**Influence of crop residue and nitrogen management on nutrient uptake, yield and economics of Rice-Wheat Cropping system**

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**Abstract**

The present investigation was conducted at the research farm of CCSHAU, Regional Research Station (RRS), Karnal during rabi seasons of 2019-20 and 2020-21. The field experiment comprised four main plot treatments viz., Zero tillage wheat-Happy seeder (ZTW-HS) with full residue (chopped), ZTW-HS with full residue (unchopped), ZTW-HS with partial residues (anchored stubbles), and conventional tillage wheat- drill sown (CTW-DS) with full residue (chopped); and six sub-plots having two nitrogen levels viz., 150 and 180 kg/ha applied into 2 and 3-splits i.e. at sowing, before 1st irrigation, after 1st irrigation, and after 2nd irrigation. Wheat variety ‘HD 2967’ was sown with happy seeder (ZT + residue) on 18th November, 2019 and 12th November, 2020. SPD design was followed with three replications. ZTW-HS with full residue (unchopped) in wheat increased the grain yield of wheat by 9.18% more than CTW-DS with full residue (chopped). Three N-splits *i.e.,* at sowing, before 1st irrigation and after 1st irrigation in wheat increased grain yield of wheat by 8.08% more than 2-splits *i.e.,* at sowing & after 1st irrigation. ZTW-HS with full residue (unchopped) with N@150 kg/ha with 3-splits *i.e.,* at sowing, before 1st irrigation and after 1st irrigation provides the best combination effect and improved the nutrient uptake in grain and straw, N, P, K and yield of wheat and provide high economic returns.

**Introduction**

The Rice-wheat cropping system (RWCS) encompasses an approximate extent of 10 million hectares (Mha) within the Indo-Gangetic Plains (IGPs) of India (Saharawat et al., 2012). On a global scale, the annual production of rice straw (RS) is estimated to range between 800-1000 million tonnes (Mt), with Asia alone accounting for approximately 600-800 Mt/year (IRRI, 2020). The RWCS has effectively sustained the equilibrium between food grain provisioning and the proliferation of the human populace since the advent of the Green Revolution or the third agricultural revolution. This accomplishment has been made feasible through the development of high-yielding varieties (HYVs) of rice and wheat, the accessibility of economically viable chemical fertilizers, farm mechanization, the expansion of irrigation networks, and the enlargement of cultivable land. However, the resource and energy-intensive tillage practices employed in the RWCS (Singh et al., 2019a, b) have engendered the deterioration of soil health (Ladha et al., 2009), adverse environmental ramifications, depletion of groundwater resources (Hira et al., 2004), as well as nutrient losses through emissions and leaching, thereby instigating diminished agricultural productivity and reduced economic gains (Chauhan et al., 2012; Srinivasan et al., 2012). The limited or negligible utilization of organic manures and crop residues (Ghosh et al., 2016), the extensive adoption of monoculture practices (Hazra et al., 2014), and the imbalanced application of chemical fertilizers (Brar et al., 2013; Singh and Benbi, 2018a) have further intensified predicaments linked to the deterioration of soil quality.

The management of rice straw (RS) generated in substantial quantities has emerged as a significant and intricate challenge, posing a menace to the long-term sustainability of rice-wheat systems (RWS) in northwestern India (Bhatt et al., 2021; Sharma and Dhaliwal, 2021). The interventions for on-site rice residue management conventionally embraced by farmers in northwestern India encompass the soil incorporation subsequent to rotavator or mouldboard plough tillage, alongside the surface retention of rice residue utilizing the Happy Seeder technology (Singh et al., 2020a). Furnishing farmers with comprehensive information and practical insights pertaining to residue management techniques is of paramount importance, especially considering the variances in field conditions and requisites across diverse locations, encompassing both zero-tillage and conventional tillage scenarios. The recommendation for incorporating crop residues roughly 15-20 days prior to wheat sowing has been put forth to augment crop productivity and soil health (Bijay-Singh et al., 2008). However, this practice entails optimized fertilizer-N management owing to the transient immobilization of applied nitrogen (N) (Yadvinder-Singh et al., 2005). Crop residue management, particularly the residues arising from cereal-based cropping systems, exhibits a close interconnection with nitrogen (N) cycling in the soil (Verhulst et al., 2010), predominantly attributable to their elevated carbon-to-nitrogen (C:N) ratios (~80:1).

Nitrogen deficiency stands out as a prominent factor limiting yields in cereal crops Shah et al., 2003). Consequently, the application of nitrogen fertilizer becomes a crucial input for achieving desirable crop productivity across most regions of the world. In the case of the widely cultivated cereal, wheat, the soil is expected to provide approximately 30 kg N/ha in a readily available form (typically as nitrate) for each tonne of grain produced. However, the capacity of soils to meet the required nitrogen quantities, ranging from 30-80 kg/ha, diminishes rapidly. The agricultural sustainability of a production system, in addition to productivity, hinges upon various factors, one of which is the assessment of its environmental and economic impacts (Helander and Delin, 2004), with a particular emphasis on improving nutrient use efficiency (NUE) (Cassman et al., 2003) and energy efficacy (Khan et al., 2009) (Dyer and Desjardins, 2003; Dalgaard et al., 2001). Nevertheless, as crop productivity continues to rise with increasing rates of nutrient application, approaching an optimum level, NUE generally experiences a decline (Barbieri et al., 2008). This decrease in NUE results in heightened costs of crop production and environmental pollution (Fageria and Baligar, 2005). Conservation agriculture-based practices exhibit the potential to enhance phosphorus availability by modifying soil microbial diversity and enzyme activity, consequently influencing the accessibility of soil phosphorus (Srinivasrao et al., 2014; Sui et al., 2015; Wang et al., 2011). Plant analysis has revealed that cereal straw typically exhibits high potassium content (ranging from 1.2% to 1.7%) compared to straw produced by other crops (Srinivasrao et al., 2014).

Nitrogen deficiency represents a significant limiting factor for cereal yields (Shah et al., 2003). Consequently, the application of nitrogen fertilizer plays a critical role in enhancing crop productivity across various global regions. In the case of wheat, the predominant cereal crop, the soil must provide approximately 30 kg N/ha in a readily available form (typically as nitrate) for each metric ton of grain produced. However, the capacity of soils to meet these nitrogen requirements, ranging from 30-80 kg/ha, declines rapidly. In addition to productivity, the agricultural sustainability of a production system relies on a multitude of factors, including the assessment of environmental and economic impacts (Helander and Delin, 2004). Notably, the optimization of nutrient use efficiency (NUE) (Cassman et al., 2003) and energy efficacy (Khan et al., 2009) assume significant importance in this context (Dyer and Desjardins, 2003; Dalgaard et al., 2001). However, despite the increasing crop productivity achieved through higher nutrient application rates approaching optimal levels, NUE generally experiences a decline (Barbieri et al., 2008). This diminished NUE results in escalated costs of crop production and environmental pollution (Fageria and Baligar, 2005). Conservation agriculture-based practices exhibit the potential to enhance phosphorus availability by influencing soil microbial diversity and enzyme activity, subsequently affecting the availability of soil phosphorus (Srinivasrao et al., 2014; Sui et al., 2015; Wang et al., 2011). Plant analysis has indicated that cereal straws typically possess high potassium content (ranging from 1.2% to 1.7%) in comparison to straw derived from other crops (Srinivasarao et al., 2014). Due to the declining NUE in the Rice-wheat cropping system (RWCS), the reliance on chemical fertilizers to sustain crop yields has been increasing. Consequently, this leads to higher direct emissions of greenhouse gases (GHGs) from soils (Mandal et al., 2015) as well as indirect emissions associated with fertilizer manufacturing and usage (; Singh et al., 2019a, 2019b).

Given the current circumstances in the Rice-wheat cropping system (RWCS), there is an imperative requirement to undertake systematic research aimed at evaluating various rice residue management practices and different nitrogen doses and scheduling, with the goal of attaining heightened productivity. Thus, it becomes crucial to develop resilient rice residue and nutrient management practices that can effectively enhance the productivity of the cropping system.

**Materials and methods**

**Experimental site and climatic conditions**

A field experiment was conducted during *rabi* seasons of 2019-20 and 2020-21. The experiment was conducted at CCSHAU Regional Research Station Uchani, Karnal situated at 29o 43' 41'' North latitude and 76 o 58' 50'' East longitudes at an elevation of 243 m above mean sea level. The soils of RRS Uchani, Karnal are derived from Indo-Gangetic alluvium, which is very deep and sandy loam in texture including with some amount of calcium carbonate in the soil profile. The surface (0–15 cm) soil was sandy loam (57.5% sand, 24.3% clay, and 18.2% clay).

The maximum temperature is about 45°C during the hot summer months of May and June, while during the winter months of December and January the minimum temperature may be near zero. The average annual rainfall of the area is around 600 mm, 70-80 per cent of which is received during the monsoon period *i.e.*, July to September, and the rest is received in showers of cyclic rains during the winter and spring seasons. The monsoonal rainfall is highly erratic in respect of its total amount, time of onset as well as distribution throughout the rains. The mean relative humidity remains nearly constant at about 75 to 90 per cent from July to March, steadily decrease in April, and remains around 40-50 per cent during the hot summer months of May and June.

**Treatment details**

The field experiment comprised four main plot treatments viz., Zero tillage wheat-Happy seeder (ZTW-HS) with full residue (chopped), ZTW-HS with full residue (unchopped), ZTW-HS with partial residues (anchored stubbles), and conventional tillage wheat- drill sown (CTW-DS) with full residue (chopped); and six sub-plots having two nitrogen levels viz., 150 and 180 kg/ha applied into 2 and 3-splits i.e. at sowing, before 1st irrigation, after 1st irrigation, and after 2nd irrigation, was conducted to evaluate the effect of establishment methods and nitrogen dose optimization and scheduling on soil fertility, growth, productivity, and economics of ZT wheat. Wheat variety ‘HD 2967’ was sown with happy seeder (ZT + residue) on 18th November, 2019 and 12th November, 2020. SPD design was followed with three replications.The 150 kg N/ha and 180 kg N/ha dose of nitrogen and phosphorus (60 kg P2O5/ha) was applied for wheat during both seasons. The full dose of phosphorus was applied as basal dose and N from DAP served as a basal dose of N. The remaining N was top-dressed as urea in 2 and 3-splits at before and after Ist irrigation and after 2nd irrigation in different treatments. The source of nitrogen and phosphorus was urea and DAP, respectively. Pre-sown irrigation was applied for both seasons during 2019-20 and 2020-21. Common irrigation as per crop needs was applied based on moisture requirement status and crop development stages.

**Rice residue management**

Rice was harvested manually at ground level. Rice residue at specified rate 6 t/ha was kept on the soil surface as partial residue in the shape of anchored stubbles, full residue load as it is, and full residue load with chopping (chopper) and spreading equally. CT treatments were with full residue incorporation after chopper and spreader. In CT, plots were ploughed by two times by using a disc harrow, and a one-time rotavator followed by planking to prepare the land for sowing. In CT with full residue load, one more pass of the rotavator was given for proper field preparation.

**Collection of plant samples and analyses**

For analysis, plant samples were collected after harvest of crops and grain and straw yield were recorded. Samples of grain and straw were collected, dried in oven at 65 ± 2 ℃ for 72 hr. Then, the samples were grounded in a stainless-steel grinder and stored in polythene bags for chemical analysis. For chemical analysis, grain and straw samples were digested in di-acid mixture of H2SO4 and HClO4 in the ratio of 9:1 in digestion chamber. The digested plant samples were analyzed for total N, P, K contents and uptake of these elements were calculated by multiplying the nutrients contents with yield. The concentration of Nitrogen was determined calorimetrically by using Nessler’s reagent methods (Lindner 1944). Phosphorus was determined by Ammonium molybdate yellow color method (Koenig and Johnson 1942). Potassium was determined by flame emission spectroscopy (Jackson 1973).

Cost of cultivation and gross income (Rs/ha) of various treatments were calculated on the basis of approved market rates for inputs and outputs fixed by Directorate of Farm, CCS HAU, Hisar for calculating economics. Net returns (Rs/ha) were worked out by subtracting the total cost of cultivation of each treatment from the gross income of respective treatment. Benefit-cost ratio was also worked out.

**Statistical analysis**

The experimental data for yield, nutrients uptake and content were statistically analyzed by the methods of analysis of variance (ANOVA) as described by Panse and Sukhatme (1985).

**Table-1 Effect of rice residue management and nutrient scheduling on dry matter accumulation (g/m2) of wheat under rice-wheat cropping system (2019-20 and 2020-21)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.N.** | **Treatment** | **30 DAS** | **60 DAS** | **90 DAS** |
| **2019-20** | **2020-21** | **2019-20** | **2020-21** | **2019-20** | **2020-21** |
| M1 | ZTW-HS with full residue (chopped) | 33.74 | 31.44 | 138.22 | 134.23 | 668.16 | 663.88 |
| M2 | ZTW-HS with full residue (unchopped) | 39.19 | 36.89 | 153.69 | 147.12 | 698.52 | 693.96 |
| M3 | ZTW-HS with partial residues (anchored stubbles) | 36.36 | 34.06 | 145.64 | 141.05 | 683.57 | 678.73 |
| M4 | CTW-DS with full residue (chopped) | 31.39 | 29.09 | 136.79 | 128.51 | 655.61 | 651.05 |
|  | **C.D. (p=0.05)** | **3.78** | **5.33** | **7.53** | **10.80** | **21.23** | **24.65** |
| T1 | N @ 150 kg/ha, 2-splits i.e. at sowing & after 1st irrigation | 35.94 | 33.64 | 141.11 | 135.03 | 668.62 | 664.06 |
| T2 | N @ 180 kg/ha, 2-splits i.e. at sowing & after 1st irrigation | 36.66 | 34.36 | 142.74 | 136.32 | 671.22 | 666.66 |
| T3 | N @ 150 kg/ha, 3-splits i.e. at sowing, before 1st irrigation and after 1st irrigation | 34.91 | 32.61 | 143.23 | 139.16 | 674.57 | 670.01 |
| T4 | N @ 180 kg/ha, 3-splits i.e. at sowing, before 1st irrigation and after 1st irrigation | 35.46 | 33.16 | 144.76 | 140.16 | 681.18 | 676.62 |
| T5 | N @ 150 kg/ha, 3-splits i.e. at sowing, after 1st irrigation and after 2nd irrigation | 33.75 | 31.45 | 141.07 | 136.75 | 678.10 | 673.54 |
| T6 | N @ 180 kg/ha, 3-splits i.e. at sowing, after 1st irrigation and after 2nd irrigation | 34.31 | 32.01 | 142.61 | 137.95 | 685.11 | 680.55 |
|  | **C.D. (p=0.05)** | **1.77** | **2.11** | **2.16** | **2.68** | **8.89** | **9.67** |

**Results and Discussion**

**Dry matter production**

M2 produced 4.54% highest dry matter accumulation at 90 DAS than M1 but similar to M3 (2.27%). M4 has 5.56% lower value over M2. The lower values were attained is due to hindrance caused by unchopped residues. Better growth and development of wheat crop was possibly due to the enhanced soil health and micro-environment by implementation of conservation-based management practices (Kumar 2000). Ram *et al*. (2013) and Dhar *et al*. (2014) reported that higher plant height, density of tillers per plant and dry matter accumulation was due to better soil hydro-thermal regime under mulching compared to no mulch treatment. Singh *et al*. (2015a) reported that all growth parameters, yield and yield attributes parameters were higher in ZT with full residue loads as compared to CT without residue. High water retention and release of nutrients to plant for a longer time where the crop residues are incorporated into soil gives taller plant height, total tillers and dry matter over control (Mbah and Nneji 2011).

Results showed that dry matter were produced by T6 was 2.25% higher than T3 in 3-split application. But under all treatments T6 (2.28%) performed better than T1. It might be due to more nitrogen dose applied up to this stage than other treatments. Due to breaking down of some amount of residues prior to planting, reduces the extent of nitrogen immobilization. Ali *et al*. (2016) reported that increasing 30% of additional nitrogen + recommended NPK dose along with rice residue retention or incorporation of rice residue retention + Sesbania along with a recommended dose of fertilizers (RDF) resulted in higher dry matter than residue retention or incorporation with RDF or residue removal or burning, due to cumulative effect of low carbon-nitrogen. This is also supported by the findings of Meelu*et al*. (1994). Kumar *et al*. (2016) reported that dry matter production was significantly differed with tillage and residue management along with nitrogen application. Nitrogen level at 150 kg/ha results in an increase in plant height, because of its immense effects on cell enlargement. Kumar *et al*. (2017) stated that among nitrogen application timing, 3-split doses viz. 1/3rd as basal, 1/3rd after 1st irrigation and 1/3rd after 2nd irrigation were significantly superior with respect to physiological indices which resulted in higher biomass accumulation than the rest of the treatments. Chaudhary *et al.* (2017) concluded that the higher dry matter accumulation in zero tillage with residue retention might be due to moderated soil temperature, favourable soil moisture and improved soil biota by a constant supply of nutrients through mineralization of rice residues. Better light interception resulted in more dry matter production in zero tillage wheat with residue retention situation than without residue application under ZT as well as CT practices (Ram *et al.*2013).

**Nutrient uptake and content by crop**

M2 produced significantly higher N (11.83%), P(6.07%) and K(2.12%) uptakein grain and N (2.94%), P(13.03%) and K(12.8%) uptake straw, statistically on par with M3 grain N (9.89%), P(6.62%) and K(3.45%) and straw N (1.82%), P(6.51%) and K(7.36%) uptake and significantly higher than M4 grain N (15.23%), P(9.24%) and K(2.99%) and straw N (12.8%), P(7.36%) and K(2.08%) uptake. The lower values were recorded under M1 in grain. Kumar *et al.* (2001) also reported the beneficial effect of residue on nitrogen uptake by the crop.

Higher N, P and K uptake in grain was attained by applying T4 (10.65, 8.86, 13.12%) and in straw N (2.17%), P(11.98%) and K(11.67%) over T1 statistically on par with T3 for grain (8.10, 6.96, 11.29%) and for straw N (1.74%), P(8.93%) and K(8.91%). Under N@150 kg/ha T5 for grain (4.03, 1.76, 2.84%) and for straw N (1.34%), P (1.30%) and K (4.18%) performed better over T1 and under N@180 kg/ha for grain T4 (8.41, 10.5, 11.44%) and for straw N (1.89%), P (15.76%) and K (9.70%) performed better over T2. Rahman *et al.* (2011) also studied the significant difference in nitrogen uptake of grain with application of different nitrogen levels. Thind et al. (2019) also stated similar effects of tillage and residue management on nitrogen contents and nitrogen uptake in grain and straw of wheat. The highest nutrient uptake of wheat under residue retention may be attributed to increase in nitrogen availability because of mineralization of nitrogen from rice straw. In addition to supplying nitrogen on decomposition, it is well established that residue retention enhances the soil quality and moderates soil temperature thereby increasing root growth, plant canopy which ultimately contributes towards increased yields and productivity (Chakraborty et al. 2008; Balwinder-Singh et al. 2011; Ram et al. 2013). Similarly, increased phosphorus content on nitrogen fertilization attribute to increased root growth, greater solubilization of the fixed forms and organic forms of phosphorus by organic acids leading to its greater availability to wheat (Argal 2017) and it also improved due to synergistic interaction between nitrogen and phosphorus metabolism in plant cells (Kumar et al. 2013). An interesting trend of higher phosphorus content in grains than straw might be due to the requirement of phosphorus for the formation of nucleic acid and phytic acid in grains, its accumulation and translocation from vegetative parts of wheat to grains (Dar et al. 2015). The higher grain yield increment with residue recycling (rice, wheat and GM) exhibited higher phosphorus acquisition capacity owing to their important functional traits like higher release of root exudates and deeper roots (Bera et al. 2017, Zhang et al. 2013).

**Graph-1 Effect of method of sowing and nitrogen management on grain nutrient uptake**

**Graph-2 Effect of method of sowing and nitrogen management on straw nutrient uptake**

**Graph-3 Effect of method of sowing and nitrogen management on grain nutrient content**

**Graph-4 Effect of method of sowing and nitrogen management on straw nutrient content**

**Available soil nitrogen, phosphorus and potassium**

The data presented in the study indicated that initially, there were no significant differences observed among the soil samples in terms of available soil nitrogen (N), phosphorus (P), and potassium (K). However, upon completion of the experiment, the effects of different treatments became evident. In the final year, Treatment M1 exhibited significantly higher levels of available N, P and K compared to the other treatments, Treatment M1 and M2 showed higher N (6.01, 4.70%), P (5.84, 5.98%) and K (4.05, 3.95%) and over M4. Among the sub-plots, Treatment T6 showed no significant difference compared to T4 but was lower than T1 numerically followed by T2. With 3-splits T6 (N-2.16%) performed better than T3, T3 performed better over T6 for P (11.65%) and T3 performed better over T4 for K (1.31%).The practice of returning rice straw to the soil in combination with cow manure was found to significantly increase soil organic matter, total N, and available P compared to situations where no residue was added (Gu et al., 2018). This finding is supported by previous studies conducted by Zhang et al. (2009), Moharana et al. (2012), and Cheng et al. (2014). Narang et al. (1999) also reported a positive impact on soil nitrogen balance when moderate levels of rice residue were incorporated along with nitrogen application (120 kg/ha), resulting in improved wheat yield, organic matter content, and available phosphorus. The incorporation of rice-wheat residue was shown to enhance the levels of inorganic and organic phosphorus in the soil, improve phosphorus use efficiency, and substitute approximately 13 kg/ha/yr of inorganic phosphorus (Gupta et al., 2007). Several other studies have demonstrated positive effects on soil organic carbon, nitrogen, phosphorus, soil-exchangeable potassium, and its uptake through in-situ residue management practices such as incorporation or retention (Yadwinder-Singh et al., 2004; Gangwar et al., 2006; Gupta et al., 2007).

**Table-2 Effect of rice residue management, wheat crop establishment methods and nutrient scheduling on soil available soil nitrogen, phosphorus and potassium (kg/ha)in wheat under rice-wheat cropping system (2019-20 and 2020-21)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.N.** | **Treatment** | **N** | **P** | **K** |
| **Initial** | **Final** | **Initial** | **Final** | **Initial** | **Final** |
| T1 | ZTW-HS with full residue (chopped) | 134.58 | 147.51 | 13.33 | 15.40 | 279.56 | 296.76 |
| T2 | ZTW-HS with full residue (unchopped) | 132.06 | 145.69 | 13.10 | 15.42 | 284.42 | 296.47 |
| T3 | ZTW-HS with partial residues (anchored stubbles) | 131.81 | 144.00 | 12.18 | 14.83 | 281.83 | 290.46 |
| T4 | CTW-DS with full residue (chopped) | 133.52 | 139.15 | 12.94 | 14.55 | 275.92 | 285.21 |
|  | **C.D. (p=0.05)** | **NS** | **3.36** | **NS** | **0.54** | **NS** | **6.35** |
| T1 | N @ 150 kg/ha, 2-splits i.e. at sowing & after 1stirrigation | 132.77 | 140.86 | 13.32 | 14.84 | 280.71 | 286.47 |
| T2 | N @ 180 kg/ha, 2-splits i.e. at sowing & after 1stirrigation | 133.67 | 141.08 | 12.97 | 14.33 | 277.45 | 288.99 |
| T3 | N @ 150 kg/ha, 3-splits i.e. at sowing, before 1st irrigation and after 1stirrigation | 134.09 | 146.27 | 12.22 | 15.81 | 279.23 | 296.28 |
| T4 | N @ 180 kg/ha, 3-splits i.e. at sowing, before 1st irrigation and after 1stirrigation | 135.54 | 147.62 | 13.90 | 14.25 | 283.69 | 292.45 |
| T5 | N @ 150 kg/ha, 3-splits i.e. at sowing, after 1stirrigation and after 2ndirrigation | 134.18 | 147.88 | 13.34 | 15.82 | 278.92 | 296.14 |
| T6 | N @ 180 kg/ha, 3-splits i.e. at sowing, after 1st irrigation and after 2ndirrigation | 133.80 | 149.43 | 13.03 | 14.16 | 282.33 | 295.64 |
|  | **C.D. (p=0.05)** | **NS** | **1.67** | **NS** | **0.33** | **NS** | **6.76** |

**Yield**

Treatment M2 resulted in higher grain yield (9.18%), straw yield (6.06%), and biological yield (9.26%) compared to Treatment M1, and it was statistically similar to Treatment M3, followed by Treatment M4. Various researchers including Singh and Yadav (2006), Soyeb (2011), Dontaniya (2013), Dhar et al. (2014), Sah et al. (2014), Singh and Kumar (2014), Chandra (2018), Kesarwani et al. (2017), and others have reported significant positive effects of crop residues on wheat yield. The higher wheat yield observed in the plots where straw was retained could be attributed to the improvement of soil nutrients facilitated by the residues and the abundance of microorganisms when straw residue was used as mulch in the field. Zero tillage (ZT) has been identified as the most efficient tillage method for conserving resources and enhancing wheat yield (Usman et al., 2013). Studies have shown that grain yield significantly increases with zero tillage compared to conventional tillage with residue incorporation (Yadav et al., 2005). The maximum wheat grain and straw yield was recorded using the happy seeder zero tillage method compared to the conventional method (Nandan et al., 2018). In the current investigation, several factors can be attributed to the higher grain yield of wheat observed under the practice of Zero Tillage with Residue Retention (ZTW + R). These factors include the influence of mulch on prolonging the vegetative stage of the crop through a reduction in soil temperature, mitigating soil evaporation, increasing soil moisture content, and reducing canopy temperature during the grain filling stage due to improved soil water availability. The findings from Thind et al. (2023), Balwinder-Singh et al. (2011), Yadvinder-Singh et al. (2014), and Jat et al. (2018) support the aforementioned reasons for the greater grain yield observed under ZTW + R. These studies have highlighted the positive effects of residue retention on soil temperature, soil moisture, and crop performance, emphasizing the agronomic benefits of adopting this practice in wheat production.Significantly higher grain yield (8.08%), straw yield (1.44%), and biological yield (10.47%) were recorded under Treatment T4, which was statistically similar but numerically higher grain and straw yield thanT3 (6.9, 0.79%), followed by T6 (6.52, 0.59%) and T5 (5.27, 0.41%). Sidhu et al. (2007) found that on average, wheat grain yield was 9-15% higher with the happy seeder zero tillage (HSZT) method of sowing in rice residues, along with fertilizer broadcast at sowing and before the first irrigation, compared to the farmer's practice of conventional tillage after burning. Based on a 4-year study, Gill et al. (2019) concluded that the most efficient nitrogen management practice for better yield was the application of 150 kg N/ha in three equal splits, with 1/3 applied as basal, 1/3 at the first irrigation at 20-25 DAS (Days After Sowing), and 1/3 at the second irrigation at 40-45 DAS, with a top dressing of urea just before irrigation. Yadvinder et al. (2015) also concluded that drilling 24 kg N/ha as DAP (Diammonium Phosphate) into the soil at sowing, followed by two top-dressings of 48 kg N/ha each just prior to the first and second irrigations, significantly increased the mean wheat yield.

Table-3 Effect of rice residue management, wheat crop establishment methods and nutrient scheduling on yield of wheat under rice-wheat cropping system (2019-20 and 2020-21)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S.N.** | **Treatment** | **Grain yield (kg/ha)** | **Straw yield (kg/ha)** | **Biological yield** **(kg/ha)** | **Harvest Index** |
| **2019-20** | **2020-21** | **2019-20** | **2020-21** | **2019-20** | **2020-21** | **2019-20** | **2020-21** |
| M1 | ZTW-HS with full residue (chopped) | 5351 | 5387 | 6609 | 7223 | 12645 | 12457 | 42.39 | 43.30 |
| M2 | ZTW-HS with full residue (unchopped) | 5849 | 5874 | 6720 | 7347 | 13769 | 13657 | 42.51 | 43.12 |
| M3 | ZTW-HS with partial residues (anchored stubbles) | 5753 | 5636 | 6800 | 7426 | 13395 | 13216 | 43.03 | 42.70 |
| M4 | CTW-DS with full residue (chopped) | 5543 | 5566 | 6458 | 6952 | 12995 | 12918 | 42.72 | 43.17 |
|  | **C.D. (p=0.05)** | **218** | **265** | **210** | **260** | **491** | **410** | **0.30** | **0.32** |
| T1 | N @ 150 kg/ha, 2-splits i.e. at sowing & after 1st irrigation | 5366 | 5332 | 6612 | 7202 | 12259 | 12316 | 42.7 | 42.11 |
| T2 | N @ 180 kg/ha, 2-splits i.e. at sowing & after 1st irrigation | 5554 | 5490 | 6626 | 7215 | 12757 | 12635 | 42.86 | 42.62 |
| T3 | N @ 150 kg/ha, 3-splits i.e. at sowing, before 1st irrigation and after 1st irrigation | 5724 | 5712 | 6667 | 7256 | 13429 | 13079 | 42.65 | 43.69 |
| T4 | N @ 180 kg/ha, 3-splits i.e. at sowing, before 1st irrigation and after 1st irrigation | 5791 | 5771 | 6682 | 7280 | 13671 | 13476 | 43.82 | 43.37 |
| T5 | N @ 150 kg/ha, 3-splits i.e. at sowing, after 1st irrigation and after 2nd irrigation | 5610 | 5652 | 6641 | 7229 | 13147 | 13435 | 42.39 | 43.01 |
| T6 | N @ 180 kg/ha, 3-splits i.e. at sowing, after 1st irrigation and after 2nd irrigation | 5698 | 5721 | 6655 | 7241 | 13943 | 13432 | 43.56 | 43.62 |
|  | **C.D. (p=0.05)** | **101** | **135** | **32** | **45** | **365** | **255** | **0.15** | **0.22** |

**Table-4 Effect of rice residue management, wheat crop establishment methods and nutrient scheduling on yield attributing parameters of wheat under rice-wheat cropping system (2019-20 and 2020-21)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S.N.** | **Treatment** | **Test weight (1000-grain weight)** | **No. of effective tillers per meter square** | **Spike length (cm)** | **No of grains/spike** |
| **2019-20** | **2020-21** | **2019-20** | **2020-21** | **2019-20** | **2020-21** | **2019-20** | **2020-21** |
| T1 | ZTW-HS with full residue (chopped) | 45.41 | 46.29 | 363.71 | 372.54 | 10.81 | 10.99 | 41.71 | 42.00 |
| T2 | ZTW-HS with full residue (unchopped) | 47.45 | 48.29 | 374.42 | 386.43 | 11.55 | 11.58 | 42.51 | 43.80 |
| T3 | ZTW-HS with partial residues (anchored stubbles) | 47.23 | 47.98 | 371.89 | 380.90 | 11.31 | 11.39 | 42.40 | 42.42 |
| T4 | CTW-DS with full residue (chopped) | 44.30 | 45.73 | 366.27 | 375.41 | 10.96 | 11.04 | 41.42 | 42.21 |
|  | **C.D. (p=0.05)** | **0.60** | **1.10** | **4.93** | **6.37** | **0.40** | **0.32** | **0.45** | **0.80** |
| T1 | N @ 150 kg/ha, 2-splits i.e. at sowing & after 1st irrigation | 45.67 | 46.65 | 364.16 | 372.02 | 11.06 | 11.16 | 41.74 | 42.38 |
| T2 | N @ 180 kg/ha, 2-splits i.e. at sowing & after 1st irrigation | 45.85 | 46.85 | 364.91 | 374.13 | 11.10 | 11.19 | 41.83 | 42.48 |
| T3 | N @ 150 kg/ha, 3-splits i.e. at sowing, before 1st irrigation and after 1st irrigation | 46.35 | 47.31 | 369.5 | 378.11 | 11.22 | 11.31 | 42.22 | 42.74 |
| T4 | N @ 180 kg/ha, 3-splits i.e. at sowing, before 1st irrigation and after 1st irrigation | 46.52 | 47.46 | 371.62 | 379.38 | 11.25 | 11.35 | 42.35 | 42.83 |
| T5 | N @ 150 kg/ha, 3-splits i.e. at sowing, after 1st irrigation and after 2nd irrigation | 46.02 | 47.01 | 366.08 | 375.75 | 11.14 | 11.23 | 41.93 | 42.57 |
| T6 | N @ 180 kg/ha, 3-splits i.e. at sowing, after 1st irrigation and after 2nd irrigation | 46.18 | 47.16 | 368.21 | 376.69 | 11.17 | 11.27 | 41.99 | 42.65 |
|  | **C.D. (p=0.05)** | **NS** | **NS** | **3.72** | **3.35** | **0.09** | **0.07** | **NS** | **NS** |

**Yield attributing characters**

Maximum spike length (5.86%), number of grains/spike (3.20%), effective tillers (6.67%) and 1000-seed weight (6.35%) were recorded in M2 than M4 but statistically similar M3. Dholiya et al. (2017) found similar results of non-significant effects of various nitrogen management practices. Tripathi et al. (2015) reported that maximum test weight and number of grains per spike were observed in zero tillage with full residue retention, followed by zero tillage without residue, and the lowest values were observed in conventional tillage with full residue incorporation. Chaudhary et al. (2017) reported that a higher number of spikelets per ear and number of grains per ear were recorded in crop residue mulching with a combination of the recommended dose of fertilizer (RDF), but higher values of these parameters were found in zero tillage compared to conventional tillage. Wheat sown with a happy seeder and zero tillage recorded higher 1000-grain weight compared to conventional tillage (Iqbal et al., 2017). Similar findings were reported by Dhar et al. (2014), where all growth, yield, and yield attributes were higher in zero tillage with full residue loads compared to conventional tillage without residue.

The differences in spike length and 1000-seed weight were not significant due to different nitrogen levels during both years of the experiment, but there was a numerical increase as the nitrogen level increased. Among different nitrogen application timings and splits, they were found to be statistically similar to each other, indicating no significant effect of timing and split application on earhead length. A higher number of grains per spike was recorded when 150 kg/ha-1 of nitrogen was applied in three splits just before irrigation (Gill et al., 2019). Ali et al. (2003) reported that high nitrogen levels promoted vegetative growth but reduced yield attributes at higher nitrogen levels.

The data for nitrogen scheduling shows that higher number of effective tillers (2.01%) and spike length (1.71%) were recorded under T4 than T1 being statistically similar to with T3, T6, T5. As per Kumar et al. (2016), the growth parameters and the number of tillers significantly differed with tillage and residue management along with nitrogen application.

**Economics**

Data regarding cost of cultivation (6.45%) and net returns (22.69%) showed that M2 had lower cost of cultivation than M4, followed by M3. Due to no initial preparatory tillage and all other operation related to sowing (i.e., furrow opening, applying seeds and fertilizer, and covering soil) completing only in one pass, it saves time, and money. Happy seeder charges were a bit higher than zero tillage and using Happy seeder after chopper and spreader again increased the cost of chopping machine charges; so, the total cost of cultivation was more than ZT sown wheat. The maximum cost of cultivation was found in CTW drill sown after using chopper and spreader and rotavator with full residue load. Due to increased number of operations for land preparation, the total cost of cultivation increased, and the lowest was incurred in ZTW without full residue retention (in anchored stubbles) due to single operation wheat sowing only. Sidhu *et al*. (2007) reported that the cost of cultivation with the Happy seeder was lesser than the cultivation with a conventional method; nearly half of the expenditure of CT. The gross, and net income, and B-C ratio were minimum with residue incorporated conventional tillage. The maximum gross returns, net returns and B-C ratio were found in wheat sown with zero tillage with full residue retention (unchopped) followed by anchored stubbles and residue removed-zero tillage (Hobbs 2007; Mitra *et. al*. 2014). As per Iqbal *et al*. (2017), Happy seeder zero-tillage gave maximum net income with a B-C ratio compared to conventional. Zero-till fertilizer-cum-seed drill system was found as the most economical and gave the highest B-C ratio than conventional wheat crop raising system and other reduced tillage systems (Singh *et al*. 2015).

**Table-5 Effect of rice residue management, wheat crop establishment methods and nutrient scheduling on economics of wheat under rice-wheat cropping system (2019-20 and 2020-21)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S.N.** | **Treatment** | **Cost of cultivation (Rs/ha)** | **Net returns (Rs/ha)** | **B:C** |
| **2019-20** | **2020-21** | **2019-20** | **2020-21** | **2019-20** | **2020-21** |
| **M1** | ZTW-HS with full residue (chopped) | 83821 | 84949 | 44297 | 40413 | 1.53 | 1.65 |
| **M2** | ZTW-HS with full residue (unchopped) | 81313 | 82441 | 56694 | 52672 | 1.66 | 1.75 |
| **M3** | ZTW-HS with partial residues (anchored stubbles) | 82567 | 83695 | 55382 | 49180 | 1.58 | 1.73 |
| **M4** | CTW-DS with full residue (chopped) | 86956 | 88084 | 44195 | 39707 | 1.48 | 1.52 |
| **T1** | N @ 150 kg/ha, 2-splits i.e. at sowing & after 1st irrigation | 83284 | 84412 | 45469 | 40352 | 1.53 | 1.64 |
| **T2** | N @ 180 kg/ha, 2-splits i.e. at sowing & after 1st irrigation | 83760 | 84889 | 48622 | 43767 | 1.54 | 1.64 |
| **T3** | N @ 150 kg/ha, 3-splits i.e. at sowing, before 1st irrigation and after 1st irrigation | 83696 | 84625 | 52298 | 47478 | 1.58 | 1.66 |
| **T4** | N @ 180 kg/ha, 3-splits i.e. at sowing, before 1st irrigation and after 1st irrigation | 83973 | 85102 | 53189 | 48216 | 1.59 | 1.67 |
| **T5** | N @ 150 kg/ha, 3-splits i.e. at sowing, after 1st irrigation and after 2nd irrigation | 83696 | 84625 | 50009 | 45845 | 1.57 | 1.65 |
| **T6** | N @ 180 kg/ha, 3-splits i.e. at sowing, after 1st irrigation and after 2nd irrigation | 83973 | 85102 | 51264 | 47301 | 1.58 | 1.66 |

**Conclusion**

ZTW-HS with full residue (unchopped) in wheat increased the grain yield of wheat by 9.18% more than CTW-DS with full residue (chopped). Three N-splits *i.e.,* at sowing, before 1st irrigation and after 1st irrigation in wheat increased grain yield of wheat by 8.08% more than 2-splits *i.e.,* at sowing & after 1st irrigation. ZTW-HS with full residue (unchopped) with N@150 kg/ha with 3-splits *i.e.,* at sowing, before 1st irrigation and after 1st irrigation provides the best combination effect and improved the nutrient uptake in grain and straw, N, P, K and yield of wheat and provide high economic returns.

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