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Research Article

Use of Tillage and Microbial Cultures for Rice Residue Management and Their Effect on Nutrient Uptake and Yield of Wheat (*Triticum aestivum* L.)

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Abstract

Burning of crop residues (CRs) emits greenhouse gases, cause problems of air-pollution, health hazards and loss of nutrients and thus is a matter of serious concern. Therefore, CRs should be managed judiciously. A field investigation was done on a sandy loam soil at Research Farm, BHU, Varanasi to evolve efficient management practices for rice (*Oryza sativa* L.) residue recycling in the succeeding wheat (*Triticum aestivum* L.) crop. The study was conducted in split plot design with four main plots tillage treatments comprising of conventional, zero, chopped residue + zero and rotavator and three sub plot treatments of microbial cultures *viz.* no culture, liquid formulation of *Trichoderma harzianum* and *Pseudomonas fluorescence* with three replications. Based on two years' data, it was observed that residue incorporation through rotavator resulted in higher nutrients' uptake by wheat crop that resulted in higher yield. Amongst the microbial cultures *P. fluorescence* was found better than the *T. harzianum* as it resulted in higher nutrient uptake and yield response.

Keywords: Rice residue, Rotavator, Zero tillage, Conventional tillage, Microbes

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Introduction

Rice and wheat are cultivated in sequence on the same land in the same year over 26 mha in South and East Asia and about 10.5 mha in India [1]. This system produces about 150 mt of paddy straw annually in the country with 1.0-1.5 kg of residue produced from every kg of harvested grain. The harvesting of rice by combines has resulted in leaving a sizeable amount of crop residues in the field. Because of the difficulties of sowing directly into crop residues, many farmers burn them. The fraction of crop residue burned ranged from 8–80% for paddy waste across all states. Among different crop residue, major contribution was 43% of rice, followed by wheat 21%, sugarcane 19% and oilseed crops around 5% [2]. Burning of crop residues due to lack of efficient and user friendly technologies for in situ recycling, not only leads to loss of considerable amount of N (100%), P (20%), K (20%) and S (80%) [3] but also contributes to the global NO_2 and CO_2 budget, killing of beneficial soil insects and microorganisms, and depletion of soil organic matter. Burning, however, also kills pests and diseases. As burning leads to loss of nutrients and environmental pollution, the alternative option of incorporation of crop residues in soil attains greater significance. For the incorporation of rice residues in soil along with sowing of succeeding wheat crop under conservation tillage system, several machines are being used such as Zero-till drill, Roto-seed drill etc. Besides slowing CO_2 emission and decreasing pollution, the retention of residues helps control weeds, preserves soil moisture, improves soil structure and enhances productivity by helping the plant make better use of nutrients like N, P and K [4]. However, this practice may have some demerits of creating temporary immobilization of nutrients due to high C:N ratio of cereal residues leading to slow decomposition and decrease in yield of crops by about 40 per cent [5]. The rate of decomposition, if enhanced either through the addition of N or by using biological agents like cellulytic micro-organisms, can add substantial quantity of nutrients locked in the residues leading to improvement in system productivity. Although, various methods of rice residue management are practiced in some parts of the country, their relative efficiency in terms of residue decomposition, nutrient availability and producing other beneficial effects is not known. This study was carried out with the objective to assess the effect of methods of rice residue incorporation using tillage and microbial cultures on nutrient uptake and yield of wheat (*Triticum aestivum* L.).

Materials and Methods

The present investigation was undertaken at Research Farm of the Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. The experimental field had been under rice-wheat cropping system for over 10 years before this experiment was started. The geographical situation of the farm lies at $25^0$20” north latitude and $83^0$0” east longitude and 128.9 m above the mean sea level. Varanasi district comes under hot subhumid (dry) agro ecological region with alluvium derived soils and a physiography of northern plain. This agro ecological region (AER) has an area of 12.1 mha (3.7 % of total geographical area) having 11.62 mha gross cropped area with an annual precipitation of 1000-1200. The mechanical and physico-chemical properties of the experimental soils are presented in **Table 1**.

Table 1 Initial physico-chemical properties of experimental soil

Parameters	Value	Parameters	Value
pH	7.85	Available P (kg ha^{-1})	16.4
EC(dS m^{-1})	0.35	Available K (kg ha^{-1})	165.4
Bulk density (Mg m^{-3})	1.42	Available S (kg ha^{-1})	12.9
Particle density (Mg m^{-3})	2.61	CEC (C mole (p^+) kg^{-1})	11.8
Water holding capacity (%)	38.2	Sand (%)	55.6
Organic C (%)	0.33	Silt (%)	18.4
Total N (%)	0.046	Clay (%)	24.2
Available N (kg ha^{-1})	162.6	Textural class	Sandy loam

The study involved field experimentation conducted for two consecutive years followed by laboratory analysis of the plant and soil samples. The field experiment was initiated by cultivation of rice during kharif season using prevalent cultural practices to obtain the residue to be incorporated by various ways. The treatments were applied using these rice residues and the effect of the treatments was assessed on the subsequent wheat crop which was sown on the same plots. The experiment was conducted in split plot design with four main plot tillage treatments comprising of conventional tillage without residue (M_1), zero tillage with residue (M_2), chopped residue + zero tillage (M_3) and rotavator with residue incorporation (M_4) and three sub plot treatments of microbial cultures *viz.* no culture (S_0), liquid formulation of *Trichoderma harzianum (T. harzianum;* S_1) and *Pseudomonas fluorescence* (*P. fluorescence;* S_2) with three replications. More details on the experimentation can be found at [6]. After the harvesting of rice crop, preparation of field for sowing of wheat crop was done according to the tillage treatments of the experiment. In conventional tillage treatment, the field was cultivated with the help of cultivator drawn by tractor and then line sowing of wheat was done. Under reduced tillage practice, field was prepared using rotavator, and then line sowing of wheat was done. Remaining plots were sown with zero-till drill. For microbial treatments, *Trichoderma harzianum* was prepared on sorghum seeds and it was applied in the field @ 300 g $tonne^{-1}$ rice residue and the *Pseudomonas fluorescence* was cultured on King’s B liquid culture media and it was applied in the field @ 1 L $plot^{-1}$ containing 106 cells mL^{-1}. The wheat variety ‘HUW 234’ is used and the recommended agronomic practices were followed during the crop growth period. Recommended doses of nitrogen, phosphorus and potassium ($N-P_2O_5-K_2O$) i.e. @ 120, 60 and 60 kg ha^{-1}, respectively were applied to both rice and wheat. Besides, 25 kg ha^{-1} Zinc sulphate was also applied to rice crop. Nitrogen was applied through urea. Uniform basal application of phosphorus and potassium was made through di ammonium phosphate (DAP) and muriate of potash (MoP), respectively to all the plots. In case of rice, entire P, K, Zn and half the dose of N were applied as basal and remaining half the dose of N was applied in two equal splits at 30 days after sowing (DAS) and 60 DAS. In case of wheat, same amount of fertilizers except Zn was applied in each plot. Half the dose of N and full dose of phosphorus and potassium were applied as basal before sowing of wheat. Remaining half of the nitrogen was applied in two equal splits at tillering and ear head initiation stages. The wheat plant samples were collected at 30 and 60 days after sowing (DAS) and at maturity to determine the nutrients (N, P, K and S) content. Various growth and yield parameters were recorded at the harvest by following standard methods. Uptake of nutrients by grain and straw was calculated by multiplying per cent of the individual nutrient in grains and straw with the corresponding yield and reported in kg ha^{-1}. Protein content of wheat grains were determined by Lowry’s method [7]. Starch content of wheat grain was determined by colorimetric method as described by [8]. Data generated as a result of experimentation were analyzed statistically by the method of “Analysis of variance” as described by [9]. The significance of the treatment effect was judged with the help of variance ratio test. Critical difference (CD) at 5 per cent level of significance was worked out to determine the difference between treatment means.

Results and Discussion

The data related to the number of grains $spike^{-1}$ of wheat under various tillage systems and microbial cultures have been presented in **Table 2**. The higher number of grains $spike^{-1}$ was counted in reduced tillage i.e. rotavator (M4) as compared to conventional tillage plots (M1). The number of grains spike^{-1} of wheat grains produced by M2 and M3 was though lower than M4 but was statistically at par during both the years. Significant effect of reduced tillage with rice residue on growth and yield attributes was due to the decomposition of rice residues and subsequent release of nutrients in soil. These findings are in agreement to those of [10]. [11] conducted an experiment to study the effect of minimum tillage in wheat after rice and they observed that plant emergence in minimum and reduced tillage treatments was significantly less, although more spikelets and grains per spike compensated the low plant emergence. The use of *P. fluorescence* (S2) resulted in higher numbers of grains spike^{-1} which was significantly higher than S0 and S1. Incorporation of rice residue without any microbial culture (S0) showed lesser grains spike^{-1} than when microbial cultures (S1 and S2) were used. The minimum tillage i.e. rotavator (M4) gave higher test weight of wheat grains and lower value was observed under conventional tillage treatment (M1). However, the effect of various tillage treatments was non-significant. The use of microbial cultures did not have significant effect on the test weight of wheat grains.

Table 2 Number of grains panicle^{-}1, test weight, grain and straw yield of wheat as affected by tillage and microbial cultures with or without residue

Treatments	**Number of grains panicle^{-1}**	**Test weight (g)**	**Grain yield (q ha^{-1})**	**Straw yield (q ha^{-1})**
M_1 – Conventional tillage	39.07	37.40	42.03	58.5
M_2 – Zero tillage	41.17	37.93	45.23	62.3
M_3 – Chopped residue + Zero tillage	41.97	38.70	46.03	62.9
M_4 – Rotavator	42.43	39.20	48.13	63.8
SEm±	0.600	0.557	0.909	1.046
CD (P= 0.05)	2.08	NS	3.15	3.62
S_0 –No culture	39.15	36.80	42.28	60.5
S_1 –*Trichoderma*	41.28	38.28	45.40	61.8
S_2 –*Pseudomonas*	43.05	39.85	48.40	63.5
SEm±	0.801	0.818	0.455	0.761
CD (P= 0.05)	2.403	NS	1.37	2.28
M x S	NS	NS	Significant	NS

The data pertaining to the grain yield of wheat under various tillage systems and microbial is presented in Table 2. From the data, it is evident that tillage treatments had significant effect on the grain yield of wheat. Rotavator (M4) gave the higher grain yield of wheat which was significantly higher than M1 and M2, while it was at par with M3. Zero tillage practice (M2) also produced significantly higher grain yield of wheat as compared to conventional tillage practice. It shows that grain yield was improved significantly by reduced tillage practices. Reducing tillage intensity increased the availability of nutrients in soil and enhanced the microbial activity responsible for organic matter decomposition and mineralization. The incorporation of rice residue to wheat might have improved the soil physical condition and thus resulted in better growth of succeeding wheat crop. On an average, reduced tillage produced 14.5% higher overall mean yield than conventional tillage. [12] observed in sub-humid sub-tropical climate that minimum tillage in conjunction with residue management practices improved and sustained the higher wheat yield. [13] reported that maximum crop productivity and grain yield obtained due to incorporation of retained residue in soil through minimum tillage may be due to increased microbial biomass and better temporal synchronization between crop demand and N supply rate, as reflected by maximum accumulation of N in the crop biomass. Crop productivity and grain yield were significantly correlated with the levels of soil microbial biomass carbon and N, N-mineralization rate and available-N. [14] also reported 20-53% increases in crop biomass and positive relationships between plant biomass/grain yield and N-mineralization rate and available-N after wheat straw application in a dryland rice based agro-ecosystem under reduced tillage condition. [15] reported that rototilling combined with chisel ploughing gave the highest wheat yield.

Application of microbial cultures in combination with rice residue significantly affected the grain yield of wheat. The higher grain yield of wheat was recorded in the treatment where *P. fluorescence* (S2) was applied as compared to the no culture (S0) and *T. harzianum* (S1). This clearly indicated that in situ incorporation of rice residue was beneficial in improving the productivity of wheat with microbial cultures *P. fluorescence*, which appeared to be essentially required for decomposition of residues into the soil. Paddy straw being a wide C/N ratio organic material, caused immobilization due to high proportion of cellulose, lignin and low nitrogen content, which resulted in locking up of available nitrogen by microorganism [16]. With progressive decomposition, carbonaceous part of the paddy straw degraded and carbon dioxide was evolved, consequently, C/N ratio narrowed down which resulted in mineralization of organic nitrogen [17]. The interaction effect of tillage practices with and without microbial cultures (MxS) was found to be significant. The treatment combination M4 x S2 was found to be significantly superior over others. The higher grain yield was recorded with the treatment combination of M4 x S2. This clearly indicated that in situ incorporation of residue was beneficial in improving the productivity of wheat under lesser soil disturbance along with the use of microbial culture *P. fluorescence*. Under such situation increased microbial activity in soil results into proper decomposition of residues in soil and subsequent release of nutrients that improves the crop yield.

The straw yield of wheat is presented in Table 2. Rotavator (M4) produced higher straw yield which was significantly higher than the yield obtained under conventional tillage (M1). The straw yields produced by M2 and M3 were although lower than M4 but the differences were non-significant. However, treatments M2 and M3 resulted into significantly higher yields as compared to M1. It is evident that reduction in tillage intensity proved to be beneficial for straw yield. Use of microbial cultures with rice residues affected significantly the straw yield of wheat. The higher straw yield of wheat was recorded in the treatment where *P. fluorescence* culture (S2) was used which was significantly higher than the treatment where no culture (S0) was applied, however, no significant difference was observed with treatment S1 which give slightly lower yield than S2. Thus, inoculation did have favourable effect on wheat straw yield. This might be due to higher rate of decomposition of rice residues thereby creation of favourable conditions for plant growth. Integration of chemical and organic sources of nutrients and microbial cultures had favourable impact on straw yield. Potential of rice residue as nutrient source for wheat was advocated earlier by several authors [18, 19]. In a similar study, [20] assessed the effectiveness of application of various combinations of urea with rice residue and other organic manures in supplying N to rice-wheat cropping sequence. They found that the application of straw and urea alone registered lower straw yield of rice than integrated use of conventional manures and urea.

Nutrients (N, P, K and S) content was analyzed in the wheat plants at 30 and 60 DAS and in grain and straw at harvest. It was observed that tillage treatments had no significant effect on N content at 30 and 60 DAS and in wheat straw, however, significantly higher N content in grain was observed in rotavator treatment (M4) as compared to conventional tillage (M1) which was at par with M2 (zero tillage) and M3 (chopped residue + zero tillage). Among the microbial cultures, application of *P. fluorescence* (S2) gave significantly higher values of N content at 30 and 60 DAS and in grain and straw as compared to values obtained under no culture treatment (S0). *T. harzianum* (S1) also give significantly higher value of N content at 30 and 60 DAS and in grain and straw as compared to no culture (S0), while it was at par with (S2). The data related to the N uptake by wheat grain and straw under various tillage systems have been presented in **Table 3**.

Table 3 Nitrogen content at different growth stages and N uptake in grain, straw and total as affected by the tillage and microbial cultures with or without residue

Treatments	N content (%)				N uptake (kg ha^{-1})		
	30 DAS*	60 DAS	Grain	Straw	Grain	Straw	Total
M_1 – Conventional tillage	3.43	2.56	1.41	0.48	59.53	28.35	87.88
M_2 – Zero tillage	3.52	2.66	1.50	0.53	67.95	33.07	101.01
M_3 – Chopped residue + Zero tillage	3.57	2.67	1.51	0.52	69.81	32.61	102.42
M_4 – Rotavator	3.62	2.70	1.53	0.54	74.00	34.75	108.74
SEm±	0.068	0.061	0.022	0.012	2.428	1.17	3.54
CD (P= 0.05)	NS	NS	0.08	NS	8.40	4.06	12.25
S_0 –No culture	3.41	2.43	1.41	0.47	59.62	28.78	88.41
S_1 –*Trichoderma*	3.55	2.67	1.51	0.53	68.50	32.67	101.17
S_2 –*Pseudomonas*	3.64	2.86	1.55	0.55	75.34	35.13	110.46
SEm±	0.035	0.044	0.017	0.009	1.343	0.88	2.04
CD (P= 0.05)	0.10	0.131	0.050	0.026	4.03	2.63	6.13
M x S	NS	NS	NS	NS	NS	NS	NS

*DAS – days after sowing

The tillage treatments differ significantly and the highest N uptake in wheat grain was recorded under rotavator (M4) while the lowest N uptake was observed under the conventional tillage practice (M1). Higher uptake of N in wheat grain under rotavator was due to more grain yield as well as higher grain N content of this treatment at different growth stages of wheat. The use of microbial cultures with rice residue significantly affected the N uptake by wheat grain. The highest uptake of N in wheat grain was recorded in the treatment comprising of *P. fluorescence* culture (S2) which gave significantly higher values than other sub plot treatments. Use of *T. harzianum* (S1) also recorded significantly higher values than the no culture treatment (S0). Rotavator (M4) treatment recorded higher N uptake by wheat straw, which was significantly higher than the value observed under the conventional tillage practice (M1). Zero tillage (M2) resulted in slightly higher values than the values obtained under chopped residue + zero tillage (M3) and these values were statistically at par with each other and with M4. This may be due to lower straw yield and lower concentration of N in wheat straw with this treatment at harvest of the crop. Application of P. *fluorescence* (S2) gave significantly higher value (35.13 kg ha^{-1}) of N uptake of wheat straw as compared to values obtained under no culture treatment (S0). Results revealed that application of microbial cultures along with rice residue enhanced the total N uptake of wheat grain. This result may be attributed to the higher rate of decomposition of rice residues with the application of microbial cultures that resulted into the release of nutrients. Fungi and bacteria are ultimately responsible for the biochemical processes in the decomposition of organic residues [21]. Microbial immobilization of available N during the early phase of crops and its pulsed release later during the period of greater N demand of crops enhanced the degree of synchronization between crop demand and N supply. [22] observed higher N uptake with shallow ploughing in combination with low fertilizer input under irrigation. The results are in agreement with earlier reporters [23, 24]. Other studies have emphasized that plant N uptake is often dependent upon the ability of the plant to utilize nitrogen for growth and is not always a useful parameter for soil N availability [25]. The bacterial inoculation is reported to have significant effect on total N uptake by wheat crop [26].

Tillage treatments had no significant effect on P content at 30 DAS and in wheat straw, however, P content of wheat plant at 60 DAS is significantly higher in M3 and in wheat grain, it is significantly higher in M4 as compared to the M1 **(Table 4**). Among the microbial cultures, application of *P. fluorescence* (S2) recorded significantly higher values of P content at all the growth stages and the higher value was recorded in *P. fluorescence* (S2) as compared to no culture treatment (S0). *T. harzianum* (S1) also gave significantly higher values of P content at all the growth stages as compared to no culture (S0). The application of microbial culture significantly improved the P content of wheat grain and among the cultures *P. flourescence* culture performed better than *T. harzianum* culture. This might be due to the P solubilization effect of this culture. Rotavator (M4) gave the higher P uptake by wheat grain and straw as compared to conventional tillage (M1). The use of microbial cultures with rice residue affected significantly the P uptake by wheat grain. The higher P uptake by wheat grain and straw was recorded in the treatment having *P. fluorescence* culture (S2) which was significantly higher than other sub plot treatments. The highest total P uptake with M4 might have been due to higher yield of grain and straw as well as higher values of P content in grain and straw. The application of microbial cultures with rice residue affected significantly the total P uptake by wheat. The higher P uptake was recorded in the treatment having *P. fluorescence* culture (S2) which was significantly higher than other sub plot treatments. The results point out that use of microbial cultures had beneficial effect on P uptake by wheat grain. Application of *P. fluorescence* caused increase in P uptake by wheat grain over *T. harzianum* culture. This observation was in tune with the finding of [27]. In the treatment S0, no microbial culture was applied but in other sub plot treatments microbial cultures viz. *P. fluorescence* and *T. harzianum* were also applied along with rice residue that resulted into the higher decomposition of rice residues and subsequent release of nutrients causing higher availability of P to plants. The higher decomposition of rice residue has been reported to increase Olsen's available P in soil [28]. It also increased total P uptake by wheat [27]. A number of other studies [29, 30] showed a slight increase in the available P in the soil and P uptake of rice and wheat in soil amended with rice or wheat straw.

Table 4 Phosphorus content at different growth stages and P uptake in grain, straw and total as affected by the tillage and microbial cultures with or without residue

Treatments	**P content (%)**				**P uptake (kg ha^{-1})**		
	30 DAS*	**60 DAS**	**Grain**	**Straw**	**Grain**	**Straw**	**Total**
M_1 – Conventional tillage	0.37	0.23	0.26	0.107	11.09	6.29	17.38
M_2 – Zero tillage	0.40	0.26	0.30	0.113	13.63	7.07	20.69
M_3 – Chopped residue + Zero tillage	0.39	0.27	0.31	0.123	14.51	7.79	22.30
M_4 – Rotavator	0.38	0.26	0.33	0.123	15.99	7.91	23.90
SEm±	0.009	0.006	0.007	0.005	0.649	0.37	1.01
CD (P= 0.05)	NS	0.020	0.03	NS	2.24	NS	3.50
S_0 –No culture	0.36	0.21	0.28	0.090	11.88	5.47	17.35
S_1 –*Trichoderma*	0.39	0.26	0.30	0.120	13.57	7.42	20.99
S_2 –*Pseudomonas*	0.41	0.29	0.33	0.140	15.96	8.91	24.87
SEm±	0.006	0.004	0.005	0.003	0.333	0.24	0.53
CD (P= 0.05)	0.02	0.012	0.015	0.009	1.00	0.72	1.58
M x S	NS	NS	NS	NS	NS	NS	NS

*DAS – days after sowing

With regard to the K content of wheat, the tillage treatments had no significant effect on K content at different growth stages (**Table 5**). Among the microbial cultures, application of *P. fluorescence* (S2) recorded significantly higher values of K content at all the growth stages as compared to values obtained under no culture treatment (S0) and with *T. harzianum* culture (S1). The value of K content with treatment S0 was significantly lower than other sub plot treatments. The difference between other two treatments (S1 and S2) was non-significant. In general, increasing application of organic sources increased potassium concentration in wheat grain. Data regarding the effect of treatments on uptake of K by wheat grain, straw and total are presented in Table 5. The tillage practices affected significantly the removal of K from soil by the wheat grain at harvesting, while for straw no significant differences were observed. The higher K uptake in grain was recorded in case of rotavator (M4) which was significantly higher than other main plot treatments. Increased K uptake due to reduced tillage was also reported by [31]. The increase in total K uptake on addition of crop residues and application of inorganic N and K fertilizer might be due to increase in the availability of plant N and K nutrient in the soil [32]. The use of microbial cultures on rice residue affected significantly the K uptake by wheat grain and straw. Significantly higher removal of K by wheat grain and straw was recorded in the treatment having *P. fluorescence* culture (S2) as compared to the treatments S1 and S2. The reduced tillage intensity with conservation tillage gave better impact on yield of grain and straw and also on nutrient concentration of grain and straw. Present findings are in tune with the findings of [33] who reported higher release of K due to minimum tillage practice. The use of microbial cultures along with rice residue affected significantly the total K uptake by wheat at harvesting stage and the higher removal of total K by wheat was recorded in the treatment having *P. fluorescence* culture (S2) which was significantly higher than no culture (S1) and at par with the treatment comprising *T. harzianum* culture (S1).

Table 5 Potassium content at different growth stages and K uptake in grain, straw and total as affected by the tillage and microbial cultures with or without residue

Treatments	**K content (%)**				**K uptake (kg ha^{-1})**		
	30 DAS*	**60 DAS**	**Grain**	**Straw**	**Grain**	**Straw**	**Total**
M_1 – Conventional tillage	2.78	2.60	0.54	1.55	22.61	91.11	113.72
M_2 – Zero tillage	2.99	2.80	0.53	1.62	24.21	100.90	125.12
M_3 – Chopped residue + Zero tillage	2.82	2.67	0.57	1.65	26.24	103.85	130.08
M_4 – Rotavator	2.92	2.54	0.59	1.66	28.79	105.89	134.68
SEm±	0.067	0.061	0.013	0.038	1.166	3.57	4.68
CD (P= 0.05)	NS	NS	NS	NS	4.03	NS	NS
S_0 –No culture	2.69	2.43	0.51	1.55	21.59	94.00	115.60
S_1 –*Trichoderma*	2.96	2.71	0.56	1.64	25.65	101.18	126.84
S_2 –*Pseudomonas*	2.99	2.83	0.60	1.67	29.14	106.13	135.27
SEm±	0.048	0.045	0.009	0.027	0.602	2.76	3.32
CD (P= 0.05)	0.144	0.133	0.027	0.080	1.81	8.29	9.97
M x S	NS	NS	NS	NS	NS	NS	NS

*DAS – days after sowing

The S content in wheat plant at 30 and 60 DAS and in wheat grain and straw at harvest is presented in **Table 6**. The tillage treatments had no significant effect at 30 and 60 DAS, whereas a significant difference was observed in grain and straw. The higher value of S content was obtained with the treatment rotavator (M4) as compared to conventional tillage practice (M1). Among the microbial cultures, application of *P. fluorescence* (S2) recorded significantly higher values of S content at all the growth stages as compared to values obtained under no culture treatment (S0), whereas it was at par with the *T. harzianum* (S1) treatment. This increase in S content may be attributed to the higher rate of decomposition of rice residues with the application of microbial cultures that resulted into the release of nutrients. Fungi and bacteria are ultimately responsible for the biochemical processes in the decomposition of organic residues [21]. Data regarding the effect of treatments on uptake of S by wheat grain, straw and total are presented in Table 6. The tillage practices affected significantly the removal of S from soil by wheat grain and straw at harvesting. The higher S uptake was recorded in case of rotavator (M4) which was significantly higher than other main plot treatments, except the treatment comprising of chopped residue + zero tillage (M3). The use of microbial cultures with rice residue significantly affected the S uptake. The higher removal of total S was recorded in the treatment having *P. flourescence* culture (S2) as compared to no culture (S0).

The data related to protein and starch content in wheat grain is presented in **Table 7**. The tillage treatments had significant differences in protein content in wheat grain. Rotavator (M4) produced the higher protein content in wheat grain which was significantly higher than the values obtained under conventional tillage practice (M1). Treatments

M3 and M4 were at par during both the years and treatments M2 and M4 differed significantly. Increase in protein content with reduced tillage practices may be due to the appropriate quantity of N supplied at critical times through gradual decomposition of rice residues. Similar results have been reported by [34]. Nitrogen fertilization has pronounced effect on increasing wheat protein. Under high fertility conditions and split N applications, the uptake of N at different growth stages got accumulated in the grain which is reflected in high grain protein [35]. Grain protein content is the result of complex interactions between N and water availability, yield and temperature [36]. Some studies have analyzed wheat grain protein content as a function of tillage system, reporting significant differences between conservation and conventional tillage practices [37]. The use of microbial cultures on rice residues affected significantly the protein content in wheat grains. The higher protein content in wheat grain was recorded in the treatment having *P. fluorescence* culture (S2) as compared to the no culture (S0) and *T. harzianum* culture (S1).

Table 6 Sulphur content at different growth stages and S uptake in grain, straw and total as affected by the tillage and microbial cultures with or without residue

Treatments	**S content (%)**				**S uptake (kg ha^{-1})**		
	30 DAS*	60 DAS	Grain	Straw	Grain	Straw	Total
M_1 – Conventional tillage	0.24	0.22	0.20	0.120	8.31	7.04	15.35
M_2 – Zero tillage	0.25	0.23	0.21	0.153	9.57	9.56	19.13
M_3 – Chopped residue + Zero tillage	0.24	0.24	0.21	0.160	9.91	10.15	20.06
M_4 – Rotavator	0.26	0.26	0.24	0.170	11.82	10.91	22.73
SEm±	0.006	0.008	0.005	0.004	0.468	0.41	0.86
CD (P= 0.05)	NS	NS	0.02	0.015	1.92	1.34	2.99
S_0 –No culture	0.21	0.22	0.18	0.110	7.74	6.66	14.40
S_1 –*Trichoderma*	0.26	0.23	0.22	0.165	9.95	10.23	20.18
S_2 –*Pseudomonas*	0.27	0.26	0.25	0.178	12.02	11.34	23.37
SEm±	0.004	0.007	0.003	0.006	0.232	0.47	0.65
CD (P= 0.05)	0.012	0.022	0.010	0.019	0.69	1.40	1.95
M x S	NS	NS	NS	NS	NS	NS	NS

*DAS – days after sowing

Table 7 Protein and starch content of wheat grain as influenced by tillage and microbial cultures with or without residue

Treatments	**Protein content (g 100 g^{-1} DM)**	**Starch content (g 100 g^{-1} DM)**
M_1 – Conventional tillage	9.72	70.97
M_2 – Zero tillage	10.50	69.23
M_3 – Chopped residue + Zero tillage	11.18	68.77
M_4 – Rotavator	11.86	67.67
SEm±	0.241	1.302
CD (P= 0.05)	0.84	NS
S_0 –No culture	9.64	72.25
S_1 –*Trichoderma*	11.01	68.73
S_2 –*Pseudomonas*	11.80	66.50
SEm±	0.163	0.928
CD (P= 0.05)	0.489	2.782
M x S	NS	NS

With regard to the starch content in wheat grain, the conventional tillage (M1) recorded higher starch content which was significantly higher than the values obtained with rotavator (M4), Zero tillage treatment (M2) and chopped residue + zero tillage (M3). Reduced starch due to high N availability as noticed here was also reported by [34] who showed that N promotes growth of additional tissues, in which the carbohydrate produced, is used in photosynthesis. The use of microbial cultures with rice residues affected significantly the starch content in wheat grains. The higher starch content in wheat grain was recorded in the treatment having no culture (S0) during both the years. The lower starch content in wheat grain was observed in the treatment where *P. fluorescence* culture (S2) was used during both the years of experimentation and it was significantly lower than S0 during both the years.

Conclusion

Rice residue management using various conservation tillage systems particularly rotavator significantly improved the nutrients (N, P, K and S) content and uptake as compared to the conventional tillage practice. Applied microorganisms particularly *P. flourescence* helped in the recycling of nutrients from the rice residue which is reflected in the nutrients' (N, P, K and S) uptake & yield. Yield and nutrient uptake of the wheat crop taken after rice was significantly improved by conservation tillage systems among which minimum tillage (rotavator) was found superior. Quality of wheat grain i.e. protein content was also improved by the use of conservation tillage systems whereas starch content declined with increase in protein content. This study suggests that retention of rice residues and its incorporation in the soil through conservation tillage practices and microbial cultures, in addition to the normal application of chemical fertilizers, could safely be adopted in rice-wheat cropping system, as it enhances nutrient uptake and grain yield of the succeeding wheat crop.

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