers increased the organic carbon content in the soil due to the sufficiency of nutrients provided by inorganic fertilizers, thereby increasing above ground and root biomass and hence organic matter (Rassol *et al.*, 2007). Others reported an increase in SOC due to addition of organic sources of nutrients along with high inputs of NPK fertilizers (Bhandari *et al.*, 2002). Shah *et al.*, (2003) reported that SOC was increased by N inputs, from both fertilizer and residue application. The similar results were also reported by Singh *et al.* (2016). Optimum levels of SOC can be managed through crop rotation, fertility maintenance including use of inorganic fertilizers and organic manures (Huggins *et al.*, 1995; Janzen *et al.*, 1998). In a 32 years long term study, it was concluded that, Both rice-wheat and maize-wheat systems, the balanced fertilization improved the SOC concentration, total SOC stocks and sequestration rate (Kukal *et al.*, 2009). The strong influence from increasing C stocks through long-term balanced fertilization under rice-wheat cropping system has been reported by many researchers (Das *et al.*, 2014; Majumdar *et al.* 2012)

2.3.4 Input saving and economic analysis/ Economics

Gupta *et al.* (2007) also reported the higher net return and benefit cost ratio upto 125 Kg N ha⁻¹ in wheat. The application of 180:50:50 kg NPK ha⁻¹ was produced highest net return 30568 ₹.ha⁻¹ and highest benefit: cost ratio 5.03 reported by Duraisami and Mani (2002). Similarly, increasing levels of NPK applied in rice increased the net return and benefit: cost ratio, giving the highest return under 100% NPK levels. Increasing levels of NPK increased both grain & straw yields of rice, thus increased the economic return (Das *et al.*, 2003). The maximum net returns of ₹19374 ha⁻¹ were recorded with controlled release nitrogen urea (6.0%) @ 60% at recommended dose. The benefit: cost ratio also registered similar trend in both year recorded by Ravishankar *et al.* (2003). The output: input ratio was maximum with the application of 90 kg P₂O₅ ha⁻¹ and P application to both rice and wheat crops every year were reported by Sharma *et al.*, (2003). Maximum net profit and highest benefit: cost ratio was obtained at N₉₀P₄₅ kg ha⁻¹. (Bhowmick and Nayak, 2000). Similarly, increasing levels of NPK applied in rice increased the net return and benefit: cost ratio, giving the highest return under 100% NPK levels.

The details of experimental techniques adopted and materials used during the present investigation “Effect of tillage, cultivars, nitrogen and residue management on crop performance and carbon sequestration in rice-wheat cropping system” are described in this chapter. The experiment was conducted during *kharif* and *rabi* 2013-14, and 2014-15.

3.1 Location of experimental site

The experiment was conducted at participatory strategic research and learning platform for climate smart village, Taraori, (29°48'51 N latitude, 76°55'26 E longitude) and 256 meters above mean sea level in Karnal district of Haryana, in collaboration with CIMMYT under CGIAR's research program on climate change, agriculture and food security. The selected field was under rice-wheat rotation continuously since more than past 15 years and belongs to Mr. Vikas Chaudhary, an innovative farmer and also secretary of the ‘Society for Conservation of Natural Resources and Empowering Rural Youth’, a young farmers' cooperative society established during 2010. Taraori is known globally for scented superfine basmati rice production and is a typical rice-wheat cultivation area. This experiment was basically initiated in June 2011, and soil organic carbon study was started in third year (2013-14) of the experiment and intensive soil sampling from four depths (0-5, 5-15, 15-30 and 30-60 cm) was undertaken in June 2013 onwards.

3.2. Climate and weather conditions

The climate of the region is semi-arid and subtropical with extreme hot and dry (June) to wet summers (July–September) during the rice growing period and cold dry winters (November–April) for wheat, with an average annual rainfall of 670 mm (75–80% of which is received during southwest monsoon and the rest during the period between October to May), minimum temperature of 0–4 °C in January, maximum temperature of 40–46 °C in June, and relative humidity of 60–95% throughout the year. The actual mean weekly meteorological data during cropping cycle from June 2013 to May 2014 and from June 2014 to May 2015 pertaining to maximum and minimum temperature, relative humidity (morning and evening), open pan evaporation, sunshine hours and total rainfall were recorded at meteorological observatory located in ICAR-Central Soil Salinity Research Institute, Karnal. The perusal of the weather data presented in Table 3.1, 3.2, 3.3 and 3.4 and Fig. 3.1, 3.2, 3.3 and 3.4 revealed that weather conditions were normal for the proper growth of *kharif* and *rabi* season crops. The mean weekly maximum temperature ranged between 30.9 to 35.3⁰C (2013) and 29.1 to 40.7⁰C (2014) in *kharif* seasons and between 14.7 to 38.9⁰C (2013-14) and 13.4 to 43.3⁰C (2014-15) in *rabi* seasons. Whereas mean weekly minimum temperature fluctuated between 17.3 to 27.3⁰C (2013) and 15.0 to 28.2⁰C (2014) during *kharif* seasons and between 3.7 to 22.1⁰C (2013-14) and 5.9 to 24.0⁰C (2014-15) in *rabi* seasons.

The mean weekly morning and evening relative humidity ranged between 81 to 93.2% and 41.6 to 73.1% in *kharif* season 2013, and between 72 to 95.4% and 37.3 to 79.1% in *kharif* 2014. During *rabi* 2013-14 and 2014-15, the mean weekly morning and evening relative humidity varied from 54.7 to 99.3% and 14.6 to 82%, and from 48.3 to 100% and 13.1 to 82%, respectively. The total rainfall recorded was 902.2 and 709 mm during 2013-14 and 2014-15, respectively, which was more than average rainfall. There was no rainfall in 25th, 27th, 36th, 37th, 39th, 40th and 42nd standard weeks during *kharif* season 2013, whereas in *kharif* season 2014, 25th, 28th, 33rd, 34th and 37th to 40th weeks didn't receive any rainfall.

Maximum rainfall was recorded in August 2013 (275.3 mm) and September 2014 (225.7 mm). In *kharif* season 2013, there was 26.06% higher rainfall as compared to *kharif* 2014 (485.9 mm), whereas in *rabi* season 2014-15 comparatively 12.33% higher rainfall was received over 2013-14 (253.7 mm). It indicates that monsoonal rainfall was highly erratic in respect of its total amount, time of onset as well as distribution during the period of investigation. Total evaporation from open PAN was 536.6 (*Kharif*) and 700.5 mm (*rabi*) in 2013-14 and 632.5 (*kharif*) and 650.2 mm (*rabi*) mm during 2014-15. During the *kharif* crop seasons, the mean weekly sunshine hours ranged between 24 to 59.5 hours in 2013 and 24.3 to 74.4 hours in 2014; while during *rabi* crop season it ranged between 0 to 79.6 hours in 2013-14 and 7.8 to 71.4 hours in 2014-15.

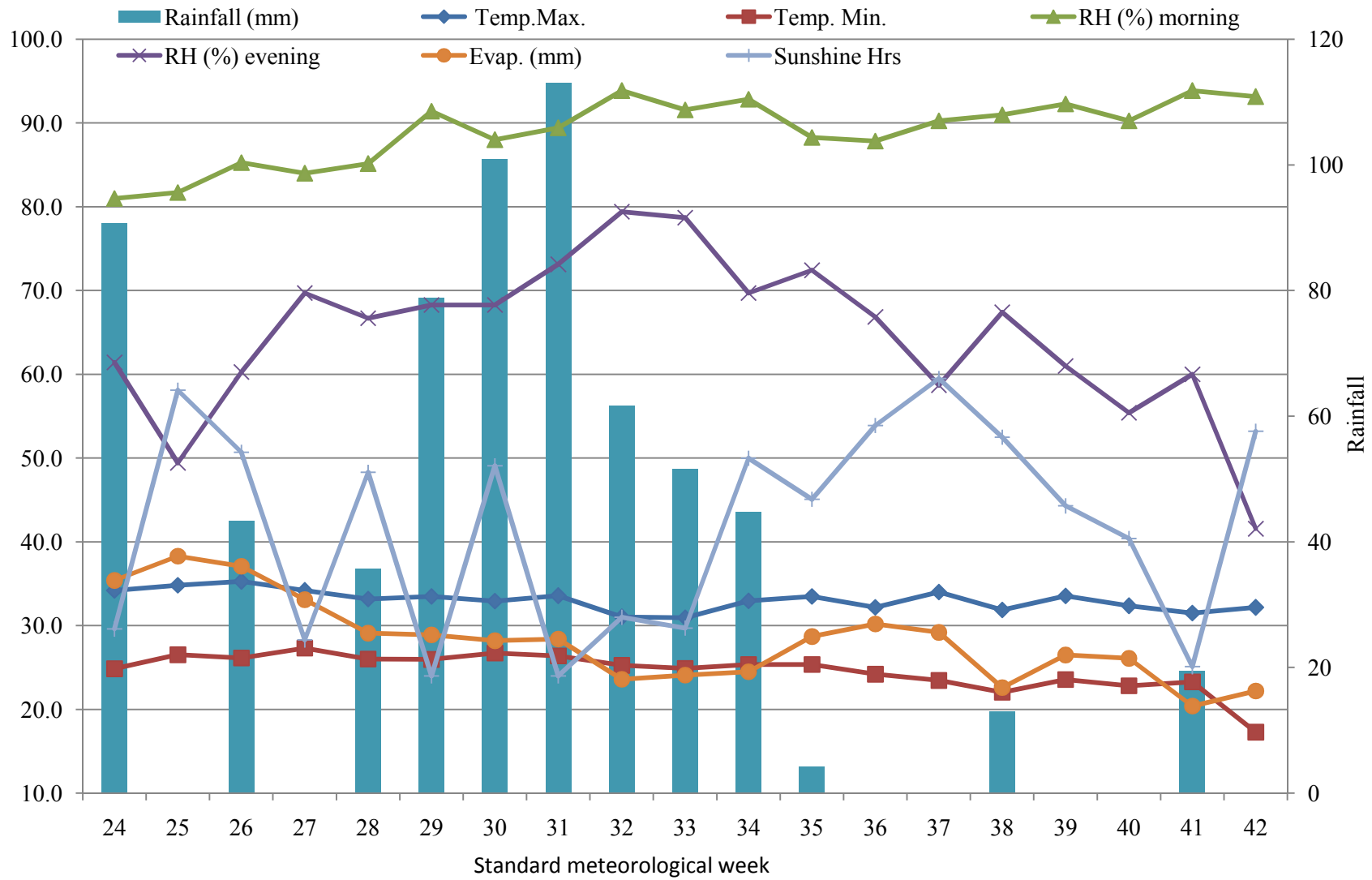


Fig. 3.1: Weekly mean values of weather parameters during rice season 2013

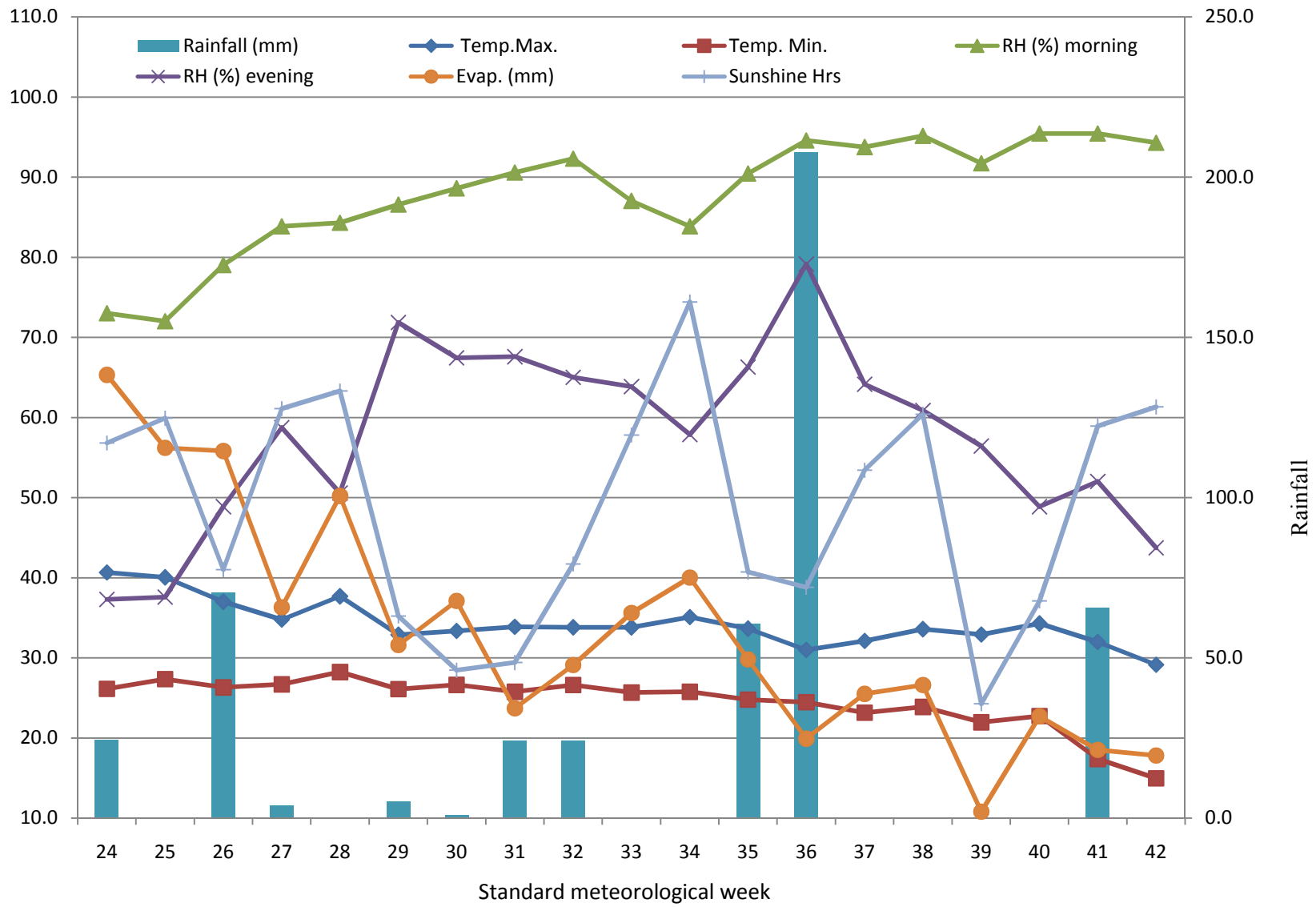


Fig. 3.2: Weekly mean values of weather parameters during rice season 2014

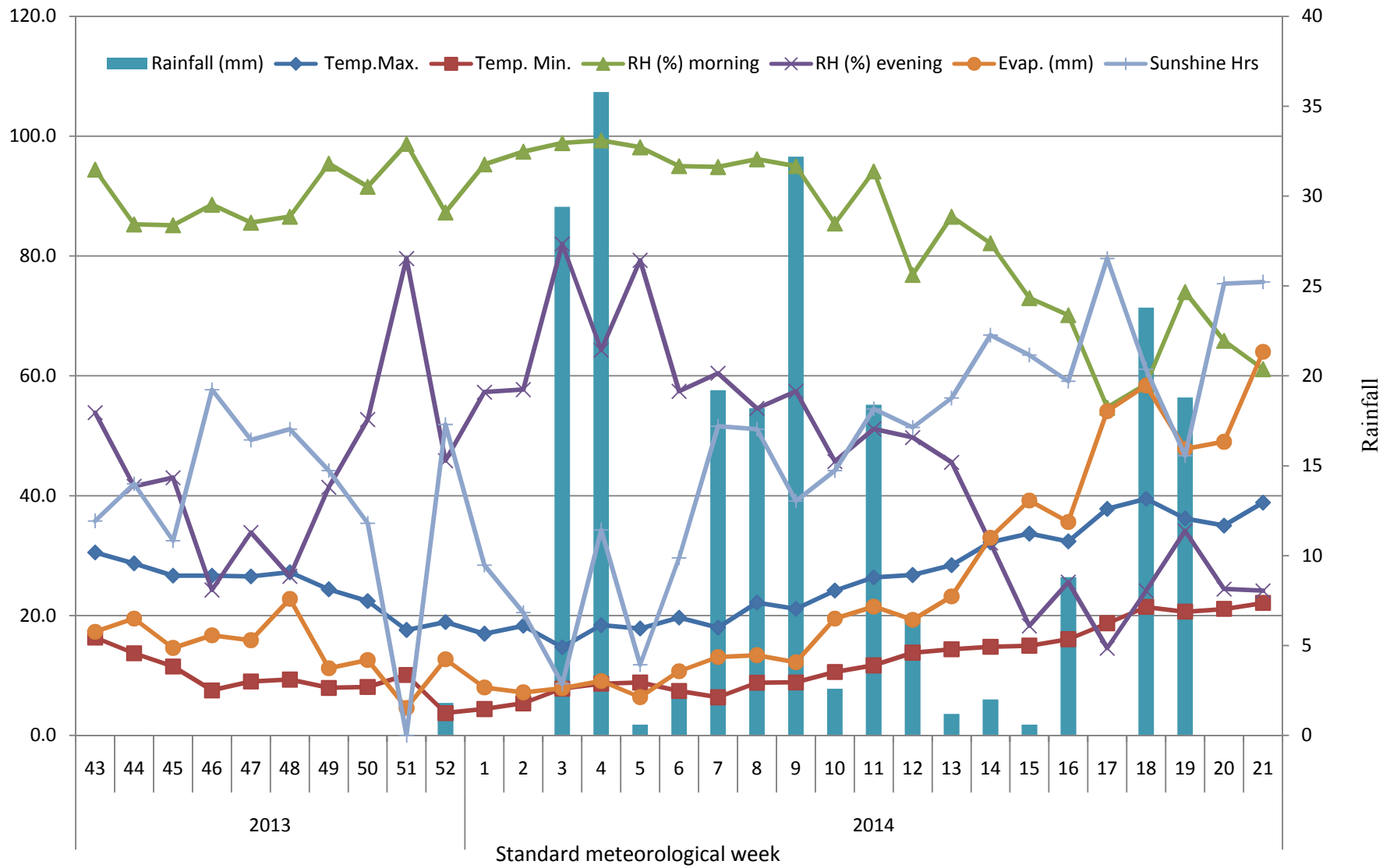


Fig. 3.3: Weekly mean values of weather parameters during wheat season 2013-14

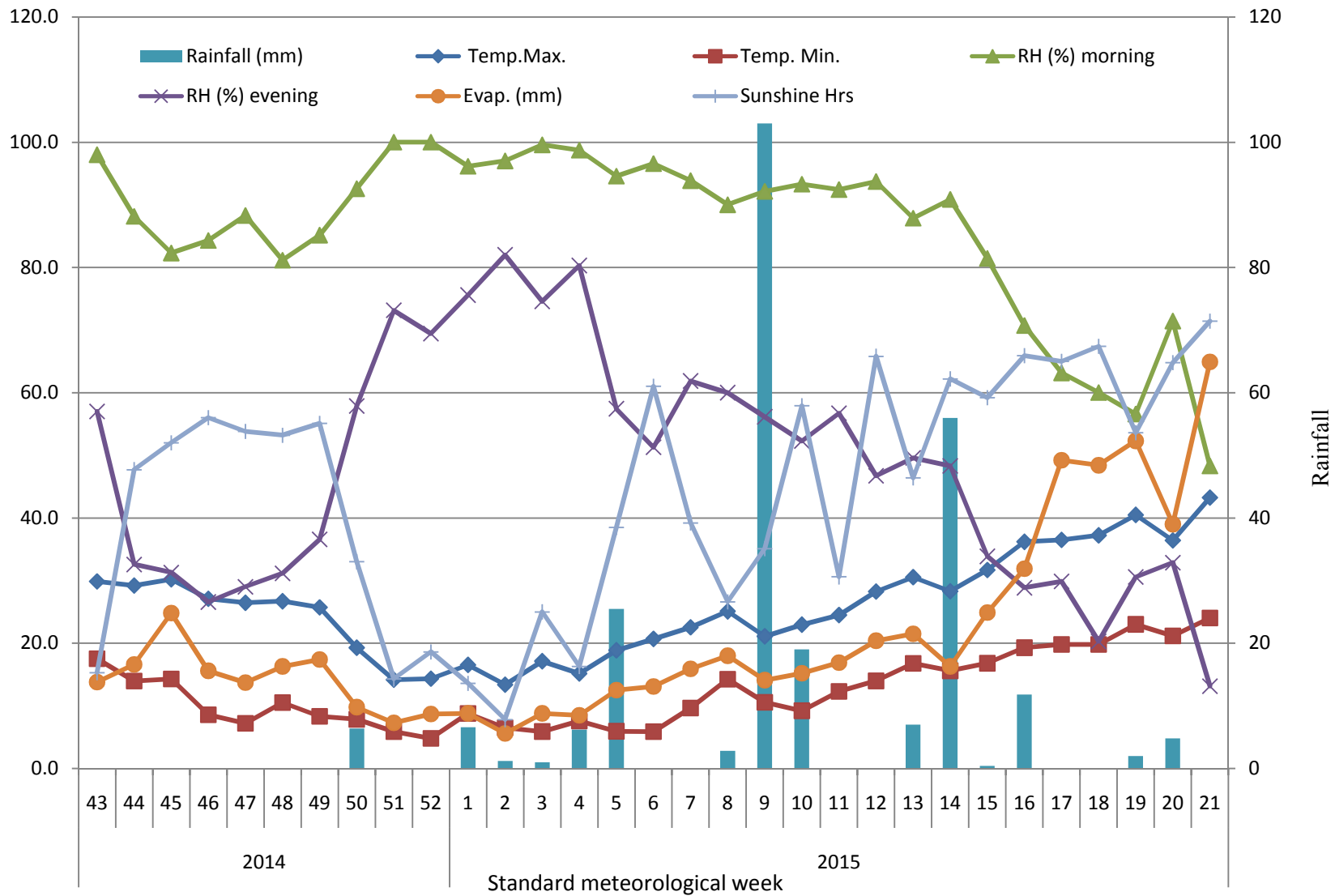


Fig. 3.4: Weekly mean values of weather parameters during wheat season 2014-15

Table 3.1: Soil physico-chemical characteristics of experimental site

Parameters	Initial baseline characterization of experimental plot (June 2011)	Characterization of the experimental plots at start of experiment (June 2013)			Method used
		PTR-CTW	ZT DSR-ZTW - R	ZT DSR-ZTW + R	
pH (1:2 :: Soil: Water)	8.03	8.028	8.029	8.003	Glass electrode pH meter method (Richards, 1954)
EC (dS m ⁻¹)	0.34	0.403	0.393	0.391	Conductivity bridge method (Richards, 1954)
Bulk density (g cm ⁻³)	1.59	1.592	1.569	1.559	Core sampling (Piper, 1966)
Infiltration rate (mm/hr)	5.40	5.36	5.93	5.97	Double Ring infiltrometer method (Bouwer, 1986)
Organic Carbon (%)	0.51	0.52	0.54	0.58	Wet digestion method (Walkley and Black, 1934)
Available Nitrogen (kg ha ⁻¹)	95	129	132	138	Alkaline permanganate method (Subbiah and Asija, 1956)
Available Phosphorous (kg ha ⁻¹)	16	15.19	15.63	15.98	Olsen's method (Olsen <i>et al.</i> , 1954)
Available Potassium (kg ha ⁻¹)	281	278	285	303	Flame photometric method (Jackson, 1973)
Soil texture	Clay loam				International pipette method (Piper, 1966)

3.3 Soil characteristics

Prior to establishment of experiment soil samples were taken from each plot for analysing physical and chemical properties of the soil. These individual plot samples were mixed, air-dried and sieved through a 2-mm screen and a representative sample was drawn for analysis for various soil physico-chemical properties using standard protocols. The information pertaining to various soil physico-chemical properties *viz.* bulk density, infiltration rates, soil reaction, electrical conductivity etc is given under Table 3.1. The soil of the experimental field was having 45.3% sand, 23.5% silt and 31.2% clay; classified as clay loam in texture, medium in organic carbon, low in available nitrogen, but medium in available phosphorus and potassium

3.4 Cropping history of the experimental field

The cropping pattern followed at the experimental field during the preceding years was rice crop in *kharif* and wheat during following *rabi* season and green gram in *summer* from last more than four years as shown in Table 3.2

Table 3.2: Cropping history of experimental field

Year	Crop Season		
	<i>Kharif</i>	<i>Rabi</i>	<i>Summer</i>
2007-08	Rice	Wheat	
2008-09	Rice	Wheat	
2009-10	Rice	Wheat	-
2010-11	Rice	Wheat	-
2011-12	Rice	Wheat	Green gram
2012-13	Rice	Wheat	Green gram
2013-14	Rice	Wheat	Green gram
2014-15	Rice	Wheat	Green gram

3.5 Experimental treatment details

The field experiment was conducted during *kharif* 2013 and 2014, and during *rabi* 2013-14 and 2014-15 for rice-wheat sequence. The treatment consisted of four tillage and crop establishment (TCE) methods in main plots and four treatments in subplot for rice (cultivar and nitrogen management) and wheat (legume and nitrogen management) crops. It was conducted in split plot factorial design having 12 treatment combinations each crop with 3 replications. The experiment was laid out keeping the same layout in both the years as shown in Fig. 3.5. The details of the treatments are follow:-

Replication III	33		34		35		36	
	C2N1/L1N1		C2N2/L2N2		C1N1/L2N1		C1N2/L1N2	ZT DSR-ZTW + R
	29		30		31		32	
	C2N1/L2N1		C2N2/L2N2		C1N2/L1N2		C1N1/L1N1	ZT DSR-ZTW - R
Replication II	25		26		27		28	
	C1N1/L2N1		C1N2/L1N2		C2N2/L2N2		C2N1/L1N1	PTR-CTW
	21		22		23		24	
	C1N1/L1N1		C2N1/L2N1		C2N2/L1N2		C1N2/L2N2	PTR-CTW
	17		18		19		20	
C2N2/L2N2		C1N1/L2N1		C1N2/L1N2		C2N1/L1N1	ZT DSR-ZTW - R	
13		14		15		16		
C1N1/L1N1		C2N1/L2N1		C1N2/L1N2		C2N2/L2N2	ZT DSR-ZTW + R	
Replication I	9		10		11		12	
	C2N2/L1N2		C1N2/L2N2		C2N1/L2N1		C1N1/L1N1	ZT DSR-ZTW + R
	5		6		7		8	
	C1N2/L2N2		C2N2/L1N2		C2N1/L1N1		C1N1/L2N1	ZT DSR-ZTW - R
	1		2		3		4	
	C1N1/L1N1		C1N2/L2N2		C2N1/L2N1		C2N2/L1N2	PTR-CTW

Fig. 3.5 Layout of plan of experiment

3.5.1 Main-plot treatment:

The three main plot treatments include tillage and crop establishment methods as described below:

- A. PTR-CTW: Conventional puddled transplanted rice followed by conventional till wheat.
- B. ZT DSR-ZTW - R: Zero till-direct seeded rice followed by zero-till wheat without residues.
- C. ZT DSR-ZTW + R: Zero-till direct seeded rice followed by direct drilling of wheat (no-till) with full residue retention.

3.5.2 Sub-plot treatments:

Each of the main plots was divided into four sub-plots. The sub-plot treatments were randomized completely and allocated to designated sub-plots.

Rice: For rice crop, four sub-plot treatments were as under:

1. C1N1: Basmati (Pusa-1121) rice with recommended dose of nitrogen.
2. C2N1: Hybrid rice (Arize 6129) with recommended dose of nitrogen.
3. C1N2: Basmati (Pusa-1121) rice with 80% of recommended dose of nitrogen as basal + GreenSeeker guided application.
4. C2N2: Hybrid (Arize 6129) rice with 80% of recommended dose of nitrogen as basal + GreenSeeker guided application.

Wheat: Similar to rice there were also 4 sub-plot treatments in wheat as well as described:

1. L1N1: Recommended dose of nitrogen without relay moongbean.
2. L2N1: Recommended dose of nitrogen + relay moongbean at last irrigation of wheat.
3. L1N2: 80% of recommended dose of nitrogen as basal supplemented with GreenSeeker guided application.
4. L2N2: 80% of recommended dose of nitrogen as basal supplemented with GreenSeeker guided application + relay green gram at last irrigation of wheat.

Experimental design: Split-Plot Design

Total treatment combinations: 12

Replications: 3

Total number of plots: 36

Gross Plot size (sub plot): 12.5 m X 8.0 m=100.0 m²

3.6 Cultural operations

The information pertaining to various cultural operations for *kharif* and *rabi* seasons is given in Table 3.3 and 3.4 for rice and wheat seasons respectively

Table 3.3: Schedule of field operations during experimentation in *kharif* season 2013 and 2014

Sr. No.	Field operations	2013		2014	
		PTR	DSR	PTR	DSR
1.	Field preparation	16.07.2013	-	05.07.2014	-
2.	Seed treatment and sowing in ZT DSR plots	-	22.06.2013	-	12.06.2014
3.	Nursery sowing	22.06.2013	-	12.06.2014	-
4.	Puddling and transplanting	16.07.2013	-	06.07.2014	-
5.	Fertilizer application				
	Phosphorus and potassium	16.07.2013	22.06.2013	06.07.2014	12.06.2014
	1 st Split of Nitrogen (basal dose)	16.07.2013	22.06.2013	06.07.2014	12.06.2014
	2 nd Split of Nitrogen (RDN plots only)	06.08.2013	13.07.2013	30.07.2014	05.07.2014
	3 rd Split of Nitrogen (RDN Plots only)	01.09.2013	06.08.2013	24.08.2014	28.07.2014
	2 nd Split of Nitrogen (For GreenSeeker guided plots only)	26.08.2013	26.08.2013	16.07.2014	16.07.2014
6.	Weed management				
	Pre seeding herbicide application	-	10.06.2013	-	04.06.2014
	Pre emergence herbicide application	17.07.2013	26.06.2013	08.07.2014	14.06.2014
	Post emergence herbicide application	-	13.07.2013	-	02.07.2014
	Manual weeding	22.08.2014	12.08.2014	09.08.2014	24.07.2014
7.	Plant protection measures				
	Insecticide application	30.09.2013	30.09.2013	10.10.2014	10.10.2014
	Fungicide application	30.09.2013	30.09.2013	18.09.2014	18.09.2014
8.	Harvesting				
	Basmati (PUSA 1121)	28.10.2013	23.10.2013	20.10.2014	17.10.2014
	Hybrid (Arize 6129)	17.10.2013	11.10.2013	16.10.2014	13.10.2014

Table 3.4: Schedule of field operations during experimentation in *rabi* season 2013-14 and 2014-15

Sr. No.	Field operations	2013-14		2014-15	
		CT	ZT	CT	ZT
1.	Field preparation	29.10.2013	-	31.10.2014	-
2.	Seed treatment and sowing	30.10.2013	30.10.2013	02.11.2014	02.11.2014
3.	Fertilizer application				
	Phosphorus and potassium application	30.10.2013	30.10.2013	02.11.2014	02.11.2014
	1 st Split of Nitrogen (Basal dose)	30.10.2013	30.10.2013	02.11.2014	02.11.2014
	2 nd Split of Nitrogen(RDN plots only)	19.11.2013	19.11.2013	26.11.2014	26.11.2014
	3 rd Split of Nitrogen (RDN plots only)	16.12.2013	16.12.2013	17.12.2014	17.12.2014
	2 nd Split of nitrogen (For GreenSeeker guided plots only)	11.01.2014	11.01.2014	15.01.2015	15.01.2014
4.	Irrigation application				
	1 st irrigation	19.11.2013	19.11.2013	24.11.2014	24.11.2014
	2 nd Irrigation	15.12.2013	15.12.2013	-	-
	3 rd Irrigation	02.04.2014	02.04.2014	-	-
5.	Sowing of relay moongbean	02.04.2014	02.04.2014	09.04.2015	09.04.2015
6.	Weed management				
	Pre seeding herbicide application	-	29.10.2013	-	31.10.2014
	Post emergence herbicide application	07.12.2013	07.12.2013	10.12.2014	10.12.2014
7.	Plant protection measures				
	Fungicide application	-	-	04.03.2014	04.03.2014
8.	Harvesting and threshing	09.04.2014	12.04.2014	14.04.2015	20.04.2015

3.6.1 Seed bed preparation and sowing

PTR-CTW: Tillage operations included two dry-harrowing followed by three puddlings and one leveling with a wooden planker after water was pounded. Twenty-five day old rice seedlings were manually transplanted at 20 cm x 20 cm spacing. After the rice harvest, wheat was sown in rows 20 cm apart (using a seed-cum-fertilizer drill) following the conventional practice of two harrowing, three ploughings (using a cultivator) and one planking (using a wooden plank).

ZT DSR-ZTW - R: Rice was directly drilled on flat land at 20 cm row spacing using the zero till multi-crop seed-cum-fertilizer planter. The seed depth was maintained at 3 cm by adjusting the depth control wheels of the planter. After manual harvest of rice and removing all residues, wheat was drilled directly without any preparatory tillage using the no-till seed-cum-fertilizer drill. For achieving optimum soil moisture for wheat sowing, pre sowing irrigation was also applied as per the need to ensure good germination.

ZT DSR-ZTW + R: The rice was planted and managed as similar to ZT DSR-ZTW - R but with retention of wheat stubbles. After harvest of rice (leaving all rice residues on surface), the wheat crop in sequence was planted in optimum soil moisture conditions using ‘Turbo Happy Seeder’, a planter which is capable of drilling directly in ample residue (anchored as well as loose) condition.

3.6.2 Water management

Rice: Under puddled transplanted rice, plots were kept continuously flooded (5 cm submergence) for initial 2 weeks, and subsequent irrigations (about 7 cm depth each) were applied before appearance of cracks at the soil surface. In ZT DSR plots, first irrigation was applied immediately after seeding, second irrigation was applied 5 days after the first irrigation and subsequent irrigations (about 5 cm depth each) were applied before appearance of cracks at the soil surface.

Wheat: Sowing of wheat was done in residual moisture, so first irrigation was applied at the CRI stage, then the subsequent irrigations were applied on frequent intervals as per crop requirement as mentioned in Table 3.4.

3.6.3 Weed management

In puddled transplanted rice plots, pretilachlor (Rifit 50% EC) @ 750 g a.i. per ha was applied at 2 days after transplanting (DAT). Under ZT DSR plots, first weeds were allowed to germinate by applying pre-sowing irrigation and then they were knockdown using non selective herbicide (glyphosate) to achieve stale seed bed for sowing. Oxadirygl 80 WP @ 90 g ai per ha at 2 days after seeding (DAS) in direct-seeded rice was applied for controlling post emerged weeds, followed by a spray Bispyribac sodium (Nominee Gold 10% SL) @ 25 g a.i. per ha + pyrazosulfuron (Saathi 10% WP) @ 20 g a.i. per ha at 25 DAS, however manual weeding was also undertaken under both PTR as

well as DSR plots as per requirement in 2013 as well as 2014 rice seasons. In wheat, at 30-35 DAS, spray of fluroxypyr (Axil 5% EC) @ 50 g a.i. per ha in 2013-14 and clodinafop (Topik 15% WP) @ 60 g a.i. per ha + metsulfuron methyl (Algrip 20% WDG) @ 4 g a.i. per ha was done to control major weeds of the crop.

3.6.4 Nutrient management

During rice seasons, the varieties used in this field study comprised of Hybrid (Arize-6129) and Basmati (Pusa-1121). The nutrient recommendation for hybrid rice (120 kg N, 60 kg P₂O₅ and 60 kg K₂O ha⁻¹), basmati rice (90 kg N, 60 kg P₂O₅ and 60 kg K₂O ha⁻¹) and wheat (150 kg N, 60 kg P₂O₅ and 60 kg K₂O ha⁻¹) were applied. Nitrogen was applied as urea after adjusting N values applied through diammonium phosphate (DAP) in three equal splits; 1/3rd basal, 1/3rd at 20–25 days after sowing/transplanting and rest 1/3rd at 40–45 DAT/DAS in rice and 1/2 as basal, 1/2 at crown root initiation stage (CRI) in wheat. Whereas, for 80% of recommended dose of nitrogen + GreenSeeker guided application, 80% of the recommended dose of nitrogen (72 kg N ha⁻¹ for basmati and 96 kg N ha⁻¹ for hybrid rice and 120 kg N ha⁻¹ for wheat) was applied as basal and rest was applied as guided by the green seeker optical sensor using standard calibration curve for rice and wheat given by RWC (2007) and Bijay-Singh *et al.* (2011), respectively. Full dose of phosphorus and potash was applied as basal through (DAP) and murate of potash (MOP).

In addition to N fertilizer applied as per treatment as described above, ZnSO₄ @ 25 kg ha⁻¹ and Sulphur as granular bentonite sulphur was also applied @ 20 kg ha⁻¹ as basal application during *kharif* season 2013 as well as 2014.

3.6.5 Calibration curve for GreenSeeker guided N application:

The GreenSeeker guided nitrogen application was computed based on vegetative index known as NDVI (Normalized difference vegetative index) and yield potential of the crop. Nitrogen (N) was calculated using following steps:

1. NDVI (biomass) = $(NIR_{\text{Reflected}} - Red_{\text{Reflected}}) / (NIR_{\text{Reflected}} + Red_{\text{Reflected}})$
2. INSEY = NDVI/days from planting to sensing (in days)
3. Potential yield (YP₀) with no added fertilizer N from the equation for grain yield and in season estimates of grain yield (INSEY) = $YP_0 = a * (INSEY)^b$ or exponential function
4. Determine pre-plant N Rich Strip (NRS)
5. Determine Response Index (RI) = $NDVI_{\text{NRS}} / NDVI_{\text{plots}}$
6. Predict potential grain yield with added N = $YPN = (YP_0 * RI)$
7. Fertilizer Requirement = $(\text{grain N uptake YPN} - \text{grain N uptake } YP_0) / (0.5 \text{ to } 0.7)$

The amount of fertilizer nitrogen applied to various 80% of RDN as basal + green seeker guided plots for the rice and wheat crops is given in the Table 3.5 as follows:-

Table 3.5: Total N (kg ha⁻¹) applied to 80% of RDN + GS guided plots for rice and wheat crop

Treatments	Rice 2013		Rice 2014		Wheat	
	Basmati	Hybrid	Basmati	Hybrid	2013-14	2014-15
PTR-CTW	125	144	103	124	153	143
ZT DSR-ZTW - R	109	123	106	126	150	144
ZT DSR-ZTW - R	119	141	114	146	148	141
Mean	118	136	108	132	150	143

3.7 Biometric observations

3.7.1 Rice

3.7.1.1 Plant height (cm)

The main shoots of five plants were tagged at random in each plot and height of the shoot was measured in centimetre at 30, 60, 90 DAS and at harvest. The height of each plant was measured from the base of the plant to the tip of the highest fully developed leaf before heading and up to tip of the panicle after heading.

3.7.1.2 Number of tillers m⁻²

Number of effective (ear bearing) and ineffective tillers (non ear bearing) were counted from 1 m² area randomly from three spots, averaged and expressed as number of tillers per square meter area at 30, 60, 90 DAS and at harvest.

3.7.1.3 Dry matter accumulation (g m⁻²)

In rice, 1 m² area was selected after leaving the first row from either side of the plot for the measurement of dry matter accumulation at 30, 60, 90 DAS and at harvest. The plant samples were harvested from ground surface by using a sickle. These samples were sun dried first and then in an oven at 65 °C till the constant weight was achieved. The dry weight was expressed as g m⁻².

3.7.1.4 Crop growth rate (CGR)

CGR is the gain in dry matter production on a unit land in a unit of time. It is expressed as gram of dry matter produced per day (Radford, 1967).

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \text{ g m}^{-2}\text{day}^{-1}$$

Where, W₁ and W₂ are dry weights of plant at time t₁ and t₂, respectively

3.7.1.5 Relative growth rate (RGR)

RGR is defined as the rate of increment in dry weight per unit plant weight per unit of time. The formula given by Blackman (1919) is as follows:

$$\text{RGR} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1} \quad \text{g g}^{-1} \text{day}^{-1}$$

Where, w_1 and w_2 are dry weights of plant at time t_1 and t_2 , respectively. Log_e , natural logarithm.

3.7.1.6 NDVI observation

The Green Seeker handheld crop sensor is an active light source optical sensor that was used to measure plant biomass and display as NDVI (Normalized Difference Vegetation Index). Green Seeker readings were taken at weekly intervals from 45 DAS.

3.7.1.7 Number of panicles m^{-2}

Numbers of panicles m^{-2} were counted from 1 m^2 area from four spots in the net plot, averaged and expressed as number of panicles per square meter for each treatment.

3.7.1.8 Panicle length (cm)

Panicle length was measured in centimetres from ten randomly selected tillers of tagged plants from each plot at harvest and averaged to get length of panicle.

3.7.1.9 Number of grains per panicle

Ten panicles from sampled plants were randomly selected; threshed and numbers of grains were counted. The average value was worked out to obtain the number of grains/ panicle.

3.7.1.10 1000-grain weight (g)

A representative sample of grains was taken from the produce of the each plot after drying and cleaning and weight of 1000-grains was recorded and expressed in grams.

3.7.1.11 Grain yield (t ha^{-1})

Produce of net plots was sun dried and threshed grains thus obtained were winnowed, cleaned and weighed. The yield recorded in kg per plot was standardized to 14% moisture using Indosaw's digital grain moisture meter (Model SH-6D) and then weight was converted into t ha^{-1} .

3.7.1.12 Straw yield (t ha^{-1})

The weight of straw was obtained by subtracting the grain weight from the total dry biomass recorded before threshing. The straw yield finally adjusted on oven dry weight basis after deducting moisture content determined by taking one kg separate sample.

3.7.1.13 Biological yield (t ha^{-1})

Biological yield was computed by adding grain and straw yield together per plot and expressed in t ha^{-1} .

3.7.1.14 Harvest index (%)

Harvest index was computed by dividing the grain (economic) yield by the total biological yield and was expressed in percentage.

$$\text{HI (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.7.1.15 Wheat equivalent yield

Wheat equivalent yield (WEY) was calculated by using following expression:

$$\text{WEY of rice} = \frac{\text{Rice yield} \times \text{Rice price}}{\text{Wheat price}}$$

3.7.2 Wheat

3.7.2.1 Plant height (cm)

Five plants from sampling were randomly selected and tagged for all the periodic height observations and their height was measured from the ground level to the tip of flag leaf at every 30 days intervals up to harvest and averaged.

3.7.2.2 Number of tillers m⁻²

Number of tillers were counted from 0.25 m² area randomly from four spots in the net plot, averaged and expressed as number of tillers per square meter area.

3.7.2.3 Dry matter accumulation (g m⁻²)

In wheat, 0.25 m² area was selected after leaving the first row from either side of the plot for the measurement of dry matter accumulation periodically. The samples were sun dried first and then in an oven at 65°C till the constant weight was arrived. The dry weight was expressed as g m⁻².

3.7.2.4 Crop growth rate (CGR)

CGR is the gain in dry matter production on a unit land in a unit of time. It is expressed as gram of dry matter produced per day (Radford, 1967).

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \text{ g m}^{-2} \text{ day}^{-1}$$

Where, W₁ and W₂ are dry weights of plant at time t₁ and t₂, respectively

3.7.2.5 Relative growth rate (RGR)

RGR is defined as the rate of increment in dry weight per unit plant weight per unit of time. The formula given by Blackman (1919) is as follows:

$$\text{RGR} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1} \text{ g g}^{-1} \text{ day}^{-1}$$

Where, w₁ and w₂ are dry weights of plant at time t₁ and t₂, respectively. Log_e, natural logarithm.

3.7.2.6 NDVI observation

The Green Seeker handheld crop sensor is an active light source optical sensor that was used to measure plant biomass and display as NDVI (Normalized Difference Vegetation Index). Green Seeker readings were taken at weekly intervals from 45 DAS.

3.7.2.7 Number of spikes m⁻²

Number of spikes m⁻² were counted from 1 m² area from four spots in the net plot, averaged and expressed as number of spikes per square metre for each treatment.

3.7.2.8 Spike length (cm)

Length of spike was measured in centimetres from the randomly selected five plants averaged and expressed as length of spike.

3.7.2.9 No. of grains per spike

Ten spikes from sampled plants were randomly selected; threshed and numbers of grains were counted. The average value was worked out to obtain the number of grains per spike.

3.7.2.10 1000-grain weight (g)

A representative sample of grains was taken from the produce of the each plot after drying and cleaning and weight of 1000-grains recorded at 14% moisture and was expressed in grams.

3.7.2.11 Grain yield (t ha⁻¹)

The net plots, leaving two border rows in each directions and half meter on opposite directions of the plots were harvested and kept for sun drying for some days in the field and then the total biomass/biological yield was recorded. After threshing, cleaning and drying the grain, the grain yield was recorded.

3.7.2.12 Straw yield (t ha⁻¹)

The weight of straw was obtained by subtracting the grain weight from the total dry biomass recorded before threshing. The straw yield finally adjusted on oven dry weight basis after deducting moisture content determined by taking one kg separate sample.

3.7.2.13 Biological yield (t ha⁻¹)

After harvesting of net plot area, total biomass was recorded by weighing the total weight of air dried bundle of wheat crop and expressed in t/ha.

3.7.2.14 Harvest index

Harvest index was computed by dividing the grain yield by the total biological yield and was expressed in percentage.

$$\text{HI (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.8 Plant chemical analysis

3.8.1 Nitrogen content and uptake

N content (%) in grain and straw was determined by modified Kjeldahl method (Prasad *et al.*, 2006). N uptake was calculated by using the following expression:

$$\text{N uptake (kg ha}^{-1}\text{) in grain/straw} = [\% \text{ N in grain/straw} \times \text{grain/straw yield (kg ha}^{-1}\text{)}]$$

$$\text{Total uptake of N (kg ha}^{-1}\text{)} = \text{N uptake in grain} + \text{N uptake in straw}$$

3.8.2 Phosphorus content and uptake

Phosphorus content in grain and straw was determined by vanadomolybdo phosphoric acid yellow colour method (Prasad *et al.*, 2006). Total P uptake (kg ha⁻¹) was calculated by following expression:

$$\text{P uptake (kg ha}^{-1}\text{) in grain/straw} = [\% \text{ P in grain/straw} \times \text{grain/straw yield (kg ha}^{-1}\text{)}]$$

$$\text{Total uptake of P (kg ha}^{-1}\text{)} = \text{P uptake in grain} + \text{P uptake in straw}$$

3.8.3 Potassium content and uptake

Potassium content in grain and straw was determined by flame photometer (Prasad *et al.*, 2006). Potassium uptake was calculated by multiplying K content with the dry matter yield

$$\text{K uptake (kg ha}^{-1}\text{) in grain/straw} = [\% \text{ K in grain/straw} \times \text{grain/straw yield (kg ha}^{-1}\text{)}]$$

$$\text{Total uptake of K (kg ha}^{-1}\text{)} = \text{K uptake in grain} + \text{K uptake in straw}$$

3.9 Soil physical properties

3.9.1 Bulk density

Soil bulk density was determined by the core sampler method from three randomly chosen places of each plot. The procedure for determining bulk density was followed as described by Chopra and Kanwar (1991).

3.9.2 Infiltration rate

Infiltration rate was measured with double ring infiltrometer (Bouwer, 1986). The required volumes of water was added in the inner ring of 20 cm diameter and 15 cm height driven 3 cm inside the soil after specific time periods depending on the water intake rate. The fall of water (*i.e.* soil intake) in the inner ring was determined through measuring the addition of water by the one litre measuring cylinder to the inner ring to keep the water level constant and this change in water with the measuring cylinder was expressed as cm/hr. Soil moisture (0–15 cm) before and after infiltration measurement was determined for the interpretation of infiltration data.

3.10 Soil organic carbon

The soil samples were collected from the respective depth in small polythene bags from each plot of the experimental field at the initial and at the end of experimentation period. The

samples were air dried and organic carbon content in soil samples were determined by Walkley and Black (1934). Soil organic carbon stock (Carbon sequestration) was calculated as follows

$$\text{SOC (Mg/ha)} = \text{SOC (\%)} \times \text{Soil depth (m)} \times \text{Bulk density (Mg/m}^3\text{)} \times 10^2 \text{ m}^2/\text{ha}$$

3.11 Economic analysis

Cost of cultivation (INR ha⁻¹) for different treatments was calculated on the basis of prevailing market rates of the inputs for each cropping season. Grain yield of wheat and hybrid rice was marketed at minimum support price for respective cropping season. However, grain (basmati) and straw (basmati, hybrid rice and wheat) was marketed as per the prevailing market rates for the respective seasons. Gross returns (INR ha⁻¹) were calculated based upon the marketed price of outputs (grain as well as straw). The details of the cost of inputs and outputs have been given in Appendix I and II. Net returns (INR ha⁻¹) were worked out by subtracting the total cost of cultivation of each treatment from gross income of respective treatment. Benefit: cost ratio was also worked out to ascertain the economic viability of different treatments. Total variable cost included the cost of input such as seeds, fertilizers, irrigation and various cultural operations such as ploughing, sowing, weeding, harvesting, threshing etc.

Utility of adopting different practices was computed by using the following data.

Gross returns = Total value of the produce (both grain and straw).

Net returns = Gross returns - Total cost of cultivation.

Benefit cost ratio (B:C) = Benefit cost ratio was worked out by using following formula.

$$\text{B: C Ratio} = \frac{\text{Gross returns}}{\text{Total cost of cultivation}}$$

3.12 Statistical analysis

The data recorded for different parameters were analyzed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez, 1983) for split plot factorial design. The Tukey's procedure was used where ANNOVA was significant and results are presented at 5% level of significance (P=0.05).

The results of present investigation entitled, “Effect of tillage, cultivars, nitrogen and residue management on crop performance and carbon sequestration in rice-wheat cropping system” conducted for two consecutive years during 2013-14 and 2014-15 are presented in this chapter with the help of appropriate tables and suitable figures.

4.1 Rice

4.1.1 Plant population

Tillage and crop establishment practices had a significant influence on plant population of rice during both years of study (Table 4.1). ZT DSR with and without residue being at par with each other resulted in significantly higher plant population as compared to PTR. Increase in plant population in ZT DSR+R ranged from 41.99% (2013) to 39.18% (2014) as compared to PTR. Cultivars and nitrogen management treatments had non-significant effects on rice plant population during both the years.

Table 4.1: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on plant population (no. /m²) of rice

Treatment	Plant population (30 DAS)	
	2013	2014
<i>Tillage and crop establishment</i>		
PTR	33.7	34.9
ZT DSR – R	56.9	55.0
ZT DSR + R	58.1	57.4
SEm±	1.42	1.88
CD at 5%	5.56	7.37
<i>Cultivars</i>		
Basmati	47.9	46.9
Hybrid	49.9	48.6
SEm±	2.31	1.63
CD at 5%	NS	NS
<i>Nitrogen management</i>		
80% RDN + GS	48.8	47.2
RDN	49.0	48.4
SEm±	2.13	1.63
CD at 5%	NS	NS

4.1.2 Plant height

The plant height of rice was influenced significantly due to different tillage and crop establishment (TCE) methods at all growth stages except 30 DAS during 2013 and 2014 (Table 4.2). Plant height increased at a faster rate up to 90 DAS during both the years. At 60 DAS, maximum plant height was recorded under ZT DSR+R closely followed by ZT DSR-R, which was significantly higher to PTR in both the years. Taller plants were recorded at 90 DAS in TPR as compared to ZT DSR-R during both years; however, it was significant during 1st year only. Similarly at harvest, PTR attained significantly higher plant height than rest of the treatments during both the years. Plant height of rice was not affected significantly with addition or removal of residues in DSR throughout the crop seasons.

Table 4.2: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on plant height (cm) of rice

Treatment	30 DAS		60 DAS		90 DAS		At harvest	
	2013	2014	2013	2014	2013	2014	2013	2014
<i>Tillage and crop establishment</i>								
PTR	33.7	34.9	65.5	67.4	107	110	107	111
ZT DSR – R	32.5	33.8	68.5	70.0	103	107	103	107
ZT DSR + R	32.5	33.9	69.9	72.1	104	107	104	107
SEm±	0.59	0.34	0.84	0.66	0.93	1.02	0.57	0.73
CD at 5%	NS	NS	3.28	2.56	2.98	3.12	2.23	2.27
<i>Cultivars</i>								
Basmati	33.3	34.5	68.1	70.2	111	116	114	119
Hybrid	32.5	33.9	67.8	70.2	99	100	97	100
SEm±	0.28	0.38	0.52	0.54	1.09	1.17	0.84	0.99
CD at 5%	NS	NS	NS	NS	3.26	3.49	2.51	2.93
<i>Nitrogen management</i>								
80% RDN + GS	32.8	34.0	67.8	69.9	105	109	105	109
RDN	33.0	34.4	68.1	70.5	105	108	106	110
SEm±	0.28	0.38	0.52	0.54	1.09	1.17	0.84	0.99
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

In general, plant height of Basmati and hybrid was recorded higher during second year i.e. 2014. Cultivars did not influence plant height significantly up to 60 DAS; however later on Basmati attained significantly higher plant height during both years of study. Basmati plants were 17 and 19 cm taller as compared to hybrid at harvest during 2013 and 2014, respectively.

However, treatments of nitrogen management showed non-significant effects on plant height during both the years.

4.1.3 Dry matter accumulation

Dry matter accumulation in rice was significantly affected by tillage and crop establishment practices up to 60 DAS, where ZT DSR with or without residue produced dry matter at par with each other, but significantly higher than PTR during both years of study (Table 4.3). Moreover during IInd year dry matter accumulation was higher as compared to Ist year irrespective of TCE treatments. During later growth period i.e. 90 DAS and at harvest, PTR produced numerically higher dry matter than ZT DSR treatments but all the three treatments were statistically similar.

Both cultivars produced similar dry matter at initial growth stages i.e. 30 DAS and 60 DAS in both 2013 and 2014. However, at later growth stages dry matter production was significantly affected by cultivars. At 90 DAS, hybrid produced 8.87 and 7.95% higher dry matter than basmati during 2013 and 2014, respectively. Whereas at harvest stages, basmati exceeded the dry matter production by 17.78% in 2013 and 14.47% in 2014 as compared to hybrid.

Dry matter accumulation of rice was not significantly influenced by nitrogen management treatments.

Table 4.3: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on dry matter accumulation (g/m²) of rice

Treatment	30 DAS		60 DAS		90 DAS		At harvest	
	2013	2014	2013	2014	2013	2014	2013	2014
<i>Tillage and crop establishment</i>								
PTR	23.9	26.1	489	501	1603	1681	2018	2045
ZT DSR– R	52.7	56.4	560	572	1480	1510	1833	1862
ZT DSR + R	53.3	57.1	566	580	1572	1589	1929	1998
SEm±	0.77	2.57	16.3	12.6	52	48	68	74
CD at 5%	2.62	8.08	55.8	41.6	NS	NS	NS	NS
<i>Cultivars</i>								
Basmati	41.9	45.5	513	530	1489	1527	2114	2121
Hybrid	44.6	47.6	564	572	1634	1659	1738	1814
SEm±	1.82	1.05	18.8	18.1	33	26	49	39
CD at 5%	NS	NS	NS	NS	99	77	146	117
<i>Nitrogen management</i>								
80% RDN + GS	44.1	47.4	537	547	1554	1544	1917	1957
RDN	42.5	45.6	540	555	1569	1603	1933	1978
SEm±	1.82	1.05	18.80	18.11	33	26	49	39
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

4.1.4 Growth indices

Tillage and crop establishment practices did not influence the crop growth rate (CGR) during the growing period except at 0-30 DAS during both the years, At 30 DAS ZT DSR with or without residue recorded significantly higher CGR rate as compared to PTR as shown in Table 4.4. On the other side, TCE methods had significant effect on relative growth rate (RGR) at all growth stages except 60-90 DAS, where PTR resulted into to significantly higher RGR as compared to ZT DSR treatments during 2013 and 2014 (Table 4.5).

Both cultivar and nitrogen management practices had non significant effect on CGR as well as RGR across the growing period irrespective of years.

Table 4.4: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on crop growth rate ($\text{g/m}^2/\text{day}$) of rice

Treatments	0-30 DAS		30-60 DAS		60-90 DAS	
	2013	2014	2013	2014	2013	2014
<i>Tillage and crop establishment</i>						
PTR-CTW	0.80	0.87	15.5	15.8	33.0	33.6
ZT DSR-ZTW - R	1.76	1.88	16.9	17.2	33.7	35.2
ZT DSR-ZTW + R	1.78	1.90	17.1	17.4	34.6	36.7
SE(m)	0.06	0.07	0.48	0.34	1.80	1.52
CD at 5%	0.19	0.27	NS	NS	NS	NS
<i>Cultivar</i>						
Basmati	1.40	1.52	17.4	17.5	35.3	36.7
Hybrid	1.49	1.59	15.6	16.1	32.2	33.7
SE(m)	0.06	0.04	0.63	0.60	1.59	0.96
CD at 5%	NS	NS	NS	NS	NS	NS
<i>Nitrogen management</i>						
80% RDN + GS	1.44	1.54	16.4	16.9	33.6	34.7
RDN	1.45	1.55	16.5	16.7	33.9	35.6
SE(m)	0.06	0.04	0.63	0.60	1.59	0.96
CD at 5%	NS	NS	NS	NS	NS	NS

4.1.5 Number of tillers

PTR resulted into significantly lower tillers as compared to rest of the treatments in both the years through out growing season (Table 4.6). Higher number of tillers were found under ZT DSR + R at all crop growth stages during both years of study and it was at par with ZT DSR - R.

Significant difference in tiller number was recorded at all growth stages among cultivars except 30 DAS. Hybrid produced 5.88 and 7.07% higher number of tillers in 2013 and 2014, respectively at harvest. Highest number of tillers was recorded under hybrid plots at 90 DAS. Nitrogen management had no significant effect on numbers of tillers during both the years at all growth stages.

Table 4.5: Effect of tillage, residues, legume and nitrogen management on relative growth rate (mg/g/day) of rice

Treatments	0-30 DAS		30-60 DAS		60-90 DAS	
	2013	2014	2013	2014	2013	2014
<i>Tillage and crop establishment</i>						
PTR-CTW	106	108	101	98.5	37.0	37.0
ZT DSR-ZTW - R	132	134	78.8	77.1	34.7	35.1
ZT DSR-ZTW + R	132	135	78.7	77.2	34.8	35.6
SE(m)	0.25	1.36	0.80	1.53	1.30	1.12
CD at 5%	0.96	5.33	3.11	5.98	NS	NS
<i>Cultivar</i>						
Basmati	122	127	88.4	84.7	35.6	36.0
Hybrid	124	125	83.7	83.8	35.4	35.8
SE(m)	1.22	0.87	1.75	1.40	1.73	1.67
CD at 5%	NS	NS	NS	NS	NS	NS
<i>Nitrogen management</i>						
80% RDN + GS	123	125	85.6	83.8	35.4	35.4
RDN	123	126	86.1	84.8	35.5	36.4
SE(m)	1.22	0.87	1.75	1.40	1.73	1.67
CD at 5%	NS	NS	NS	NS	NS	NS

Table 4.6: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on tillers (no./m²) of rice

Treatments	30 DAS		60 DAS		90 DAS		At harvest	
	2013	2014	2013	2014	2013	2014	2013	2014
<i>Tillage and crop establishment</i>								
PTR	34	35	234	238	265	272	258	264
ZT DSR- R	94	90	291	286	318	323	313	316
ZT DSR + R	99	94	292	296	325	332	320	321
SEm±	3.8	3.8	3.6	6.3	7.1	12.9	13.0	8.5
CD at 5%	12.5	12.7	11.7	20.6	23.8	42.5	42.9	27.4
<i>Cultivars</i>								
Basmati	73	70	257	255	288	293	288	289
Hybrid	78	76	288	292	317	325	306	311
SEm±	2.1	2.1	6.4	4.9	7.7	7.3	5.6	6.4
CD at 5%	NS	NS	19.2	14.6	23.0	21.7	17.2	20.1
<i>Nitrogen management</i>								
80% RDN + GS	76	73	270	271	299	307	294	299
RDN	75	72	274	276	305	310	300	301
SEm±	2.1	2.1	6.4	4.9	7.7	7.3	5.6	6.4
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

4.1.6 Yield attributes

Data presented in Table 4.7 revealed that tillage and crop establishment methods significantly influenced the yield attributes of rice in both the years except panicle length and test weight. PTR produced significantly lower number of effective tillers in comparison to ZT DSR with residue and without residue; however it produced significantly higher number of grains per panicle in 2013 and 2014. PTR produced 12.87 and 9.84% higher and 15 and 10.71% higher number of grain per panicle over ZT DSR-R and ZT DSR+R in 2013 and 2014, respectively. Both ZT DSR-R and ZT DSR + R resulted into significantly higher number of unfilled grains per panicle in comparison to PTR in both the years.

Table 4.7: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on yield attributes of rice

Treatment	Effective tillers/m ²		Panicle length (cm)		Grains/panicle (No.)		Unfilled grains / panicle (No.)		1000-grain wt. (g)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
<i>Tillage and crop establishment</i>										
PTR	251	257	24.6	25.1	132	140	6.22	6.20	23.6	23.5
ZT DSR – R	306	309	23.3	24.6	115	119	14.8	12.8	23.3	23.3
ZT DSR + R	312	317	23.4	24.7	119	125	15.9	13.7	23.3	23.3
SEm _±	12.0	9.0	0.25	0.45	2.18	1.10	0.38	0.53	0.15	0.23
CD at 5%	36.6	27.9	NS	NS	8.49	4.27	1.49	2.08	NS	NS
<i>Cultivars</i>										
Basmati	280	282	24.4	25.2	111	116	12.4	11.1	25.5	25.4
Hybrid	300	307	23.1	24.4	132	140	12.2	10.7	21.3	21.3
SEm _±	5.48	6.41	0.32	0.22	1.42	1.78	0.50	0.58	0.14	0.16
CD at 5%	16.3	19.1	0.97	0.67	4.23	5.28	NS	NS	0.43	0.49
<i>Nitrogen management</i>										
80% RDN + GS	286	293	23.7	24.8	120	127	12.6	10.9	23.3	23.3
RDN	294	295	23.8	24.9	123	129	12.0	10.9	23.5	23.4
SEm _±	5.48	6.41	0.32	0.22	1.42	1.78	0.50	0.58	0.14	0.16
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Cultivars also significantly affected all yield attributes except unfilled grains per panicle. Hybrid produced significantly higher number of effective tillers, number of grains per panicle in comparison to plots under basmati over both the years. In 2013, 15.90% and in 2014, 17.14% higher numbers of grains were recorded in hybrid as compared to basmati. Basmati produced significantly higher panicle length and test weight during both years. Test weight in basmati was recorded 16.58 and 16.31% higher in comparison to hybrid during 2013 and 2014, respectively.

Treatments for nitrogen management failed to produce any significant variation on yield attributes of rice during both years of experimentation (Table 4.7).

Table 4.8: Interaction effect between cultivars and tillage and crop establishment methods on effective tillers

Year	2013		2014	
Treatment	Basmati	Hybrid	Basmati	Hybrid
PTR	265	238	267	247
ZT DSR – R	274	340	282	338
ZT DSR + R	303	323	297	337
SEm+	9.49		10.71	
CD at 5%	28.22		33.02	

Interaction effects of tillage and crop establishment methods and cultivars on effective tillers are given in Table 4.8. Hybrid under ZT DSR-R and ZT DSR+R produced significantly higher number of effective tillers per meter square in comparison to PTR over both the years. Basmati under ZT DSR + R produced significantly higher no. of tiller as compared to rest of the treatment during 2013. Hybrid under ZT DSR-R produced 19.41 and 16.56% higher number of tillers in comparison to basmati during 2013 and 2014, respectively. Whereas in 2014, hybrid rice produced significantly higher number of effective tillers in ZT DSR treatment as compared to basmati. PTR produced lower number of effective tiller irrespective of years and cultivars (Table 4.8).

4.1.7 Yield

Tillage and crop establishment and nitrogen management treatments failed to produce significant variation on grain, straw and biological yield, harvest index and wheat equivalent yield of rice over both the years except grain yield in 2013, where RDN produced significantly higher grain yield of rice as compared to other treatments (Table 4.9).

Hybrid produced significantly higher grain, straw and biological yield, harvest index and wheat equivalent yield in comparison to basmati during 2013 and 2014. However, maximum grain yield (6.85 and 7.15 t/ha during 2013 and 2014 respectively), biological yield (15.5 and 15.73 t/ha during 2013 and 2014 respectively) and harvest index (44.3 and 45.51% during 2013 and 2014 respectively) were recorded under the hybrid plots.

4.1.8 Economics

The total cost of cultivation, gross returns, net returns and benefit cost ratio for various treatments *viz.* tillage and crop establishment methods, cultivars and nitrogen management is given in Table 4.10 and Fig. 4.1. Among various tillage and crop establishment methods, highest cost of

cultivation and gross returns were recorded under PTR during 2013 and 2014. However, ZT DSR-R resulted into maximum net return and benefit cost ratio under both the years. In year 2014, higher values for total cost of cultivation were recorded irrespective of treatments. Whereas, year 2013 resulted into better gross returns, net returns and benefit cost ratio across the TCE treatments. Highest cost of cultivation was recorded under PTR (₹43320 and ₹48890/ha during 2013 and 2014 respectively) which was 16.42 and 14.25% higher in comparison to ZT DSR-R and ZT DSR + R, respectively. Whereas, highest gross returns (₹137180 and ₹11997/ha during 2013 and 2014 respectively) was recorded under PTR. ZT DSR-R resulted into maximum benefit cost ration in both 2013 (2.74) and 2014 (1.80).

Table 4.9: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on yields and harvest index of rice

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Biological yield (t/ha)		Harvest index (%)		WEY (t/ha)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
<i>Tillage and crop establishment</i>										
PTR	5.96	6.17	8.31	8.42	14.3	14.6	41.8	42.3	9.68	8.18
ZT DSR – R	5.75	5.80	8.03	8.14	13.8	13.9	41.7	41.6	9.30	7.73
ZT DSR+ R	5.84	5.93	8.11	8.19	13.9	14.1	41.9	42.0	9.39	7.77
SEm±	0.07	0.13	0.15	0.17	0.18	0.18	0.45	0.86	0.1	0.18
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<i>Cultivars</i>										
Basmati	4.84	4.79	7.67	7.92	12.5	12.7	38.8	37.4	12.50	9.28
Hybrid	6.85	7.15	8.63	8.57	15.5	15.7	44.3	45.5	6.42	6.51
SEm±	0.06	0.06	0.11	0.13	0.13	0.16	0.40	0.40	0.07	0.09
CD at 5%	0.17	0.18	0.35	0.40	0.41	0.49	1.19	1.19	0.22	0.27
<i>Nitrogen management</i>										
80% RDN + GS	5.72	5.91	8.08	8.22	13.8	14.2	41.2	41.4	9.37	7.83
RDN	5.98	6.02	8.23	8.27	14.2	14.2	41.8	41.9	9.55	7.97
SEm±	0.06	0.06	0.11	0.13	0.13	0.16	0.40	0.40	0.07	0.09
CD at 5%	0.17	NS	NS	NS	NS	NS	NS	NS	NS	NS

Among cultivars, cost of cultivation was higher under treatments which included hybrid in both the years; however, gross returns, net returns and benefit cost ratio were higher under basmati cultivar in both 2013 and 2014.

Nitrogen management 80% RDN + GS incurred higher cost of cultivation as compared to RDN in both the years. Notable higher gross returns, net returns and benefit cost ratio were recorded under RDN than 80% RDN + GS during 2013 and 2014.

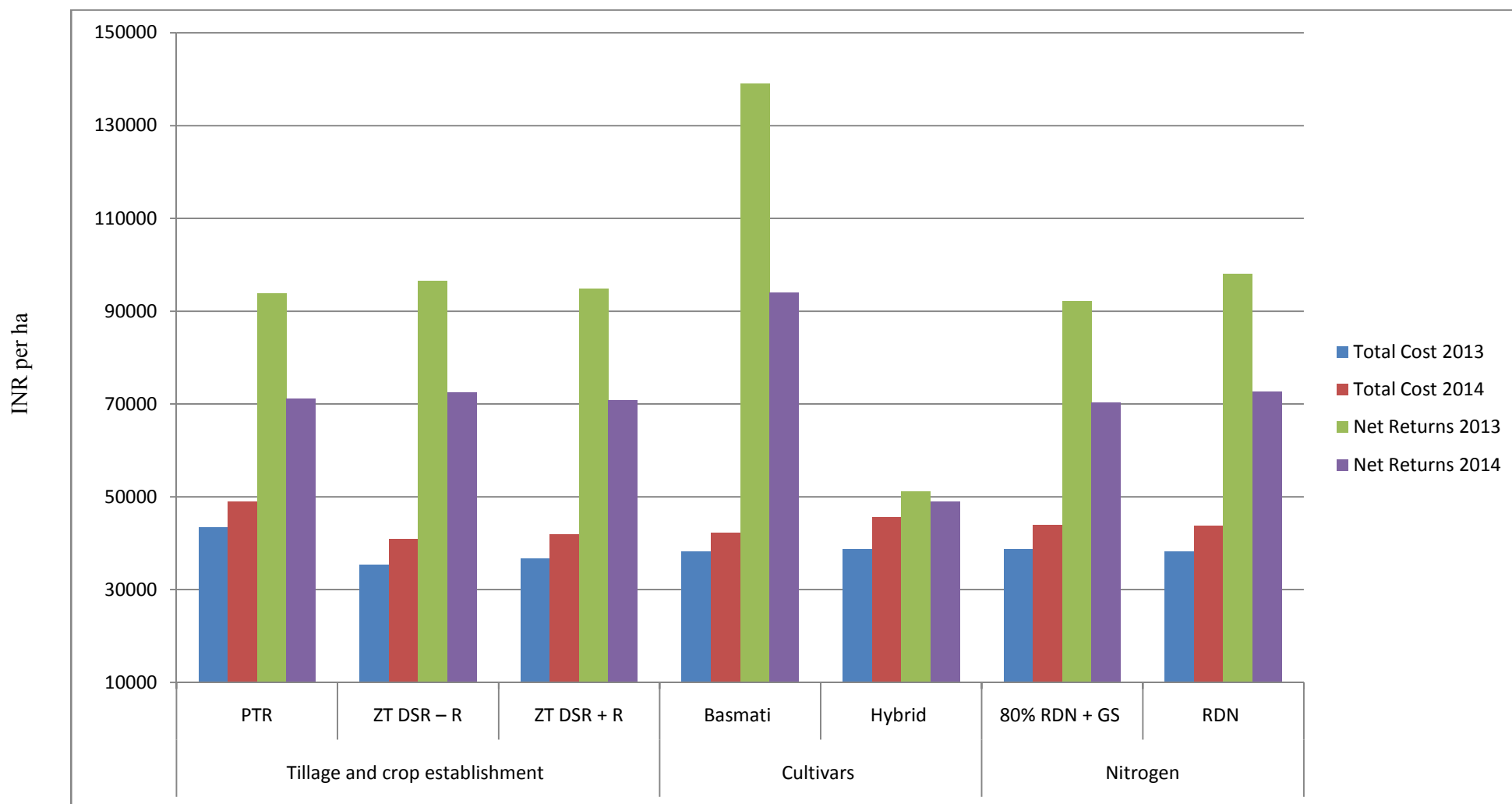


Fig. 4.1 Effect of tillage and crop establishment, cultivars and nitrogen management on total cost of cultivation, and net return in rice

Table 4.10: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on economics of rice

Treatment	Total cost (x 10 ³ ₹ ha)		Gross returns (x10 ³ ₹ ha)		Net returns (x 10 ³ ₹ ha)		B:C	
	2013	2014	2013	2014	2013	2014	2013	2014
<i>Tillage and crop establishment</i>								
PTR	43.32	48.89	137.18	119.97	93.85	71.08	2.16	1.46
ZT DSR – R	35.40	40.86	131.90	113.36	96.50	72.53	2.74	1.80
ZT DSR + R	36.72	41.92	131.49	112.69	94.77	70.76	2.59	1.71
<i>Cultivars</i>								
Basmati	38.21	42.26	177.23	136.26	139.02	94.00	3.61	2.24
Hybrid	38.75	45.50	89.81	94.42	51.06	48.91	1.33	1.08
<i>Nitrogen management</i>								
80% RDN + GS	38.75	43.98	130.87	114.32	92.12	70.34	2.40	1.63
RDN	38.21	43.78	136.19	116.35	97.96	72.58	2.59	1.69

Table 4.11: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on nitrogen content (%) and uptake (kg/ha) of rice grain and straw

Treatment	Grain N content		Straw N content		Grain N uptake		Straw N uptake	
	2013	2014	2013	2014	2013	2014	2013	2014
<i>Tillage and crop establishment</i>								
PTR	1.023	1.033	0.409	0.418	61.0	63.8	33.2	34.9
ZT DSR – R	1.026	1.035	0.408	0.417	59.0	60.0	33.7	35.3
ZT DSR + R	1.024	1.034	0.409	0.417	59.7	61.4	34.5	35.7
SEm±	0.004	0.003	0.002	0.002	0.63	1.52	0.64	0.61
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
<i>Cultivars</i>								
Basmati	1.025	1.035	0.415	0.413	49.7	49.6	30.7	32.8
Hybrid	1.023	1.033	0.413	0.412	70.1	73.9	36.9	37.9
SEm±	0.001	0.001	0.001	0.001	0.59	0.63	0.46	0.58
CD at 5%	NS	NS	NS	NS	1.76	1.88	1.37	1.73
<i>Nitrogen management</i>								
80% RDN + GS	1.024	1.032	0.408	0.417	59.7	61.2	33.5	35.2
RDN	1.025	1.035	0.409	0.418	60.2	62.2	34.0	35.4
SEm±	0.001	0.001	0.001	0.001	0.59	0.63	0.46	0.58
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

4.1.9 Nitrogen content and uptake in rice grain and straw

Data pertaining to nitrogen content and uptake in grain and straw has been shown in Table 4.11. TCE methods, cultivars and nitrogen management treatments showed non significant effect on N content in grain as well as straw during 2013 and 2014. Similarly N uptake in grain and straw also showed non significant effects for TCE methods and nitrogen treatments. However between cultivars, significantly higher grain and straw N uptake was in hybrid during both years. Maximum grain N uptake (70.1 and 73.9 kg/ha during 2013 and 2014 respectively) as well as straw N uptake (36.9 and

37.9 kg/ha during 2013 and 2014 respectively) was found in hybrid cultivar as compared to basmati cultivar. The N uptake in grain was 29.15 and 32.87% higher as compared to basmati during 2013 and 2014 respectively. Similarly 16.8 and 13.51% higher straw N uptake was recorded in hybrid during 2013 and 2014, respectively. Nitrogen treatments did not influence N content and uptake in grain and straw during both the years of study

4.1.10 Phosphorus content and uptake in rice grain and straw

Data pertaining to effect of tillage, crop establishment, residues, cultivars and nitrogen management on phosphorus content (%) and uptake (kg/ha) of rice grain and straw is given in Table 4.12. Similar to N content and uptake, P content in grain and straws was not significantly affected by TCE methods and nitrogen treatment during both the years. Only the treatments for cultivars showed significant effects; where hybrid showed significantly higher P uptake in grain as well as straw during both 2013 and 2014. Maximum grain P uptake (10.57 and 11.18 kg/ha) and straw P uptake (3.96 and 4.07 kg/ha) was recorded during 2013 and 2014 respectively.

Table 4.12: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on phosphorus content (%) and uptake (kg/ha) of rice grain and straw

Treatment	Grain P content		Straw P content		Grain P uptake		Straw P uptake	
	2013	2014	2013	2014	2013	2014	2013	2014
<i>Tillage and crop establishment</i>								
PTR	0.154	0.156	0.045	0.046	9.21	9.65	3.67	3.87
ZT DSR – R	0.155	0.157	0.046	0.047	8.92	9.13	3.79	3.98
ZT DSR + R	0.155	0.156	0.046	0.047	9.01	9.26	3.83	3.96
SEm±	0.001	0.001	0.001	0.001	0.102	0.23	0.057	0.061
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
<i>Cultivars</i>								
Basmati	0.155	0.157	0.046	0.047	7.53	7.52	3.56	3.80
Hybrid	0.154	0.156	0.046	0.047	10.57	11.18	3.96	4.07
SEm±	0.001	0.001	0.001	0.001	0.08	0.10	0.053	0.063
CD at 5%	NS	NS	NS	NS	0.25	0.31	0.15	0.18
<i>Nitrogen management</i>								
80% RDN + GS	0.155	0.156	0.045	0.046	8.94	9.30	3.76	3.88
RDN	0.155	0.157	0.046	0.047	9.15	9.40	3.77	3.99
SEm±	0.001	0.001	0.001	0.001	0.08	0.10	0.053	0.063
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

4.1.11 Potassium content and uptake in grain and straw

Data recorded for grain and straw potassium content and uptakes is given in Table 4.13. Similar to N and P contents in grain and straw, TCE and nitrogen management treatments showed

similar trend for K content and uptake in grain and straw during both years of study. Cultivars differed in respect to K content and uptake in grain and straw and Hybrid showed significantly higher uptake in grain as well as in straw. Hybrid cultivar recorded 29.01 and 32.77% higher grain uptake as compared to basmati during 2013 and 2014 respectively.

Table 4.13: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on potassium content (%) and uptake (kg/ha) of rice grain and straw

Treatment	Grain K content		Straw K content		Grain K uptake		Straw K uptake	
	2013	2014	2013	2014	2013	2014	2013	2014
<i>Tillage and crop establishment</i>								
PTR	0.302	0.307	1.30	1.31	18.0	19.0	105	110
ZT DSR – R	0.305	0.309	1.32	1.33	17.5	17.9	108	113
ZT DSR + R	0.304	0.309	1.31	1.32	17.7	18.1	110	113
SEm±	0.001	0.001	0.004	0.004	0.29	0.51	2.13	2.23
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
<i>Cultivars</i>								
Basmati	0.304	0.309	1.31	1.33	14.7	14.8	102	108
Hybrid	0.303	0.308	1.30	1.32	20.8	22.0	114	116
SEm±	0.001	0.001	0.001	0.001	0.17	0.19	1.58	1.82
CD at 5%	NS	NS	NS	NS	0.52	0.58	4.69	5.41
<i>Nitrogen management</i>								
80% RDN + GS	0.303	0.308	1.31	1.33	17.3	18.3	107	111
RDN	0.304	0.309	1.31	1.33	18.0	18.5	109	113
SEm±	0.001	0.001	0.001	0.001	0.17	0.19	1.58	1.82
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

4.1.12 Total NPK uptake

Tillage and crop establishment methods and nitrogen management treatments failed to produce significant variation on total NPK uptake during both the years of experiment except total N uptake during 2013, where RDN resulted into significantly higher total N uptake in rice as compared to other treatments (Table 4.14).

Cultivars significantly influenced the total NPK uptake irrespective of years. Total NPK uptake was significantly higher under hybrid as compared to basmati during 2013 and 2014. In comparison to basmati, hybrid resulted into 24.8 and 25.8% total N, 23.4 and 25.6% total P and 13.3 and 10.8% higher total K uptake as compared to basmati cultivar during 2013 and 2014, respectively.

Table 4.14: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on total (grain and straw) NPK uptake (Kg/ha) in rice

Treatments	Total N uptake		Total P uptake		Total K uptake	
	2013	2014	2013	2014	2013	2014
<i>Tillage and crop establishment</i>						
PTR-CTW	94.2	98.8	12.9	13.5	123	129
ZT DSR-ZTW - R	92.7	95.3	12.7	13.1	126	131
ZT DSR-ZTW + R	94.3	97.1	12.8	13.2	128	132
SE(m)	0.97	1.43	0.12	0.22	2.29	2.21
CD at 5%	NS	NS	NS	NS	NS	NS
<i>Cultivar</i>						
Basmati	80.4	82.3	11.1	11.3	117	123
Hybrid	107	111	14.5	15.2	135	138
SE(m)	0.79	0.99	0.10	0.14	1.61	1.89
CD at 5%	2.34	2.94	0.31	0.40	4.80	5.63
<i>Nitrogen management</i>						
80% RDN + GS	92.2	96.6	12.6	13.3	125	130
RDN	95.2	97.4	13.0	13.3	127	131
SE(m)	0.79	0.99	0.31	0.14	1.61	1.89
CD at 5%	2.34	NS	NS	NS	NS	NS

4.2 Wheat

4.2.1 Plant population per meter row length

Data recorded for plant population under various treatments for tillage and residue management, legume integration and nitrogen management is given in Table 4.15. Plant population was not influenced significantly due to tillage and residue management, nitrogen management and legume treatments in both the cropping seasons. However, numerically higher plant population was recorded during year 2014-15.

4.2.2 Plant height

Tillage and crop establishment methods did not influence the plant height up to 60 DAS under both crop seasons of 2013-14 and 2014-15 but after that there was significant difference within treatments (Table 4.16). Furthermore, statistically similar plant height was observed under zero tilled wheat with residue (ZTW + R) and without residue (ZTW – R), which was significantly higher as compared to conventional tilled wheat (CTW) beyond 90 DAS for crop season 2013-14 and 2014-15. ZTW+R showed maximum plant height in both the cropping seasons; 2013-14 (102.71 cm) and 2014-15 (100.13 cm). Nitrogen management and legume inclusion had no significant influence on plant height of wheat.

Table 4.15: Effect of tillage, residues, cultivars and nitrogen management on plant population (no. /m.r.l.) of wheat

Treatment	Plant population (20 DAS)	
	2013-14	2014-15
<i>Tillage and residue</i>		
PTR-CTW	17.7	18.2
ZT DSR-ZTW – R	17.4	19.0
ZT DSR-ZTW + R	17.7	19.8
SEm ₊	0.50	0.32
CD at 5%	NS	NS
<i>Nitrogen management</i>		
80% RDN + GS	17.6	18.9
RDN	17.6	19.1
SEm ₊	0.38	0.49
CD at 5%	NS	NS
<i>Legume</i>		
Without Greengram	17.6	18.8
With Greengram	17.6	19.3
SEm ₊	0.38	0.49
CD at 5%	NS	NS

4.2.3 Dry matter accumulation

Dry matter accumulation was significantly affected by tillage and residue management practices at different growth stages except at 30 DAS during both years (Table 4.17). ZT DSR-ZTW + R produced statistically similar dry matter up to 90 DAS to ZT DSR-ZTW - R, but it was significantly higher to PTR-CTW during both the cropping seasons. At harvest, ZT DSR-ZTW + R accumulated 2.85 and 4.33% higher dry matter as compared to PTR-CTW during 2013-14 and 2014-15 respectively, which was significantly higher in comparison to rest of the treatments during both years.

Nitrogen management and legume inclusion in rotation failed to produce significant effect on dry matter production during both the cropping seasons.

4.2.4 Growth indices

Treatments for tillage and residue management practices, nitrogen management and legume inclusion in cropping system failed to produce any significant effect on crop growth rate and relative growth rate during 2013-14 and 2014-15 (Table 4.18 and 4.19). During both year of study numerically higher value of CGR and RGR was recorded under ZT DSR-ZTW+R as compared to rest of the treatments.

Table 4.16: Effect of tillage, residues, legume and nitrogen management on plant height (cm) of wheat

Treatment	30 DAS		60 DAS		90 DAS		120 DAS		At harvest	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
<i>Tillage and residue</i>										
PTR-CTW	25.1	27.4	40.0	43.4	72.6	74.6	95.1	96.3	98.4	97.3
ZT DSR-ZTW – R	25.3	27.4	40.9	43.4	74.4	75.7	96.9	97.4	101	99.9
ZT DSR-ZTW + R	25.7	28.9	40.7	44.0	75.6	76.4	97.9	99.5	103	100
SEm±	0.32	0.72	0.70	0.62	0.31	0.24	0.40	0.46	0.56	0.65
CD at 5%	NS	NS	NS	NS	1.24	0.78	1.57	1.74	1.95	2.20
<i>Nitrogen management</i>										
80% RDN + GS	25.7	28.6	40.5	43.4	73.3	75.1	96.3	97.6	101	98.9
RDN	25.0	27.3	40.6	43.8	75.1	75.8	96.8	97.8	100	99.3
SEm±	0.24	0.51	0.48	0.53	0.86	0.64	0.66	0.50	0.60	0.51
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<i>Legume</i>										
Without Greengram	25.2	27.8	40.5	43.6	73.6	75.2	96.1	97.5	100	98.8
With Greengram	25.5	28.1	40.5	43.6	74.8	75.7	97.1	98.0	101	99.5
SEm±	0.28	0.51	0.48	0.53	0.86	0.64	0.66	0.50	0.60	0.51
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.17: Effect of tillage, residues, legume and nitrogen management on dry matter accumulation (g/m²) of wheat

Treatment	30 DAS		60 DAS		90 DAS		120 DAS		At harvest	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
<i>Tillage and residue</i>										
PTR-CTW	33.4	34.1	139	144	621	634	937	944	1224	1193
ZT DSR-ZTW – R	33.7	34.5	143	146	658	664	956	962	1248	1222
ZT DSR-ZTW + R	34.1	35.6	145	149	678	685	975	981	1260	1247
SEm±	0.41	0.84	1.02	1.09	8.34	7.50	4.39	5.83	3.78	5.88
CD at 5%	NS	NS	3.08	3.65	27.8	23.2	14.0	17.6	12.1	18.8
<i>Nitrogen management</i>										
80% RDN + GS	34.0	35.1	142	146	643	655	955	961	1243	1219
RDN	33.6	34.4	143	147	662	667	956	964	1247	1223
SEm±	0.61	0.51	3.55	2.65	10.9	8.32	6.01	9.83	6.94	9.24
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<i>Legume</i>										
Without Greengram	33.4	34.4	141	146	651	660	954	959	1239	1215
With Greengram	34.2	35.0	143	147	654	663	957	965	1252	1226
SEm±	0.61	0.51	3.55	2.65	10.9	8.32	6.01	9.83	6.94	9.24
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.18: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on crop growth rate (g/m²/day) of wheat

Treatments	0-30 DAS		30-60 DAS		60-90 DAS		90-120 DAS	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
<i>Tillage and residue</i>								
PTR-CTW	1.11	1.14	3.54	3.65	16.1	16.4	9.90	9.85
ZT DSR-ZTW - R	1.13	1.15	3.63	3.72	17.2	17.3	10.0	10.0
ZT DSR-ZTW + R	1.14	1.19	3.68	3.77	17.8	17.9	10.5	10.3
SE(m)	0.01	0.03	0.20	0.05	0.79	0.42	0.70	0.46
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
<i>Nitrogen management</i>								
80% RDN + GS	1.33	1.17	3.63	3.72	17.3	17.4	9.81	9.88
RDN	1.12	1.15	3.61	3.71	16.7	17.0	10.4	10.2
SE(m)	0.02	0.02	0.12	0.10	0.32	0.29	0.55	0.59
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
<i>Legume</i>								
Without greengram	1.11	1.15	3.57	3.69	17.0	17.1	9.64	9.63
With greengram	1.14	1.17	3.67	3.74	17.0	17.2	10.6	10.4
SE(m)	0.02	0.02	0.12	0.10	0.32	0.29	0.55	0.59
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.19: Effect of tillage, residues, legume and nitrogen management on relative growth rate (mg/g/day) of wheat

Treatments	0-30 DAS		30-60 DAS		60-90 DAS		90-120 DAS	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
<i>Tillage and residue</i>								
PTR-CTW	116	117	47.4	47.7	49.8	49.5	12.1	12.0
ZT DSR-ZTW - R	117	118	48.0	48.0	51.0	50.5	12.4	12.4
ZT DSR-ZTW + R	118	119	48.1	48.1	51.5	51.0	13.8	13.3
SE(m)	0.44	0.81	1.62	0.87	2.33	0.67	1.09	0.61
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
<i>Nitrogen management</i>								
80% RDN + GS	117	118	47.7	47.7	50.3	50.5	12.3	12.2
RDN	117	118	47.9	48.1	51.2	50.1	13.2	12.8
SE(m)	0.61	0.51	1.08	0.83	0.72	0.72	0.73	0.69
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
<i>Legume</i>								
Without greengram	117	118	47.8	47.4	50.3	50.1	12.3	12.1
With greengram	118	118	47.9	48.3	51.2	50.5	13.3	12.9
SE(m)	0.61	0.51	1.08	0.83	0.72	0.72	0.73	0.69
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.20: Effect of tillage, residues, legume and nitrogen management on total tillers (no./m²) of wheat

Treatment	30 DAS		60 DAS		90 DAS		120 DAS		At harvest	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
<i>Tillage and residue</i>										
PTR-CTW	203	205	373	367	376	387	379	389	378	369
ZT DSR-ZTW – R	205	207	388	392	411	423	415	431	416	402
ZT DSR-ZTW + R	208	209	396	399	420	427	425	434	424	414
SEm±	2.08	2.19	15.3	12.4	7.82	7.51	2.7	5.8	5.1	9.3
CD at 5%	NS	NS	NS	NS	24.4	29.3	10.4	18.3	20.0	28.6
<i>Nitrogen management</i>										
80% RDN + GS	207	209	383	388	400	414	410	417	404	389
RDN	204	207	389	384	404	410	403	419	408	401
SEm±	3.06	3.22	6.32	6.03	8.37	6.53	6.2	5.7	7.5	5.7
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<i>Legume</i>										
Without Greengram	204	206	385	384	401	411	405	417	405	395
With Greengram	206	208	386	387	404	414	408	419	407	396
SEm±	3.06	3.22	6.32	6.03	8.37	6.53	6.2	5.7	7.5	5.7
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

4.2.6 Number of tillers

Data recorded on number of tillers at various crop growth stages during both cropping seasons has been provided in Table 4.20. Tillage and residue management practices resulted into significant effects on number of tillers at all growth stages except at 30 DAS and 60 DAS during both years of study. ZT DSR-ZTW+R produced significantly higher tillers compared to PTR-CTW, however it was at par with ZT DSR-ZTW-R at 90, 120 DAS and at harvest. At harvest, ZT DSR-ZTW+R produced 10.84% (2013-14) and 10.86% (2014-15) higher number of tillers as compared to PTR-CTW.

Treatments for nitrogen management as well as inclusion of legume in cropping system of rice-wheat failed to produce significant variations on tiller production.

Table 4.21: Effect of tillage, residues, legume and nitrogen management on yield attributes of wheat

Treatment	Effective tillers (no./m ²)		Spike length (cm)		Grains/spike (no.)		1000 grain wt. (g)	
	2013-14	2014-15	2013-14	2013-14	2014-15	2014-15	2013-14	2014-15
<i>Tillage and residue</i>								
PTR-CTW	372	361	10.2	9.95	49.0	46.4	40.9	40.3
ZT DSR-ZTW – R	404	386	10.3	10.2	51.2	49.3	41.1	40.6
ZT DSR-ZTW + R	410	392	10.4	10.3	52.1	50.9	41.5	41.2
SEm _±	7.43	6.74	0.10	0.20	0.57	0.36	0.25	0.18
CD at 5%	22.56	20.94	NS	NS	2.22	1.44	NS	NS
<i>Nitrogen management</i>								
80% RDN + GS	391	380	10.3	10.1	51.0	49.1	41.2	40.9
RDN	399	379	10.4	10.1	50.6	48.6	41.1	40.5
SEm _±	4.93	5.19	0.19	0.18	0.42	0.59	0.26	0.21
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
<i>Legume</i>								
Without Greengram	395	378	10.2	10.1	50.3	48.8	41.0	40.5
With Greengram	396	381	10.5	10.2	51.2	48.8	41.3	40.8
SEm _±	4.93	5.19	0.19	0.18	0.42	0.59	0.26	0.21
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

4.2.7 Yield attributes

Effective tillers and grains per spikes differed significantly due to tillage and residue management practices in both the cropping seasons; however spike length and test weight remained unaffected (Table 4.21). Both effective tillers and grains per spike produced under ZT DSR-ZTW-R and ZT DSR-ZTW+R were found statistically at par, however those were significantly higher than

PTR-CTW during both years. ZT DSR-ZTW+R produced 9.27 and 7.91% higher effective tillers in comparison to PTR-CTW during 2013-14 and 2014-15 respectively. Similarly number of grains per spike was 5.95 and 8.84% higher under ZT DSR-ZTW+R as compared to PTR-CTW during 2013-14 and 2014-15 respectively. Effective tillers were did not influence significantly due to nitrogen management and legume inclusion.

4.2.8 Yield and harvest index

Tillage and residue management practices showed significant effect on grain, straw and biological yield and harvest index of wheat during both of the cropping seasons (Table 4.22). Grain, straw and biological yield of wheat were significantly higher under ZT DSR-ZTW+R as compared to other treatments during 2013-14 but in second year it was statistically at par with ZT DSR-ZTW-R. Under PTR-CTW 9.44 and 17.09% lower grain yield was recorded as compared to ZT DSR-ZTW+R during 2013-14 and 2014-15, respectively. Harvest index of wheat crop was significantly higher in ZT DSR-ZTW+R followed by ZT DSR-ZTW-R and lowest was under PTR-CTW during both crop seasons.

Table 4.22: Effect of tillage, residues, legume and nitrogen management on yields and harvest index of wheat

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Biological yield (t/ha)		Harvest Index (%)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
<i>Tillage and residue</i>								
PTR-CTW	5.61	5.09	6.63	5.94	12.24	11.04	45.85	46.18
ZT DSR-ZTW – R	5.98	5.76	7.00	6.64	12.99	12.42	46.08	46.45
ZT DSR-ZTW + R	6.14	5.96	7.14	6.86	13.29	12.83	46.23	46.50
SEm±	0.03	0.08	0.03	0.11	0.07	0.19	0.05	0.05
CD at 5%	0.11	0.25	0.10	0.37	0.22	0.63	0.18	0.17
<i>Nitrogen management</i>								
80% RDN + GS	5.83	5.59	6.84	6.46	12.68	12.05	46.01	46.37
RDN	5.99	5.63	7.01	6.51	13.00	12.14	46.08	46.38
SEm±	0.08	0.10	0.08	0.13	0.16	0.22	0.06	0.06
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
<i>Legume</i>								
Without Greengram	5.89	5.59	6.91	6.45	12.81	12.05	45.99	46.36
With Greengram	5.93	5.63	6.93	6.51	12.87	12.14	46.11	46.39
SEm±	0.08	0.10	0.08	0.13	0.16	0.22	0.06	0.06
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

Treatments for nitrogen management and legume inclusion in cropping system had no significant effects on grain yield, straw yield, biological yield and harvest index during any of the

cropping season (Table 4.22) but numerically higher values were recorded under RDN and greengram inclusion during both years of study.

4.2.9 Economics

Total cost of cultivation, gross returns, benefit cost ratio (B:C) of wheat under various tillage and residue management practices, nitrogen management and legume integration treatments is given in Table 4.23 and Fig. 3.2. Total cost of cultivation, gross returns, net returns and benefit cost ratio varied with tillage and residue management practices. PTR-CTW incurred highest cost of cultivation followed by ZT DSR-ZTW+R and ZT DSR-ZTW-R during both of the cropping seasons. During 2013-14 and 2014-15, PTR-CTW showed 12.73 and 12.01% higher cost of cultivation in comparison to ZT DSR-ZTW+R. Maximum gross returns, net returns and benefit cost ratio were recorded under ZT DSR-ZTW-R in both seasons. Under ZT DSR-ZTW-R, 13.80 and 20.39% higher net returns was recorded in 2013-14 and 2014-15 cropping seasons, respectively as compared to PTR-CTW. ZT DSR-ZTW-R showed higher benefit cost ratio in 2013-14 (3.06) as well as in 2014-15 (3.29) over rest of the treatments.

RDN resulted into comparatively higher cost of cultivation, but revealed lower gross returns, net returns and benefit cost ratio during both the years. Legume integration increased the cost of cultivation, however reduced the net return as well as benefit cost ratio during 2013-14 and 2014-15.

Table 4.23: Effect of tillage, residues, legume and nitrogen management on economics of wheat

Treatment	Total cost (x 10 ³ ₹ha ⁻¹)		Gross returns (x 10 ³ ₹ha ⁻¹)		Net returns (x 10 ³ ₹ha ⁻¹)		B:C	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
<i>Tillage and residue</i>								
PTR-CTW	25.92	24.30	83.63	77.44	57.71	53.13	2.23	2.19
ZT DSR-ZTW – R	22.89	20.37	88.84	87.12	66.95	66.74	3.06	3.29
ZT DSR-ZTW + R	22.62	21.38	86.03	86.53	63.42	65.15	2.82	3.06
<i>Nitrogen management</i>								
80% RDN + GS	23.47	21.98	85.06	83.42	61.59	61.44	2.62	2.79
RDN	23.48	22.06	87.27	83.97	63.80	61.91	2.71	2.81
<i>Legume</i>								
Without Greengram	22.16	20.70	85.86	83.40	63.70	62.71	2.90	3.06
With Greengram	24.79	23.34	86.48	83.99	61.68	60.65	2.51	2.63

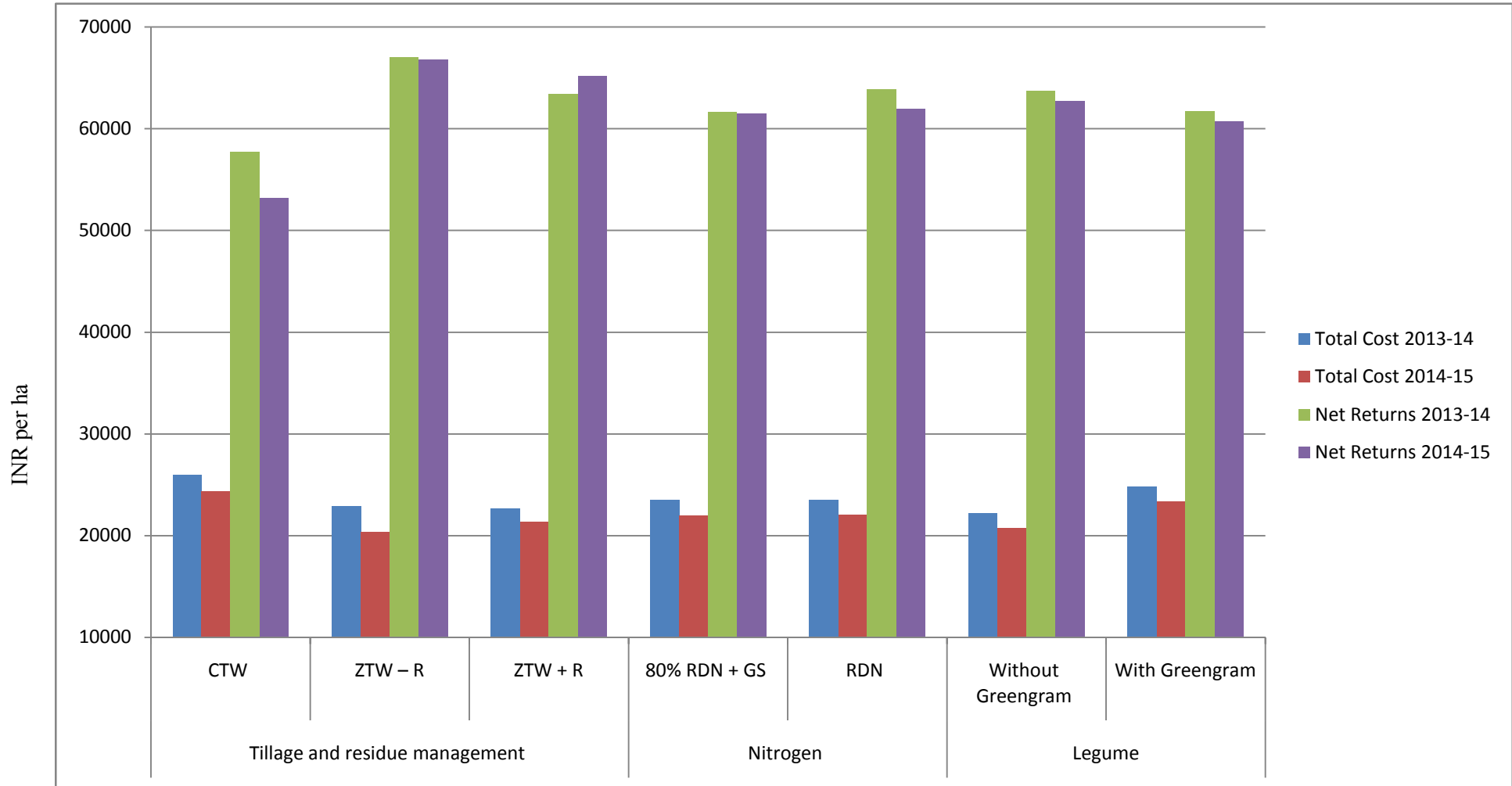


Fig. 4.2 Effect of tillage and residue management, nitrogen and legume integration on total cost of cultivation and net returns in wheat

4.2.10 Nitrogen content and uptake in wheat grain and straw

Tillage and residue management, nitrogen and legume integration treatments showed non significant effect on grain N content in both the cropping seasons (Table 4.24). Grain N uptake was significantly affected by tillage and residue management practices in both of the cropping seasons. ZT DSR-ZTW+R showed 9.87 and 3.22% higher grain N uptake as compared to PTR-CTW and ZT DSR-ZTW-R during 2013-14 and 17.49 and 4.08% during 2014-15. Similarly ZT DSR-ZTW+R resulted into higher straw N uptake (8.83 and 3.30% during 2013-14 and 16.56 and 4.54% during 2014-15) in comparison to PTR-CTW and ZT DSR-ZTW-R respectively.

Nitrogen management and legume treatments failed to produce any significant effect on grain and straw N content and uptake during both years of study.

Table 4.24: Effect of tillage, residues, legume and nitrogen management on nitrogen (N) content (%) and uptake (kg/ha) of wheat grain and straw

Treatment	Grain N content		Straw N content		Grain N uptake		Straw N uptake	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
<i>Tillage and residue</i>								
PTR-CTW	1.524	1.544	0.464	0.471	85.59	78.73	30.77	28.01
ZT DSR-ZTW – R	1.521	1.541	0.463	0.470	91.10	88.87	32.42	31.23
ZT DSR-ZTW + R	1.530	1.550	0.469	0.476	94.04	92.50	33.49	32.65
SEm±	0.005	0.005	0.003	0.003	0.54	1.19	0.37	0.67
CD at 5%	NS	NS	NS	NS	2.13	4.67	1.45	2.64
<i>Nitrogen management</i>								
80% RDN + GS	1.536	1.544	0.465	0.472	91.37	86.33	31.88	30.48
RDN	1.524	1.546	0.466	0.473	89.12	87.06	32.58	30.78
SEm±	0.003	0.003	0.001	0.001	1.24	1.61	0.37	0.53
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
<i>Legume</i>								
Without Greengram	1.523	1.543	0.464	0.471	90.06	86.54	32.21	30.56
With Greengram	1.528	1.548	0.466	0.473	90.42	86.86	32.24	30.70
SEm±	0.003	0.003	0.001	0.001	1.24	1.61	0.37	0.53
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

4.2.11 Phosphorus content and uptake in wheat grain and straw

Data on P content in wheat grain and straw was not influenced by different tillage and residue, nitrogen and legume management treatment both in 2013-14 and 2014-15 (Table 4.25). However, P uptake by wheat grain and straw was significantly affected by tillage and residue management practices. ZT DSR-ZTW+R showed highest P uptake by grain as well as straw in both cropping seasons.

Nitrogen management and legume treatments failed to produce significant effect on grain and straw P content and uptake during both years of study.

Table 4.25: Effect of tillage, residues, legume and nitrogen management on phosphorous (P) content (%) and uptake (kg/ha) of wheat grain and straw

Treatments	Grain P content		Straw P content		Grain P uptake		Straw P uptake	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
<i>Tillage and residue</i>								
PTR-CTW	0.226	0.229	0.058	0.059	12.67	11.69	3.84	3.51
ZT DSR-ZTW – R	0.227	0.230	0.058	0.059	13.57	13.28	4.07	3.94
ZT DSR-ZTW + R	0.228	0.232	0.059	0.060	14.04	13.85	4.21	4.12
SEm±	0.003	0.003	0.003	0.003	0.138	0.23	0.057	0.098
CD at 5%	NS	NS	NS	NS	0.54	0.90	0.22	0.38
<i>Nitrogen management</i>								
80% RDN + GS	0.227	0.230	0.050	0.059	13.27	12.87	4.01	3.83
RDN	0.227	0.231	0.059	0.060	13.58	13.00	4.07	3.89
SEm±	0.001	0.001	0.002	0.002	0.18	0.24	0.04	0.067
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
<i>Legume</i>								
Without Greengram	0.226	0.230	0.058	0.059	13.42	12.92	4.00	3.83
With Greengram	0.228	0.231	0.059	0.060	13.43	12.95	4.07	3.88
SEm±	0.001	0.001	0.002	0.002	0.18	0.24	0.04	0.067
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

4.2.12 Potassium content and uptake in wheat grain and straw

Unlikely to N and P content by grain and straw of wheat, none of treatments showed significant effects in both the cropping seasons (Table 4.26). In case of grain and straw K uptakes, tillage and residue management practices showed significant effects. ZT DSR-ZTW+R showed maximum grain K uptake during 2013-14 (26.01 kg/ha) and 2014-15 (25.76 kg/ha), which was found statistically at par with ZT DSR-ZTW-R but superior to PTR-CTW during both cropping seasons. However, total straw K uptake under ZT DSR-ZTW+R was found significantly higher over rest of the treatments in 2013-14 (96.31 kg/ha), whereas during 2014-15, it was significant over PTR-CTW, but at par with ZT DSR-ZTW-R.

Nitrogen management and legume treatments failed to produce significant effect on grain and straw K content and uptake during both years of study.

Table 4.26: Effect of tillage, residues, legume and nitrogen management on potassium (K) content and uptake of wheat grain and straw

Treatment	Grain K content		Straw K content		Grain K uptake		Straw K uptake	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
<i>Tillage and residue</i>								
PTR-CTW	0.418	0.426	1.342	1.369	23.47	21.74	88.98	81.37
ZT DSR-ZTW – R	0.420	0.429	1.340	1.367	25.15	24.70	93.81	90.84
ZT DSR-ZTW + R	0.424	0.432	1.348	1.375	26.01	25.76	96.31	94.36
SEm±	0.003	0.003	0.005	0.005	0.25	0.42	0.49	1.51
CD at 5%	NS	NS	NS	NS	1.01	1.67	1.92	5.91
<i>Nitrogen management</i>								
80% RDN + GS	0.420	0.428	1.342	1.369	24.59	23.95	91.99	88.44
RDN	0.421	0.430	1.344	1.371	25.17	24.19	94.08	89.27
SEm±	0.002	0.002	0.003	0.003	0.34	0.42	1.08	1.54
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
<i>Legume</i>								
Without Greengram	0.419	0.427	1.341	1.368	24.88	24.05	93.01	88.06
With Greengram	0.422	0.430	1.346	1.372	24.87	24.09	93.06	89.65
SEm±	0.002	0.002	0.003	0.003	0.34	0.42	1.08	1.54
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

Table 4.27: Effect of tillage, crop establishment, residues, cultivars and nitrogen management on total (grain and straw) NPK uptake (Kg/ha) in wheat

Treatments	Total N uptake		Total P uptake		Total K uptake	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
<i>Tillage and residue</i>						
PTR-CTW	116	107	16.5	15.2	112	102
ZT DSR-ZTW - R	124	120	17.6	17.2	119	114
ZT DSR-ZTW + R	127	125	18.2	18.0	122	119
SE(m)	0.84	1.82	0.19	0.32	0.75	1.94
CD at 5%	3.26	7.12	0.75	1.27	2.91	7.6
<i>Nitrogen management</i>						
80% RDN + GS	121	117	17.3	16.7	117	111
RDN	124	118	17.6	16.9	119	112
SE(m)	1.62	2.14	0.23	0.31	1.43	1.98
CD at 5%	NS	NS	NS	NS	NS	NS
<i>Legume</i>						
Without greengram	122	117	17.4	16.7	118	112
With greengram	123	117	17.5	16.8	118	112
SE(m)	1.62	2.14	0.23	0.31	1.43	1.98
CD at 5%	NS	NS	NS	NS	NS	NS

4.2.13 Total NPK uptake

Data shown in Table 4.27 revealed that tillage and residue management practices showed varied effects on total NPK uptake. ZT DSR-ZTW with and without residue resulted into significantly higher total NPK uptake during 2013-14 and 2014-15 as compared to PTR-CTW. Treatments for nitrogen management and legume integration failed to produce any significant effects on total NPK uptake in both cropping seasons.

4.2.14 System grain yield and economics

Tillage and residue management practices showed varied effects on system grain yield (Wheat equivalent), total cost, gross returns and net returns (Table 4.28). PTR-CTW resulted into lowest system grain yield and net returns. ZT DSR-ZTW + R produced maximum system grain yield, but gross return and net return were higher under ZT DSR-ZTW – R.

Treatment with basmati resulted into higher system grain yield, gross returns and net returns. Comparatively higher cost of cultivation was observed under hybrid treatments. Between nitrogen management treatments, higher system grain yield, total cost, gross returns and net returns were recorded under RDN.

Table 4.28: Effect of tillage, residues, legume and nitrogen management on system grain yield (wheat equivalent) and system economics

Treatments	System grain yield (t/ha)		Total cost (x 10 ³ ₹ha ⁻¹)		Gross return (x 10 ³ ₹ha ⁻¹)		Net return (x 10 ³ ₹ha ⁻¹)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Tillage and residue								
PTR-CTW	15.30	13.28	69.2	73.2	220.9	197.4	151.6	124.2
ZT DSR-ZTW - R	15.29	13.50	57.3	59.2	220.7	200.5	163.4	141.3
ZT DSR-ZTW + R	15.54	13.74	59.3	63.3	217.5	199.2	158.2	136.0
Cultivar								
Basmati	18.34	14.91	61.7	64.2	262.3	220.2	200.6	156.0
Hybrid	12.41	12.10	62.2	67.6	177.1	177.9	114.9	110.3
Nitrogen								
80% RDN + GS	15.26	13.41	60.9	64.7	216.7	197.7	155.8	133.0
RDN	15.48	13.60	63.0	67.1	222.6	200.3	159.6	133.2

4.3 Soil physio-chemical properties

4.3.1 Soil pH and electrical conductivity

Data presented in Table 4.29 revealed that soil pH and electrical conductivity was not significantly affected by tillage, crop establishment and residue as well as by nitrogen and legume management treatments. However, a very slight decrease was observed in IInd year values.

Table 4.29: Effect of tillage, crop establishment, residues, legume and nitrogen management on soil pH and electrical conductivity

Treatment	Soil pH			Electrical conductivity (dS/m)		
	June 2013	June 2014	June 2015	June 2013	June 2014	June 2015
<i>Tillage, crop establishment and residue</i>						
PTR-CTW	8.028	8.029	8.023	0.403	0.409	0.409
ZT DSR-ZTW – R	8.008	7.985	7.957	0.393	0.400	0.38
ZT DSR-ZTW + R	8.003	7.98	7.964	0.391	0.403	0.373
SE(m)	0.01	0.048	0.06	0.013	0.009	0.013
CD at 5%	NS	NS	NS	NS	NS	NS
<i>Nitrogen management</i>						
80% RDN + GS	8.019	8.008	8.00	0.395	0.408	0.389
RDN	8.006	7.988	7.963	0.397	0.4	0.386
SE(m)	0.017	0.040	0.03	0.011	0.012	0.08
CD at 5%	NS	NS	NS	NS	NS	NS
<i>Legume</i>						
Without Greengram	8.017	7.977	7.981	0.393	0.406	0.382
With Greengram	8.008	8.019	7.982	0.399	0.402	0.392
SE(m)	0.017	0.040	0.03	0.011	0.012	0.08
CD at 5%	NS	NS	NS	NS	NS	NS

Table 4.30: Effect of tillage, crop establishment, residues, legume and nitrogen management on bulk density and soil infiltration rate

Treatments	Bulk density(mg/m ³)			Infiltration rate (mm/hr)		
	June 2013	June 2014	June 2015	June 2013	June 2014	June 2015
<i>Tillage, crop establishment and residue</i>						
PTR-CTW	1.592	1.584	1.582	5.36	5.33	5.35
ZT DSR-ZTW – R	1.569	1.575	1.559	5.93	6.02	6.09
ZT DSR-ZTW + R	1.559	1.563	1.563	5.97	6.07	6.14
SEm±	0.021	0.012	0.016	0.042	0.039	0.028
CD at 5%	NS	NS	NS	0.16	0.15	0.11
<i>Nitrogen management</i>						
80% RDN + GS	1.571	1.576	1.572	5.76	5.81	5.88
RDN	1.576	1.572	1.564	5.75	5.81	5.84
SEm±	0.005	0.005	0.009	0.013	0.017	0.038
CD at 5%	NS	NS	NS	NS	NS	NS
<i>Legume</i>						
Without Greengram	1.571	1.563	1.556	5.74	5.81	5.90
With Greengram	1.576	1.585	1.579	5.75	5.81	5.82
SEm±	0.005	0.005	0.009	0.013	0.017	0.038
CD at 5%	NS	NS	NS	NS	NS	NS

4.3.2 Bulk density and infiltration rate

Bulk density was not influenced by tillage, crop establishment and residue management practices, nitrogen management and legume integration treatments (Table 4.30). However infiltration rate was significantly affected by tillage and residue management practices. Significantly higher infiltration rate was recorded under ZT DSR-ZTW + R as compared to PTR-CTW. After termination of experiment (June 2015), 12.86% higher infiltration rate was recorded under ZT DSR-ZTW + R in comparison to PTR-CTW (5.35 mm/hr), whereas, it was almost similar in ZT DSR-ZTW + R and ZT DSR-ZTW + R.

Nitrogen management and legume integration treatments failed to produce significant variation in infiltration rate.

Table 4.31: Effect of tillage, crop establishment, residues, legume and nitrogen management on available nitrogen, available phosphorus and available potassium

Treatment	Available nitrogen (kg/ha)			Available phosphorus (kg/ha)			Available potassium (kg/ha)		
	June 2013	June 2014	June 2015	June 2013	June 2014	June 2015	June 2013	June 2014	June 2015
<i>Tillage, crop establishment and residue</i>									
PTR-CTW	129.22	127.83	128.51	15.19	15.18	15.24	278.26	271.94	264.45
ZT DSR-ZTW – R	132.53	136.67	139.34	15.63	15.81	16.17	285.19	291.52	301.77
ZT DSR-ZTW + R	138.61	144.41	149.63	15.98	16.31	16.95	303.29	314.99	326.07
SEm±	0.89	1.28	2.28	0.15	0.10	0.12	4.01	4.34	2.96
CD at 5%	3.49	4.98	8.93	0.57	0.39	0.48	15.67	16.96	11.54
<i>Nitrogen management</i>									
80% RDN + GS	132.99	136.22	139.05	15.61	15.75	16.07	288.23	290.91	297.07
RDN	133.93	136.38	139.27	15.58	15.79	16.18	289.60	294.72	297.77
SEm±	0.87	0.48	0.82	0.09	0.10	0.08	1.71	1.68	3.42
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS
<i>Legume</i>									
Without Greengram	132.20	135.60	138.45	15.54	15.67	16.08	288.81	291.83	296.12
With Greengram	134.73	137.01	139.87	15.66	15.86	16.17	289.03	293.80	298.74
SEm±	0.87	0.48	0.82	0.09	0.10	0.08	1.71	1.68	3.42
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS

4.3.3 Available nitrogen, phosphorus and potassium in soil

Year wise available N, P and K status in soil has been given in Table 4.31. Tillage, crop establishment and residue management practices had significant effect on the available N, P and K in soil. Over the cropping cycles, CA management practices i.e. ZT DSR-ZTW-R and ZT DSR-ZTW+R showed higher available nutrients (N, P and K) status in soil. ZT DSR-ZTW + R resulted into

comparatively higher available N, P and K as compared to rest of the treatments. At termination of the experiment (June, 2015), PTR-CTW resulted into significantly lower available N (128.51 kg/ha), P (15.24 kg/ha) and K (264.45 kg/ha) in comparison to rest of the treatments, which was 8.43, 6.10 and 14.11% lower to ZT DSR-ZTW-R and 16.43, 11.22 and 23.30% lower to ZT DSR-ZTW+R, respectively.

Though nitrogen management and legume integration showed non-significant impacts on available N, P and K status in soil, However, RDN and inclusion of legume showed superiority in residual status of nutrients (N, P and K)

Table 4.32: Effect of tillage, residue, legume and nitrogen management on soil organic carbon (%)

Treatment	At start of the experiment (June 2013)				After completion of the experiment (June 2015)			
	0-5 cm	5-15 cm	15-30 cm	30-60 cm	0-5 cm	5-15 cm	15-30 cm	30-60 cm
<i>Tillage, crop establishment and residue</i>								
PTR-CTW	0.64	0.48	0.29	0.21	0.66	0.51	0.32	0.21
ZT DSR-ZTW – R	0.86	0.65	0.42	0.21	0.91	0.73	0.45	0.23
ZT DSR-ZTW + R	0.98	0.72	0.43	0.22	1.06	0.81	0.48	0.23
SEm±	0.028	0.063	0.013	0.014	0.008	0.020	0.014	0.007
CD at 5%	0.108	0.016	0.050	NS	0.030	0.079	0.054	NS
<i>Nitrogen management</i>								
80% RDN +GS	0.82	0.61	0.37	0.20	0.87	0.68	0.41	0.22
RDN	0.82	0.62	0.39	0.23	0.88	0.69	0.42	0.22
SEm±	0.017	0.016	0.019	0.014	0.019	0.012	0.008	0.005
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS
<i>Legume</i>								
Without greengram	0.82	0.61	0.38	0.21	0.87	0.68	0.41	0.22
With greengram	0.84	0.62	0.39	0.23	0.88	0.69	0.42	0.22
SEm±	0.017	0.016	0.019	0.014	0.019	0.012	0.008	0.005
CD at 5%	NS	NS	NS	NS	NS	NS	NS	NS

4.3.4 Soil organic carbon

Depth wise data recorded for soil organic carbon (SOC) analysis has been given in Table 4.32. Tillage, crop establishment and residue management practices significantly influenced the soil organic carbon up to 30 cm depth. At deeper depth (30-60 cm) SOC was not influenced by any of the treatments. Maximum value for soil organic carbon was found in uppermost layer (0-5 cm). Thereafter with the increase in soil depth, a substantial decrease in organic carbon values was recorded across the treatments and over the years. After termination of the experiment SOC increased by 8.16% (0-5 cm), 12.5% (5-15 cm), and 11.62% (15-30cm) under ZT DSR-ZTW + R in comparison to its initial year's values and moreover these values were also found significantly higher as compared

to PTR-CTW over the years. Data shown in Table 4.33 revealed that tillage, crop establishment and residue management practices had significant effect on total soil organic carbon stock and sequestration rate. ZT DSR-ZTW + R treatment resulted into significantly higher SOC stock with maximum sequestration rate.

Treatment for nitrogen management and inclusion of legume in cropping system failed to produce significant effects on soil organic carbon, total SOC stocks as well as carbon sequestration rate.

Table 4.33: Effect of tillage, residue, legume and nitrogen management on total soil organic carbon (SOC) stock and carbon sequestration rate (0-15 cm)

Treatments	SOC (Mg/ha)	Carbon sequestration rate (Mg/ha/year)
<i>Tillage and residue</i>		
PTR-CTW	13.32(1.31)	0.32
ZT DSR-ZTW – R	18.51(6.50)	1.62
ZT DSR-ZTW + R	21.02(9.01)	2.25
SEm+	0.43	0.11
CD at 5%	1.34	0.34
<i>Nitrogen</i>		
80% RDN + GS	17.56(5.55)	1.39
RDN	17.67(5.66)	1.41
SEm+	0.11	0.03
CD at 5%	NS	NS
<i>Legume</i>		
Without Greengram	17.49(5.48)	1.37
With Greengram	17.74(5.73)	1.43
SEm+	0.11	0.03
CD at 5%	NS	NS

The study entitled “Effect of tillage, cultivars, residue and nitrogen management on crop performance and carbon sequestration in rice-wheat cropping system” was conducted during 2013-14 and 2014-15. The results on growth parameters, yield attributes and yields of rice and wheat crops, along with its productivity as influenced by tillage, crop establishment, nitrogen and residue management treatments have been presented in previous chapter with the help of appropriate tables and suitable figures. An attempt, therefore, has been made in this chapter to assign appropriate reasons along with suitable findings of other workers to support and compare present investigations.

5.1 Weather and crop growth

Crop growth, development and consequently the yield potential of rice and wheat crops were greatly influenced by the weather conditions prevailing during the crop seasons 2013-14 and 2014-15. The productivity of rice and wheat showed a variation in two years of experimentation. Weather data of two cropping years (Fig. 3.1, 3.2, 3.3 and 3.4) revealed the total rainfall recorded was 902.2 mm and 709.0 mm during 2013-14 and 2014-15, respectively, which was more than average rainfall. In *kharif* season 2013, there was 26.06% higher rainfall as compared to *kharif* 2014 (485.9 mm), whereas in *rabi* season 2014-15 comparatively 12.33% higher rainfall was received over 2013-14 (253.7 mm). Total number of rainy days recorded during *kharif* season 2013 (33) and 2014 (22) and *rabi* season 2013-14 (20) and 2014-15 (20) shows variation in the amount and distribution of rainfall during the period of investigation. During *rabi* season 2014-15, distribution of rainfall was very poor; 103 mm rainfall was received alone in 9th standard meteorological week, which hampered the crop growth and development of wheat. Mean maximum and minimum temperature prevailed during the period were favourable hence no problem was encountered in germination of crop during both the years of study. A close examination of weather data revealed that during *rabi* season in both the years rainfall is nearly same (222.4 mm in 2013-14 and 253 mm in 2014-15) but there was variation in distribution. During 2013-14, rainfall was evenly distributed in crop period.

5.2 Rice

5.2.1 Growth parameters

The different growth parameters, *viz.* plant height, numbers of plant or tillers, dry matter accumulation of rice were influenced significantly due to tillage, crop establishment, residues and nitrogen management practices in both the years of study. The plant height of rice was recorded significantly higher under PTR as compared to both ZT DSR – R and ZT DSR + R. Similarly higher plant height under puddled transplanted rice was recorded by Choudhary, 2016. This may be due to better availability and less competition for nutrients under transplanted rice.

Initially the dry matter accumulation upto 60 DAS was lower under PTR (Table 4.3) as compared to ZT DSR with and without residue because in DSR the plants were already established, whereas in PTR there was set back due to transplanting as some time was required to establishment of seedlings. Secondly, the high plant population in ZT DSR leads to higher dry matter upto this stage. In later part of the crop growth stages i.e. at 90 DAS and onwards, there was non significant difference in DSR and PTR. This may be due to the more availability of irrigation water to PTR and better weed control lead to higher crop growth and finally leads to non-significant difference in dry matter accumulation. At initial growth stage i.e. 30 DAS, PTR resulted into significantly higher CGR, whereas at later stages i.e. 60 DAS and onwards all TCE methods showed similar CGR. PTR resulted into significantly lower tillers per meter square in comparison to rest of the treatments in both the years at all growth stages. Similarly, Awan *et al.* (2007) reported maximum productive tillers m^{-2} (336) in direct seeded rice than manual transplanted crop (229). Higher seed rate under DSR is the key reason behind high tillering. These results are in consistent with findings of Kumar and Ladha, 2011; Farooq *et al.*, 2011; Pathak *et al.* 2011 and Gill, 2008.

Cultivars did not influence plant height significantly up to 60 DAS, beyond which Basmati attained significantly higher plant height during 2013 and 2014. At harvest stages, basmati exceeded the dry matter production by 17.78% in 2013 and 14.47% in 2014 (Table 4.3) as compared to hybrid. However, 5.88 and 7.07% higher no. of tiller were recorded for the plots under hybrid in 2013 and 2014 respectively as compared to basmati at harvest stage. CGR increased at a faster rate in basmati as compared to hybrid which resulted in high dry matter by basmati in later growth stages (Tripathi *et al.*, 2008). Treatments for nitrogen management also had non significant effect on plant height, dry matter accumulation and no. of tillers on all the growth stages during both 2013 and 2014. The total N supplied in 80% basal + GS (127 kg/ha) was more compared to RDN (120 kg/ha). Since 80% RDN + GS was applied at the time of sowing/transplanting, so it leads to more nitrogen losses as compared to RDN, which was splitted thrice as compared to two splits which lead to less leaching losses. These situations lead to non-significant difference in plant height, tillers and finally on dry matter. Applying N in splits as per need of the crop can considerably increase the N-use efficiency of crop and improve the productivity of rice (Sharif, 1994 and Thakur, 1990).

5.2.2 Yield and yield attributes

The ultimate effect of experimental variables is reflected in the final yield of crop and thus, it is a major criterion to identify the efficiency of various treatments in a given situation. Tillage and crop establishment methods significantly influenced the effective tillers per meter square, no. of grains per panicle and no. of unfilled grains per panicle in both the years (Table 4.7). In general, number of effective tillers was recorded higher in ZT DSR as compared to PTR during both the years. Similar results of higher tillers in DSR compared to TPR and higher spikelet sterility in DSR were

also reported by Choudhury *et al.* (2007) and Bhushan *et al.* (2007). Singh (2005) also reported significantly higher number of panicles per unit area in wet seeded rice than in transplanted rice. In present study, rice plots under PTR produced significantly lower no of effective tillers per meter square in comparison to ZT DSR; however it produced significantly higher no. of grains per panicle during 2013 and 2014. PTR produced 13.2 and 10.1% higher and 14.4 and 10.7% higher no. of grain per panicle over ZT DSR-R and ZT DSR+R in 2013 and 2014, respectively. Probably, it was due to higher competition among tillers for photosynthesis under DSR as compared to PTR, which reduced the panicle length and number of grains per panicle. Higher number of grains per panicle under PTR as compared to DSR has been also reported by Akhgari and Kaviani (2011) and Veeresh *et al.* (2011). However, tillage and crop establishment methods failed to produce significant effect on panicle length and test weight (Table 4.5). Yield attributes varied significantly between cultivars except unfilled grains per panicle. Hybrid produced significantly higher no. of effective tillers, no. of grains per panicle in comparison to basmati during both the years, which might be due to genetic make up of hybrid having higher production potential. Variation in grain yield of cultivars has been also reported by Mahajan *et al.*, 2011. Plots under basmati rice showed significantly higher panicle length and test weight in 2013 and 2014. Test weight in basmati was recorded 16.58 and 16.31% higher in comparison to hybrid during 2013 and 2014 respectively (Table 4.5).

TCE methods had no significant effect on grain yield, straw yield, biological yield and harvest index over both the years (2013 and 2014). This is in agreement with the results reported by Piggin *et al.* (2002), Ladha *et al.* (2009) and Jat *et al.* (2009). Poor grain yield under TPR may be attributed due to poor rooting as results of poor soil physical properties such as compaction and poor soil aggregation (Gathala *et al.*, 2011b; Kumar *et al.*, 2011).

5.2.3 Economics

Tillage and residue management practice showed varied effect on total cost of cultivation, gross returns, net returns and benefit cost ratio. PTR incurred highest cost of cultivation followed by ZT DSR+R and ZT DSR-R during both of the cropping seasons (Table 4.10). During 2013-14 and 2014-15, PTR showed 12.73 and 12.01% higher cost of cultivation in comparison to ZT DSR+R, which was due to more tillage operations in PTR. Maximum gross returns, net returns and benefit cost ratio were recorded under ZT DSR-R in rice season 2013 and 2014. It was due to reduction in cost of cultivation specially tillage and labour cost for transplanting. The present investigation findings are analogous to many other similar studies where DSR showed potential to reduce total labour requirements from 11 to 66% depending on season, location, and type of DSR compared with PTR (Rashid *et al.* 2009). Labour requirements for crop establishment decreased by more than 75% with direct seeding compared with transplanting (Dawe, 2005). Direct seeding has been reported to lower cost of cultivation due to skipping of puddling, nursery raising and transplanting for maintaining

recommended plant population and also due to early maturity under direct seeding (Gill, 2008). Higher returns under direct seeding of rice were also reported by Sharma *et al.* (2004).

Among cultivars, cost of cultivation was higher under treatments which included hybrid cultivation in both the years. It was mainly due expensive seeds, however gross returns, net returns and benefit cost ratio were higher under treatments with basmati in both 2013 and 2014. Higher market price (more than 2.5 times to hybrid) of Basmati resulted in to better returns. Because of higher market price of basmati in 2013 (₹36 kg⁻¹), it showed highest gross returns (₹17723 ha⁻¹), net returns (₹139020 ha⁻¹) and benefit cost ratio (3.61).

5.3 Wheat

5.3.1 Growth parameters

Tillage and residue management practices significantly affected the growth parameters viz. plant height, dry matter accumulation and no. of tillers, ZT DSR-ZTW with and without residue proved superior in plant height, tiller number and dry matter accumulation as compared to PTR-CTW (Table 4.16, 4.17 and 4.20). This might be due to better soil health and micro-environment created by continuous adoption of conservation agriculture based management practices. Wilhelm (1989) also reported better growth of the wheat crop under no-till treatments. Yadav *et al.* (2005) also reported marginally higher growth parameters of wheat crop under ZT than CT. Numerically higher values of growth parameters were recorded during 2013-14 than 2014-15, which might be due to better crop establishment of crop resulted congenial weather conditions. Plant population, plant height, no. of tillers and dry matter accumulation of wheat crop were statistically at par under different treatments of legume and nitrogen management.

5.3.2 Yield attributes and yield

Effective tillers and grains per spike differed significantly due to tillage and residue management practices in both the cropping seasons; however spike length and test weight remained unaffected (Table 4.21). Effective tillers and grains per spike produced under ZT DSR-ZTW-R and ZT DSR-ZTW+R were found statistically at par with each other, however significantly higher than PTR-CTW during both years. Notably higher no. of effective tillers and grains per spike were found in 2014 over 2013 irrespective of treatments. It might be because of residue retention, which ultimately improved the soil moisture conservation. Grain yield and harvest index produced under PTR-CTW was significantly lower as compared to ZT DSR-ZTW - R and ZT DSR-ZTW + R. On the other side treatment under ZT DSR-ZTW+R produced highest straw yield and biological yield, which were significantly higher to rest of the two treatments during both of the cropping seasons. Jat *et al.* (2005) also reported that the productivity of wheat was higher by 7.3% under no-till (5.56 t/ha) compared to conventional till planting (5.12 t/ha). Similarly Yadav *et al.*, (2005) reported that

continuous adoption of ZT in wheat resulted into similar or increased grain yield of wheat over conventional sowing. Gathala *et al.*, (2011a) and Kumar and Ladha, (2011) demonstrated an 8-9% reduction in wheat yield when sown after PTR compared with wheat sown after direct sown rice (DSR) in non-puddled conditions. Gupta *et al.* (2007) has also reported that yield performance of wheat was marginally better under ZT practices.

Residue retention under zero tillage treatments further increased the values of growth parameters, yield attributes and yields of wheat than CTW and ZTW without residue application, might be due to favourable soil moisture, moderated soil temperature, and improved soil fertility due to constant supply of nutrients through mineralization of crop residues. Similarly, Ram *et al.* (2010) reported higher yields under ZT with residue due to the cumulative effects of higher light interception, more dry matter production, low soil and canopy temperature, more soil moisture, tillers, grains/ear and 1000-grain weight than no-residue application under ZT as well as CT practices. The results of higher wheat productivity under ZT are in agreement with earlier short-term studies (Jat *et al.*, 2009 and Gathala *et al.*, 2009). Grain, straw and biological yield and harvest index during 2013-14 cropping season resulted in to higher values of these parameters irrespective of treatments. Moreover, heavy rainfall i.e. 199 mm during reproductive period resulted in lower productivity during 2014-15. Nitrogen management and legume treatments had no significant effects on grain, straw and biological yield and harvest index during any of the cropping season; however inclusion of greengram in cropping sequence resulted in numerically superior yield during both the years. RDN had an edge in grain yield and yield parameters of wheat as compared to 80% RDN + GS which might be due to better N use efficiency in RDN treatment because N was applied 50% at sowing and rest 50% at 1st irrigation, whereas 80% N was applied at sowing in other treatment which might have reduced N use efficiency. The optimum use of N fertilizer will come from matching N supply with crop demand for N (Bhardwaj *et al.*, 2010) and losses of N can be large when the N application is not synchronized with crop growth and development (Bijay-Singh *et al.* 2011).

5.3.3 Economics

Cost of cultivation of wheat crop under different tillage and residue management practices varied from minimum with ZTW-R (22890 and 20370 ₹ ha⁻¹) to maximum under CTW (25920 and 24300 ₹ ha⁻¹) in year 2013-14 and 2014-15, respectively. The maximum net returns (66950 and 66740 ₹ ha⁻¹) and benefit cost ratio (3.06 and 3.29) were recorded under ZTW-R during 2013-14 and 2014-15, while minimum net returns (57710 and 53130 ₹ ha⁻¹) with benefit cost ratio (2.23 and 2.19) were obtained under CTW 2013-14 and 2014-15, respectively. More number of tillage operations contributed greatly to cost of cultivation in any crop production system resulting to lower economic returns (Labios *et al.*, 1997). The higher cost of production under CTW practices was due to more number of tillage operations, which diminished the net returns during both the years of investigation.

Under treatments for nitrogen management, RDN resulted into marginally higher cost of cultivation, gross returns, net returns and benefit cost ratio in both the years, however it was statistically similar with 80% RDN + GS (Table 4.23).

Greengram inclusion in rotation increased the cost of cultivation, because due to rains the crop was damaged during both years of study and no grain was harvested, which resulted in increase in cost of cultivation..

5.4 Total NPK uptake

Tillage and crop establishment methods and nitrogen management treatments in rice failed to produce significant variation on total NPK uptake during both the years except total N uptake in 2013-14, where RDN resulted into significantly higher total N uptake in rice as compared to other treatments (Table 4.14). The Numerical higher total N, P and K uptake under ZT DSR is in agreement with study conducted by Seema *et al.* (2015). Behra *et al.*, 2007 has also reported maximum N, P and K uptakes under ZT rice, which might be due to addition of nutrients through residue, improved physical environment favourable for better microbial activity that might helped in mineralization resulting better availability of nutrients (macro and micro) to crops and thus increased the uptake under these treatments. Rice cultivars significantly influenced the total NPK uptake irrespective of years. Being higher yield potential of hybrid, nutrients demand is higher as compared to basmati. Therefore total NPK uptake was significantly higher under hybrid as compared to basmati during both 2013-14 and 2014-15. In comparison to basmati, hybrid resulted into 24.8 and 25.8% higher total N, 23.4 and 25.6% higher total P and 13.3 and 10.8% higher total K uptake during 2013-14 and 2014-15, respectively. Mahajan *et.al.*, 2011 has also reported varied rate of nutrients uptake by various cultivars.

In Wheat crop, tillage and residue management practices showed varied effects on total NPK uptake. ZT DSR-ZTW with and without residue resulted into significantly higher total NPK uptake during 2013-14 and 2014-15 (Table 4.27). Residue retention on soil surface suppresses the growth of weeds, increased the moisture availability and moderates the soil temperature. Thus, it increased the biomass accumulation which ultimately increased the grain yield of crops (Patra *et al.*, 2004). Torbert and Reves (1994) reported higher N uptake efficiencies under CA practices is caused by reduced soil traffic. Whereas treatments for nitrogen management and legume integration failed to produce any significant effects on total NPK uptake in wheat during both cropping seasons.

5.5 Soil organic carbon

Tillage, crop establishment and residue management practices significantly influenced the soil organic carbon up to 30 cm depth. At deeper depth (30-60 cm) SOC was not influenced by any of the treatments. Maximum value for soil organic carbon was found in uppermost sampling layer (0-5 cm). Thereafter with the increase in soil depth, a substantial decrease in organic carbon values was

recorded irrespective of treatments and year. After termination of the experiment SOC increased by 8.16% (0-5 cm) under ZT DSR-ZTW + R in comparison to its initial year's values and moreover these values were also found significantly higher as compared to PTR-CTW irrespective of year. Nitrogen management and legume integration treatments showed non-significant effects on soil organic carbon.

However inclusion of greengram in crop rotation improved SOC as compared to its initial year's values, which might be due to incorporation of greengram in soil. Similar findings were also reported by Sarkar and Kar (2011). Conservation agriculture, reduced/zero tillage, crop rotation and retention of a rational amount of residue is a practice that leads to soil organic C sequestration and C sequestration is a strategy to achieve food security through improvement of soil quality (Govaerts *et al.*, 2009; Lal, 2004). Zero-tillage, on the other hand, combined with permanent soil cover, has been shown to result in a build-up of organic carbon in the surface layers (Lal, 2013). No-tillage minimizes SOM losses and is a promising strategy to maintain or even increase soil C and N stocks (Bayer *et al.*, 2000).

Field experiment entitled “Effect of tillage, cultivars, nitrogen and residue management on crop performance and carbon sequestration in rice-wheat cropping system” was conducted during 2013-14 and 2014-15 at participatory strategic research and learning platform for climate smart village, Taraori (Karnal) in collaboration with CIMMYT under CGIAR’s research program on climate change, agriculture and food security. The experiment was laid out in split plot design with three replications on clay loam soil. Treatments comprised of three tillage, crop establishment and residue management practices *viz.* PTR-CTW, ZT DSR-ZTW – R and ZT DSR-ZTW + R and four sub plot treatments consisting of two level of nitrogen management *viz.* RDN and 80% RDN + GS guided N application coupled with two legume integration treatments *i.e.* greengram and without greengram during *rabi* and two cultivars *i.e.* basmati and hybrid during *kharif* treatments. The major findings are summarized below:

6.1 Rice

- 6.1.1 The plant height was higher under PTR at all growth stages except 30 and 60 DAS. Significantly lower dry matter accumulation under PTR was recorded only at early growth stages (30 and 60 DAS) as compared to ZT DSR with and without residue. Comparatively higher no. of tillers were recorded under ZT DSR as compared to PTR irrespective of growth stages and year.
- 6.1.2 Basmati produced significantly taller plants at all growth stages except 30 and 60 DAS. Hybrid produced significantly higher dry matter at all growth stages except initial growth stages *i.e.* 30 and 60 DAS. Significantly higher no. of tillers were recorded under hybrid across the crop growth period, except at 30 DAS.
- 6.1.3 Treatments for nitrogen management did not influence the plant height, dry matter accumulation and number of tiller in rice during both 2013 and 2014.
- 6.1.4 ZT DSR with and without residue resulted into significantly higher CGR rate as compared to PTR only at 0-30 DAS, whereas at 60-90 DAS, PTR resulted into significantly higher RGR as compared to ZT DSR treatments during 2013 and 2014
- 6.1.5 PTR produced significantly lower number of effective tillers in comparison to ZT DSR with residue and without residue. PTR produced 13.22 and 10.08% higher and 14.37 and 10.74% higher number of grain per panicle over ZT DSR-R and ZT DSR+R in 2013 and 2014, respectively.
- 6.1.6 ZT DSR with and without residue resulted into significantly higher number of unfilled grains per panicle in comparison to PTR in both the years.

- 6.1.7 Number of grains were higher (15.51 and 17.59% during both 2013 and 2014 respectively) in hybrid as compared to basmati. Basmati produced significantly higher panicle length and test weight during both years. Test weight in basmati was recorded 16.58 and 16.31% higher in comparison to hybrid during 2013 and 2014, respectively.
- 6.1.8 Treatments for nitrogen management had non-significant variation on yield attributes of rice during both years of experimentation.
- 6.1.9 Tillage and crop establishment and nitrogen management treatments failed to produce significant variation on grain, straw and biological yield, harvest index and wheat equivalent yield of rice over both the years except grain yield in 2013, where RDN produced significantly higher grain yield of rice as compared to other treatment.
- 6.1.10 Hybrid produced significantly higher grain yield, straw biological and harvest index and wheat equivalent yield in comparison to basmati during 2013 and 2014.
- 6.1.11 Highest cost of cultivation and gross returns were recorded under PTR in comparison to ZT DSR-R and ZT DSR + R, during both the years of study.
- 6.1.12 ZT DSR-R resulted into better net returns and maximum benefit cost ration in 2013 and 2014.
- 6.1.13 Cost of cultivation was higher under treatments which included hybrid in both the years, however, gross returns, net returns and benefit cost ratio were higher under treatments with basmati during 2013 and 2014.
- 6.1.14 Nitrogen management in 80% RDN + GS incurred higher cost of cultivation as compared to RDN in both the years. Notable higher gross returns, net returns and benefit cost ratio were recorded under RDN than 80% RDN + GS during 2013 as well as 2014.
- 6.1.15 TCE methods and nitrogen management treatments resulted into non significant effect on NPK content and uptake in grain as well as straw during 2013 and 2014.
- 6.1.16 Significantly higher grain and straw NPK uptake was recorded in hybrid as compared to basmati during both the years of experimentation.
- 6.1.17 Total NPK Uptake (grain and straw) was recorded similar under tillage and crop establishment and nitrogen management treatments irrespective of years.
- 6.1.18 Between cultivars, hybrid resulted into significantly higher NPK uptake in both 2013 as well as 2014 cropping seasons.

6.2 Wheat

- 6.2.1 Tillage and residue management practices resulted into significant effects on plant height and number of tillers at all growth stages except at 30 DAS and 60 DAS during both years of study. ZT DSR-ZTW+R showed maximum height in both the cropping seasons; 2013-14 (102.71 cm) and 2014-15 (100.13 cm). At harvest, ZT DSR-ZTW+R produced 10.84 and 10.86% higher number of tiller as compared to PTR-CTW during 2013-14 and 2014-15 respectively.

- 6.2.2 Dry matter accumulation was significantly affected by tillage and residue management practices at different growth stages except at 30 DAS during 2013-14 and 2014-15. At harvest, ZT DSR-ZTW + R resulted into significantly higher dry matter accumulation in comparison to rest of the treatments in 2013-14 (1260 g/m²) as well as 2014-15 (1247 g/m²).
- 6.2.3 Treatments for nitrogen management as well as inclusion of legume in cropping system of rice-wheat failed to produce significant variations on plant height, dry matter accumulation and tiller production.
- 6.2.4 Treatments for tillage and residue management practices, nitrogen management and legume inclusion in cropping system resulted into similar crop growth rate and relative growth rate during 2013-14 and 2014-15.
- 6.2.5 Effective tillers and grains per spikes differed significantly due to tillage and residue management practices in both the cropping seasons; however spike length and test weight remained unaffected. Both effective tillers and grains per spike produced under ZT DSR-ZTW-R and ZT DSR-ZTW+R were found statistically at par, however those were significantly higher than PTR-CTW during both years.
- 6.2.6 ZT DSR-ZTW+R produced 9.26 and 7.90% higher effective tillers in comparison to PTR-CTW during 2013-14 and 2014-15, respectively.. Similarly 5.96 and 8.78% higher number of grains per spike were recorded under ZT DSR-ZTW+R in comparison to PTR-CTW during 2013-14 and 2014-15, respectively.
- 6.2.7 Effective tillers were not influenced significantly due to nitrogen management and legume inclusion.
- 6.2.8 Grain, straw and biological yield and harvest index produced under PTR-CTW was significantly lower as compared to both ZT DSR-ZTW - R and ZT DSR-ZTW + R during both cropping seasons.
- 6.2.9 Treatments for nitrogen management and legume inclusion in cropping system had no significant effects on grain, straw and biological yield and harvest index during any of the cropping season
- 6.2.10 PTR-CTW incurred highest cost of cultivation followed by ZT DSR-ZTW+R and ZT DSR-ZTW-R during both of the cropping seasons.
- 6.2.11 Maximum gross returns, net returns and benefit cost ratio were recorded under ZT DSR-ZTW-R in both seasons. Under ZT DSR-ZTW-R, 13.8 and 20.39% higher net returns were recorded in 2013-14 and 2014-15 cropping seasons, respectively as compared to PTR-CTW.
- 6.2.12 Under treatments for nitrogen management, RDN resulted into comparatively higher cost of cultivation, but lower gross returns, net returns and benefit cost ratio during both the years.
- 6.2.13 Legume integration increased the cost of cultivation, however reduced the net return as well as benefit cost ratio during 2013-14 and 2014-15.

- 6.2.14 Tillage and residue management, nitrogen and legume integration treatments showed non significant effect on grain and straw NPK content in both the cropping seasons.
- 6.2.15 Grain and straw NPK uptake was significantly affected by tillage and residue management practices in both of the cropping seasons, where ZT DSRZTW+R showed maximum NPK uptake.
- 6.2.16 Nitrogen management and legume treatments failed to produce any significant effect on grain and straw NPK contents and uptakes during both years of study.
- 6.2.17 CA management practices i.e. ZT DSR-ZTW - R and ZTDSR-ZTW + R showed increase in available nutrients (N, P and K) status in soil.
- 6.2.18 Nitrogen management and legume integration showed non-significant impacts on available N, P and K status in soil, However, RDN and inclusion of legume showed superiority in residual status of nutrients.
- 6.2.19 ZT DSR-ZTW with and without residue resulted into significantly higher total NPK uptake as compared to PTR-CTW.
- 6.2.20 Treatments for nitrogen management and inclusion of green gram in cropping system did not influence the total (grain and straw) NPK Uptake in both 2013-14 and 2014-15.
- 6.2.21 ZT DSR-ZTW + R produced maximum system grain yield, but gross return and net return were higher under ZT DST-ZTW – R.
- 6.2.22 Treatment with basmati resulted into higher system grain yield, gross returns and net returns. RDN resulted into higher system grain yield, total cost, gross returns and net returns.

6.3 Soil properties

- 6.3.1 Soil pH, electrical conductivity, bulk density was not significantly affected by tillage, crop establishment and residue as well as by nitrogen and legume management treatments
- 6.3.2 Significantly 12.86% higher infiltration rate was recorded under ZT DSR-ZTW + R as compared to PTR-CTW (5.35 mm/hr) during June 2015.
- 6.3.3 CA based management practices i.e. ZT DSR-ZTW-R and ZT DSR-ZTW+R resulted into increase in available nutrients (N, P and K) status in soil.
- 6.3.4 Tillage, crop establishment and residue management practices significantly influenced the soil organic carbon up to 30 cm depth. After completion of experiment (June 2015), SOC increased by 8.16% (0-5 cm), 12.5% (5-15 cm), and 11.62% (15-30cm) under ZT DSR-ZTW + R in comparison to its initial year's values.
- 6.3.5 ZT DSR-ZTW + R resulted into significantly higher SOC stock with maximum sequestration rate as compared to rest of the treatments.
- 6.3.6 Treatments for nitrogen management and legume inclusion in crop rotation did not influence the soil organic carbon.

6.4 Conclusion

- 6.4.1 Plant height, dry matter accumulation and no. of tillers were significantly affected by tillage and crop establishment method during both the year for both of the crops.
- 6.4.2 Wheat grown under ZT DSR-ZT W +R resulted 8.63% (2013-14) and 14.60% (2014-15) higher grain yield compared PTR-CTW. In both the years higher grain yield was observed under hybrid than Basmati.
- 6.4.3 Treatment with full residue retention (ZT DSR-ZTW + R) showed highest potential of carbon sequestration; where up to depth of 30 cm, SOC was significantly affected by tillage and residue management.
- 6.4.4 Maximum system net return was computed under ZT DSR-ZTW – R treatment in both the years i.e. ₹163451/ha (2013-14) and ₹141275/ha (2014-15); which was 7.28 and 12.08% higher than PTR-CTW in 2013-14 and 2014-15, respectively. Cultivation of basmati rice was more remunerative irrespective of growing season.

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Appendix I: Common cost (₹/ha) of wheat cultivation and value of produce

Items	2013-14			2014-15		
	CT	ZT-R	ZT+R	CT	ZT-R	ZT+R
Inputs						
Seed	3200	3200	3200	3400	3400	3400
Tillage	6000	-	-	6000	-	-
Seed drilling	1500	2000	3000	1500	2000	2500
Fertilization	6221	6221	6221	6186	6186	6186
Irrigation	1680	1680	1680	420	420	420
Herbicides	1750	3450	3450	1050	2650	2650
Fungicide	1000	1000	1000	1325	1325	1325
Harvesting and threshing	3000	3000	3000	3000	3000	3000
Outputs						
Loose residue	5000/ha			3500/ha		
Grain	14000/ton			14500/ton		

Appendix II: Common cost (₹/ha) of rice cultivation and value of produce

Items	Basmati (Pusa 1121)						Hybrid (Arize 6129)					
	2013			2014			2013			2014		
	CT	ZT-R	ZT+R	CT	ZT-R	ZT+R	CT	ZT-R	ZT+R	CT	ZT-R	ZT+R
Inputs												
Seed	813	1300	1300	813	1300	1300	2500	4000	4000	2500	4000	4000
Tillage	7000	-	-	7000	-	-	7000	-	-	7000	-	-
Seed drilling	-	2000	3000	-	2000	3000	-	2000	3000	-	2000	3000
Nursery raising cost	1250	-	-	1250	-	-	1250	-	-	1250	-	-
Transplanting cost	5000	-	-	5000	-	-	5000	-	-	5000	-	-
Fertilization	7000	7000	7000	7359	7359	7359	7075	7075	7075	7452	7452	7452
Irrigation	7600	6800	6800	12000	9000	9000	7200	6400	6400	12000	9000	9000
Herbicides	600	4175	4175	600	4175	4175	600	4175	4175	600	4175	4175
Manual weeding	1500	3000	3000	1500	3000	3000	15000	3000	3000	1500	3000	3000
Insecticide and fungicide	3200	3200	3200	2675	2675	2675	1100	1100	1100	2675	2675	2675
Harvesting and threshing	9000	9000	9000	9500	9500	9500	9500	9500	9500	10000	10000	10000
Outputs												
Loose residue	3550/ha			2500/ha			-			-		
Grain	36000/ton			28100/ton			13100/ton			13200/ton		

ABSTRACT

Title of thesis : **Effect of tillage, cultivars, nitrogen and residue management on crop performance and carbon sequestration in rice-wheat cropping system**

Full name of degree holder : **Pardeep Kumar**

Admission No. : **2012A6D**

Title of degree : Doctor of Philosophy in Agronomy

Name and address of Major Advisor : **Dr. Satish Kumar**
Prof. (Agronomy)
Assoc. Dean, Post Graduate Studies
CCS Haryana Agricultural University, Hisar
Haryana, INDIA-125004

Degree awarding University/Institute : **CCS Haryana Agricultural University, Hisar-125 004, Haryana (India)**

Year of award of degree : 2016

Major subject : **AGRONOMY**

Total number of pages in the thesis : 76+xi+II

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Key words: Tillage and Crop Establishment (TCE), Conservation Agriculture (CA), Direct Seeded Rice (DSR), Conventional Tillage (CT), Residue Management, Soil organic carbon (SOC)

A field experiment entitled “*Effect of tillage, cultivars, nitrogen and residue management on crop performance and carbon sequestration in rice-wheat cropping system*” was conducted at the participatory strategic research and learning platform for climate smart agriculture, Taraori, Karnal, Haryana during *Kharif*, and *rabi* seasons of 2013-14 and 2014-15 in collaboration with CIMMYT under CGIAR’s research program on climate change, agriculture and food security (CIMMYT-CCAFS). The treatment consisted of three tillage and crop establishment (TCE) methods in main plots and four treatments in subplot for rice (cultivar and nitrogen management) and wheat (legume and nitrogen management) crops. It was conducted in split plot factorial design having twelve treatment combinations each crop with three replications. Plant height, dry matter accumulation and no. of tillers were significantly affected by tillage and crop establishment method in both the year for both of the crops. Treatment ZT DSR-ZTW + R showed higher CGR and RGR as compared to rest of the treatments. Yield attributes of rice such as effective tillers, number of grains per panicle, 1000 grain weight etc were significantly influenced by TCE, Where PTR produced significantly lower number of effective tillers in comparison to ZT DSR but it produced higher number of grain per panicle over ZT DSR+R. Wheat grown under ZT DSR-ZT W +R resulted 8.63% (2013-14) and 14.60 % (2014-15) higher grain yield as compared to PTR-CTW. In both the years higher grain yield was observed under hybrid than Basmati. Treatment with full residue retention (ZT DSR-ZTW + R) showed highest potential of carbon sequestration; where up to depth of 30 cm, SOC was significantly affected by tillage and residue management. Tillage and residue management practices showed varied effects on system grain yield (Wheat equivalent), total cost, gross returns and net returns, where PTR-CTW resulted into lowest system grain yield and net returns. ZT DSR-ZTW + R produced maximum system grain yield. Maximum system net return was computed under ZT DSR-ZTW – R treatment in both the years i.e. ₹.163451/ha (2013-14) and ₹.141275/ha (2014-15); which was 7.28 and 12.08% higher than PTR-CTW in 2013-14 and 2014-15, respectively. Cultivation of basmati rice was more remunerative irrespective of growing season.

MAJOR ADVISOR

SIGNATURE OF STUDENT

HEAD OF THE DEPARTMENT

CURRICULUM VITAE

- (a) **Name** : Pardeep Kumar
(b) **Date of Birth** : 03.01.1987
(c) **Place of Birth** : Karnal (Haryana)
(d) **Mother's Name** : Smt. Sneha Lata
(e) **Father's Name** : Sh. Sultan Singh
(f) **Permanent Address** : Vill. Gohida, P.O. Amupur
Teh. Nissing, Distt. Karnal (Haryana)
Pin - 132024
(g) **Telephone (Home)** : +91 9896496570
(h) **Mobile** : +91 7027560007
(i) **E-mail** : pardeepsagwal@gmail.com
(j) **Academic Qualification**



Degree	University/Board	Year of Passing	Percentage of marks	Subjects
Ph.D. Agronomy	COA, Hisar CCS HAU, Hisar	2016	75.40	Major: Agronomy Minor: Soil Science
M.Sc. Agriculture	COA, Hisar CCS HAU, Hisar	2010	75.59	Major: Agronomy Minor: Soil Science
B.Sc.(Hons.) Agri.	COA, Kaul CCS HAU, Hisar	2008	67.70	Major : Crop Improvement and Seed Technology

- (k) **Co-Curricular Activities:**
- i). Sports (Volley ball and Kabaddi)
 - ii). NCC College Commander during Graduation
 - iii). Working Group Member YPARD India

(l) Medals/Honors received:

- i). Climate Food and Farming Network Fellowship (CLIFF-2015) under CGIAR's Research Program on Climate Change, Agriculture and Food Security (CAAFS) collaboration with University of Copenhagen and Aarhus University, Denmark
- ii). Ph.D. Merit Scholarship from CCS HAU, Hisar
- iii). CIMMYT Fellowship for Ph.D. Research Work

(m) Publications

- ✓ Participation National/International Conferences/Workshops/ Seminars/Internships: 11
- ✓ National/International Training: 6
- ✓ Book: 1
- ✓ Articles: 2
- ✓ Extended Summaries: 2
- ✓ Research Papers: 4

- (l) **Language known:** Hindi, English, Punjabi and Ordia

UNDERTAKING OF COPY RIGHT

I, **Pardeep Kumar**, Admn. No. **2012A6D**, undertake that I give copy right to the CCS HAU, Hisar of my thesis entitled “Effect of tillage, cultivars, nitrogen and residue management on crop performance and carbon sequestration in rice-wheat cropping system”.

I also undertake that patent, if any, arising out of the research work conducted during the programme shall be filed by me only with due permission of the competent authority of CCS HAU, Hisar.

SIGNATURE OF THE STUDENT