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Yield and Nutrient Uptake Influenced by Tillage Crop Establishment and Residue Management in Rice-Wheat Cropping System

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Abstract

The field experiments were conducted during rainy season (June to October) and winter season (November to April) of 2010−11 and 2011−12 at the research farm of Indian Agricultural Research Institute, New Delhi to assess the effect of tillage and residue management practices on yields and nurient uptake by crops in rice –wheat cropping system. Direct seeding under unpuddled condition, transplanting under puddled condition, brown manuring and mungbean residue incorporation before sowing of direct-seeded rice were practiced in rice, while zero-till sowing, conventional till sowing and rice residue application with zero-till wheat were tested in wheat crop. During first year nutrient uptake under transplanted rice was significantly higher than the rest of the treatments. In second year, treatments where rice residue was applied in previous season wheat crop and mungbean residue incorporation showed comparable N, P and K uptake with the TPR treatments. In case of wheat the uptake of nutrients were not significantly influenced during first year of study but in second year, the treatments where rice residue was applied with zero-till wheat and mungbean residue was incorporated in previous DSR showed significantly higher N, P and K uptake. In first year of study TPR produced significantly higher yield (5.37 t ha^{-1}) while in second year mungbean residue incorporation with direct seeded rice produced significantly at par yield (5.61 t ha^{-1}) than the transplanted rice (5.75 t ha^{-1}). Productivity of wheat under all the treatments during first year remained at par but in second year MBR+DSR-ZTW+RR-MB produced significantly highest yield (5.33 t ha^{-1}).

Keywords: Direct-seeded rice, nutrient uptake, brown manuring, zero-tillage, productivity

1. Introduction

Rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L. emend Fiori and Paol) are major cereals contributing to food security and income in South Asia. These crops are grown either as a monoculture or in rotations in tropical and sub-tropical environments of South Asia. In the irrigated and favorable rainfed lowland areas, rice–rice (R-R) and rice-wheat (R-W) are the predominant cropping systems (Timsina et al., 2011). Rice–wheat is the most important cropping system for food security in South Asia (13.5 mha), providing food for more than 400 million people. It gained prominence from the mid-1960s with the introduction of short-duration and high-yielding varieties of rice and wheat. At the moment, the rotation has spread in the most fertile regions and has covered about 10.3 mha in the Indo-Gangetic Plain (IGP) of India (Singh et al., 2011). It is more popular in the non-traditional rice-growing states of Punjab, Haryana and Uttar Pradesh, and less in traditional rice-growing states of Bihar and West Bengal. In India, it contributes 26% of total cereal production and 60% of total calorie intake (Gupta et al., 2003). Despite the endowment of good soil, highest percentage of land under cultivation, and ample sunshine and vast human resources in the Indo-Gangetic plains, the crop productivity is low. Among the various factors responsible for low productivity, availability of water is regarded as the most limiting factor because crops are very much sensitive to soil moisture stress, particularly at their critical growth stages. Strategies to minimize crop water stress include irrigation and conservation of soil moisture by increased infiltration, reduced evaporation and optimum use of available soil water. Mulching in this regard seems vital option to increase the water holding capacity. Besides irrigation, tillage is one of the basic inputs of crop production that alters the rhizosphere environment by modifying most of the physical properties of the soil (Guzha, 2004). However, the extent of the impact of tillage is variable depending upon the inherent soil characteristics and climatic conditions. The efficiency of input use, *viz.* water, fertilizer and others depends on tillage and crop establishment practices. It is, therefore, essential that soil environment be manipulated suitably for ensuring a good crop stand and improving resource-use efficiency. Resource degradation problems are manifesting in several ways in the present-day agriculture. The area under this system is static and the productivity and sustainability of the system are threatened because of the inefficiency of current production practices, shortage of resources, such as water and labour, fuel and socio-economic changes (Ladha et al., 2003). Rice–wheat is the dominant cropping system in the north-western plain zone and a lot of research work has been done on various agronomic management practices for improving productivity but there is lack of information on resource-conserving techniques, such as direct-seeding of rice, brown manuring with *Sesbania aculeata*, zero-till sowing of wheat as well as effect of residue management on productivity, nutrient uptake by crops and soil health. Comparative evaluation of direct-seeded and transplanted rice and the performance of following crop of wheat under conventional and zero tillage conditions with residue management options require a thorough investigation.

2. Materials and Methods

The field experiments were conducted during rainy season (June to October) and winter season (November to April) of 2010−11 and 2011−12 at the research farm of Indian Agricultural Research Institute, New Delhi (28.4° N latitude, 77.1° E longitude and 228.6 m above mean sea level). The mean annual rainfall of Delhi is 672 mm and more than 80% generally occurs during the monsoon season (July-September) with mean annual evaporation 850 mm. The soil at site was sandy clay loam with bulk density of 1.48 Mg m^{-3} and field capacity of 25.4 % (w/w). It had 0.54% organic carbon, 170.6 kg $KMnO_4$ oxidizable N/ha, 18.6 kg 0.5 N $NaHCO_3$ extractable P ha^{-1}, 275 kg 1.0 N NH_4OAc exchangeable K ha^{-1}, 8.0 pH and 0.36 dS/m EC in the top 15 cm of soil. The experimental treatments comprised *viz*. direct-deeded rice – zero-till wheat (DSR-ZTW), direct seeded rice – zero-till wheat+rice residue (DSR-ZTW+RR), direct seeded rice + brown manuring – zero-till wheat (DSR+BM-ZTW), direct seeded rice + brown manuring – zero-till wheat + rice residue (DSR+BM-ZTW+RR), mungbean residue + direct seeded rice –zero-till wheat + relay mungbean (MBR+DSR-ZTW+MB), mungbean residue + direct seeded rice –zero-till wheat+rice residue +relay mungbean (MBR+DSR-ZTW+RR+MB), transplanted rice-conventional till wheat (TPR-CTW) and transplanted rice-zero-till wheat (TPR-ZTW). The experiment was laid out in randomized block design and replicated thrice. Rice 'PRH 10'and wheat 'HD 2894', varieties were taken for experimentation. The sowing for direct-seeded rice and nursery raising was done in the second forth-night of June and transplanting of seedling was done in second week of July, while rice was harvested in the last week of October during both the years. Zero-till and conventional till wheat was sown in the second week of November and last week of November respectively and harvested in second week of April during both the years. For brown manuring practice seeds of *sesbania* @ 40 kg ha^{-1} was broadcasted together with the sowing of direct seeded rice as per treatments and then *sesbania* crop was knocked down at 30 days after sowing with 2,4-D ester. Sowing of relay mungbean was done into the respective treatments in the second forth-night of march by broadcasting in the standing wheat crop and after one picking of pods, it's residues was incorporated into soil in respective treatments through rotavator in June before sowing of direct-seeded rice. After harvesting of rice, it's choped residue was applied into respective treatments @ 5.0 t ha^{-1} before sowing of zero-till wheat through happy seeder. The cultivation of both season crops was done with the recommended package of practices. The number of irrigations applied in direct seeded rice, transplanted rice, zero-till wheat and conventional till wheat were 11, 21, 5, 5 and 17, 23, 6, 6 during 2010-11 and 2011-12 respectively. Comparatively higher number of irrigations were applied during 2011-12 in rice crop due to shortage of rainfall. Nitrogen content (%) in grain and straw was determined by modified Kjeldahl method, phosphorus content by vanadomolybdo phosphoric acid yellow colour method and potassium content by flame photometer (Prasad et al., 2006). Nitrogen, phosphorus and potassium uptake were calculated by using the following expression:

Nutrient uptake (kg ha^{-1}) in grain/straw = [% Nutrient in grain/straw×grain/straw yield (kg ha^{-1})]

Total uptake of N/P/K (kg ha^{-1}) = Nutrient uptake in grain+ Nutrient uptake in straw

All the observations of the study were recorded as per standard methods at different intervals and at harvest. All these experimental data recorded under observations were statistically analyzed in accordance with the 'Analysis of Variance' technique as described by Fisher (1950). Wherever variance ratio (F value) was found significant, critical difference (CD) values at 5% level of probability were computed for making a comparison between treatments. To elucidate the nature and magnitude of treatments effects, standard errors of means (SEm±) and CD (p=0.05) were computed.

3. Results and Discussion

3.1. Yields of rice and wheat

Productivity of rice in terms of yield was significantly influenced due to tillage and residue management. During first year the transplanted rice produced significantly higher yields than the rest treatments but in second year TPR produced significantly similar yields with the treatments where mungbean residue was incorporated (Table 1). Mungbean residue incorporated treatments produced significantly higher yield than the rest residue treatments except DSR+BM-ZTW+RR treatment. Dhiman et al. (2000) also reported similar findings. Lowest yield was recorded under the treatment (DSR-ZTW) where no-residue was applied during both the seasons. Residue management practices over time enhances the physico-chemical properties of soil, which results better yields. Under

Table 1: Productivity of rice and wheat as influenced by tillage, crop establishment, brown manuring and residue management

Treatment	First year				Second year			
	Rice		Wheat		Rice		Wheat	
	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
[1]DSR-ZTW	4.66	7.22	4.62	6.82	5.07	7.96	4.95	6.70
[1]DSR-ZTW+RR	4.62	7.16	4.50	6.53	5.18	8.10	5.08	6.85
[2]DSR+BM-ZTW	4.36	6.97	4.38	6.36	5.15	8.06	5.00	6.73
[2]DSR+BM-ZTW+RR	4.30	6.88	4.48	6.49	5.42	8.22	5.12	6.89
[1]MBR+DSR-ZTW+ MB	4.56	7.14	4.59	6.67	5.34	8.10	5.26	7.04
[1]MBR+DSR-ZTW+RR+MB	4.61	7.02	4.46	6.52	5.61	8.33	5.33	7.12
[3]TPR-CTW	5.37	7.97	4.57	6.60	5.57	8.37	4.80	6.63
[3]TPR-ZTW	5.30	7.93	4.40	6.55	5.75	8.58	4.91	6.68
SEm±	0.12	0.20	0.08	0.093	0.11	0.13	0.10	0.11
CD (p=0.05)	0.36	0.62	NS	NS	0.32	0.38	0.32	0.32

1, 2, and 3 were maintained similarly in first year

transplanted rice, better availability of water, nutrients and less weed infestation resulted comparatively higher yields (Johnson et al., 2002). In wheat, tillage, residue management and brown manuring practice in previous crop could not affect grain and straw yields significantly in first cropping cycle. However, significantly higher yields were recorded under mungbean residue incorporated in previous direct seeded rice and zero-till wheat with rice residue treatment (MBR+DSR-ZTW+RR+MB) than the no-residue treatments (Dudwal et al., 2018). During second year lowest yield performance was recorded under conventional till-wheat (TPR-CTW) which was grown after puddled transplanted rice. Mungbean is a leguminous crop and its cultivation and residue incorporation improves soil properties and fertility status which resulted better yields of succeeding crops (Adil et al., 2010). Borie et al. (2006) also reported positive effects of mungbean cultivation and residue incorporation. Similarly rice residue application increases organic matter into the soil over time, smoother weeds growth and maintain moisture in soil for longer time and finally owing to better yield of crops (Singh et al., 2011). The yield of wheat after puddled transplanted rice was recorded lower than the wheat grown after direct-seeded rice, this might be due to deterioration of soil properties due to puddling in rice crop (Yadav et al., 2004).

3.2. Nutrient uptake in rice and wheat

Total uptake of macronutrients (N, P and K) by rice was influenced by different treatments (Table 2 and 3). In general,

Table 2: Nutrient uptake (kg ha^{-1}) in rice as influenced by tillage, crop establishment and brown manuring in first year of study

Treatment	N			P			K		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
[1]DSR-ZTW	61.98	41.37	103.35	5.28	6.08	11.37	14.14	115.70	129.83
[1]DSR-ZTW+RR	61.14	40.95	102.09	5.12	6.01	11.12	14.02	114.81	128.83
[2]DSR+BM-ZTW	58.14	40.01	98.15	4.94	5.90	10.84	13.24	111.94	125.18
[2]DSR+BM-ZTW+RR	57.15	39.46	96.61	4.91	5.76	10.67	13.11	110.59	123.69
[1]MBR+DSR-ZTW+ MB	60.46	40.91	101.37	5.16	6.00	11.15	13.84	114.47	128.31
[1]MBR+DSR-ZTW+RR+MB	60.85	40.16	101.01	5.15	5.87	11.02	14.01	112.60	126.61
[3]TPR-CTW	71.79	45.84	117.63	6.24	6.99	13.24	16.40	128.20	144.60
[3]TPR-ZTW	70.86	45.53	116.39	6.07	6.92	12.99	16.20	127.57	143.77
SEm±	1.75	1.14	2.32	0.22	0.17	0.31	0.38	3.21	3.34
CD (p=0.05)	5.32	3.46	7.05	0.67	0.53	0.93	1.16	9.74	10.14

1, 2, and 3 were maintained similarly in first year

Table 3: Nutrient uptake (kg ha^{-1}) in rice sown after wheat as influenced by tillage, crop establishment, brown manuring and residue management in second year

Treatment	N			P			K		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
DSR-ZTW	67.22	45.53	112.74	5.68	6.63	12.31	15.39	127.63	143.03
DSR-ZTW+RR	69.07	46.43	115.50	5.87	6.80	12.67	15.74	129.95	145.69
DSR+BM-ZTW	68.88	46.33	115.21	5.91	6.79	12.70	15.73	129.38	145.11
DSR+BM-ZTW+RR	72.48	47.41	119.88	6.30	7.02	13.31	16.57	132.17	148.74
MBR+DSR-ZTW-MB	71.47	46.60	118.07	6.26	6.86	13.12	16.34	130.14	146.48
MBR+DSR-ZTW+RR-MB	75.07	48.03	123.10	6.64	7.16	13.80	17.20	133.94	151.13
TPR-CTW	74.42	47.99	122.41	6.39	7.31	13.69	17.05	134.59	151.64
TPR-ZTW	76.77	49.25	126.02	6.67	7.44	14.11	17.64	138.08	155.72
SEm±	1.51	0.67	1.81	0.22	0.17	0.26	0.31	1.96	2.17
CD (*p*=0.05)	4.56	2.04	5.50	0.68	0.52	0.79	0.95	5.95	6.57

the pattern of grain and straw yield followed in nutrient uptake too. Crop establishment and tillage practices, brown manuring and residue management practices showed significant variations in nutrient uptake. During first year nutrient uptake under TPR was significantly higher than the rest of the treatments. Direct seeding and brown manuring showed similar response in first season rice crop. In second year rice crop which was sown after wheat, the treatments where rice residue was applied in previous wheat crop and mungbean residue incorporation showed comparable N, P and K uptake with the TPR treatments. The highest values for N, P and K uptake in grain and straw were recorded under TPR grown after zero-tilled wheat followed by the treatment in which rice and mungbean residue incorporation was done. The higher total nutrient uptake was due to increased dry matter production with tillage and application of crop residues. The overall improvement in growth and nutrients uptake of rice crop due to residual effect of crop residues applied to previous season could be ascribed to their pivotal role in improvement of several physiological and bio-chemical processes, viz. root development, photosynthesis, energy transformation (ATP and ADP), symbiotic biological N_2 fixation and in protein synthesis (Tisdale et al., 1995; Ali et al., 2002). In case of wheat, nutrients uptake in grain and straw were not significantly influenced due to tillage and residue management practices during first year of study (Table 4). Though, the maximum N, P and K uptake in grain and straw was recorded under DSR-ZTW treatment. In second year, the treatments where rice residue was applied with zero-till wheat and mungbean residue was incorporated in previous DSR crop, significantly higher N, P and K uptake was recorded than the rest of the treatments. N, P and K uptake in both grain and straw was found to be maximum under MBR+DSR-ZTW+RR-MB treatment in second year wheat crop. While, minimum was recorded under TPR-

Table 4: Nutrient uptake (kg ha^{-1}) in wheat as influenced by tillage and residue management in first year

Treatment	N			P			K		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
[1]DSR-ZTW	74.4	30.1	104.5	15.7	3.7	19.4	21.4	111.9	133.3
[2]DSR-ZTW+RR	72.4	28.9	101.3	15.4	3.6	19.0	21.0	107.5	128.5
DSR+BM-ZTW	70.6	28.4	99.0	15.0	3.5	18.5	20.4	104.5	124.9
DSR+BM-ZTW+RR	72.3	29.0	101.3	15.5	3.7	19.1	21.0	106.9	127.9
[1]MBR+DSR-ZTW-MB	73.9	29.4	103.3	15.6	3.6	19.2	21.2	109.5	130.7
[2]MBR+DSR-ZTW+RR-MB	71.9	28.9	100.8	15.4	3.5	18.9	20.8	107.3	128.2
TPR-CTW	73.1	28.9	102.0	15.3	3.5	18.9	21.0	108.1	129.2
TPR-ZTW	70.6	28.8	99.4	14.8	3.5	18.3	20.3	107.4	127.7
SEm±	1.27	0.58	1.32	0.32	0.08	0.34	0.42	1.98	2.32
CD (*p*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

1 and 2 were maintained similarly in first year

CTW treatment. The residue application in both the crops resulted in production of higher dry matter and thus uptake of higher N, P and K than other treatments. Puddling and over tilling in previous season crop deteriorate the physical properties of soil and hence affect the growth and uptake of nutrients in succeeding crop. The higher uptake of nutrients in wheat crop was due to residual effect of tillage and residues applied to previous crops (Singh et al., 2004) (Table 5).

Table 5: Nutrient uptake (kg ha^{-1}) in wheat as influenced by tillage and residue management in second year

Treatment	N			P			K		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
DSR-ZTW	79.7	29.7	109.4	16.9	3.7	20.5	22.8	110.2	133.0
DSR-ZTW+RR	82.1	30.6	112.7	17.5	3.8	21.3	23.8	112.9	136.7
DSR+BM-ZTW	80.7	29.9	110.6	17.2	3.6	20.9	23.3	110.9	134.1
DSR+BM-ZTW+RR	82.9	30.9	113.8	17.8	3.8	21.6	24.1	113.8	137.9
MBR+DSR-ZTW-MB	85.3	31.7	117.0	18.4	4.0	22.4	24.9	116.5	141.5
MBR+DSR-ZTW+RR-MB	86.4	32.2	118.6	18.7	4.0	22.8	25.3	118.0	143.4
TPR-CTW	76.9	29.2	106.1	16.2	3.6	19.8	22.0	108.7	130.7
TPR-ZTW	78.8	29.5	108.4	16.6	3.6	20.2	22.6	109.7	132.3
SEm±	1.70	0.59	1.87	0.40	0.05	0.39	0.67	2.19	2.29
CD (p=0.05)	5.16	1.79	5.68	1.23	0.15	1.18	22.8	6.64	6.94

4. Conclusion

Transplanted rice gave significantly higher yield (5.37 t ha^{-1}) and uptake of major nutrients in initial year than direct seeded rice. However, in second year, treatment mungbean residue incorporation plus direct seeded rice followed by zero-till wheat plus rice residue (MBR+DSR-ZTW+RR-MB) uptake comparable major nutrients and gave at par yield with transplanted rice (5.61 t ha^{-1}). Tillage and different residue management practices could not bring out significant difference in nutrient uptake and wheat productivity in starting year, but significantly higher nutrient uptake and yield of wheat (5.33 t ha^{-1}) was recorded with the incorporation of mungbean residue in rice, followed by zero-till wheat with rice residues (MBR+DSR-ZTW+RR-MB) in second year of study.

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7. References

Adil, K.K., Qureshi, S., Kayani, W.K., Qureshi, R., Waheed, A., Arshad, M., Gulfraz, M., Laghari, M.K., 2010. Assessment of wheat yield potential after cropping of mungbean (*Vigna radiata*). Pakistan Journal of Botany 42(3), 1535−1541.

Borie, F., Rubio, R., Rouanet, J.L., Morales, A., Borie, G., Rojas, C., 2006. Effects of tillage systems on soil characteristics, glomalin and mycorrhizal propagules in a Chilean Ultisol. Soil and Tillage Research 88, 253−261.

Dhiman, S.D., Nandal, D.P., Hariom., Mehla, D.S., 2000. Productivity and economic feasibility of rice (*Oryza sativa*)-based cropping systems in North-Western India. Indian Journal of Agricultural Sciences 70(9), 571−573.

Dudwal, B.L., Das, T.K., Sharma, A.R., 2018. Effect of tillage and residue management on productivity of crops in rice-wheat cropping system. Chemical Science Review and Letters 7(26), 474−478.

Gupta, R.K., Hobbs, P.R., Jiaguo, J., Ladha, J.K., 2003. Sustainability of post-green revolution agriculture, pp. 1–25. In: Ladha, J.K. et al. (Eds.), Improving the productivity and sustainability of rice–wheat systems: issues and impacts. ASA Spec. Publ. 65, ASA, CSSA, and SSSA, Madison, WI.

Guzha, A.C., 2004. Effects of tillage on soil micro-relief, surface depression storage and soil water storage. Soil and Tillage Research 81(1), 57−69.

Johnson, A.M., Clayton, G.W., Wall, P.C., Sayre, K.D., 2002. Sustainable cropping systems for semiarid regions. Paper Presented in the International Conference on Environmentally Sustainable Agriculture for Dry Areas for the Second Millennium, 15–19 September, Shijiazhuang, Hebei Province, China.

Ladha, J.K., Pathak, H., Padre, A.T., Dawe, D., Gupta, R.K., 2003. Productivity trends in intensive rice–wheat cropping systems in Asia. In: Ladha, J.K. et al. (Eds.), Improving the productivity and sustainability of rice–wheat systems: issues and impacts. ASA Spec. Publ. 65, ASA, CSSA, and SSSA, Madison, WI. pp, 45–76.

Masood, A., Ganeshsmurthy, A.N., Rao, S., 2002. Role of pulses in soil health and sustainable crop prodcution. Indian Journal of Pulse Research 15(2), 107–117.

Prasad, R., Shivay, Y.S., Kumar, D., Sharma, S.N., 2006. learning by doing exercise in soil fertility (A practical manual for soil fertility), Division of Agronomy, Indian Agricultural Research Institute, New Delhi, pp. 68.

Singh, Y., Ladha, J.K., Khind, C.S., Bueno, C.S., 2004. Effects of residue decomposition on productivity and soil fertility in rice-wheat rotation. Soil Science Society of America Journal 68, 854−864.

Singh, R., Sharma, A.R., Dhayani, S.K., Dube, R.K., 2011. Tillage and mulching effects on performance of maize (*Zea mays*) – wheat (*Triticum aestivum*) cropping system under varying land slopes. Indian Journal of Agricultural Sciences 81(4), 330–335.

Timsina, J., Buresh, R.J., Dobermann, A., Dixon, J., 2011. Rice-maize systems in Asia: Current situation and potential, Los Banos (Philippines): IRRI and CIMMYT, 232p.

Tisdale, S.L., Nelson, W.L., Beaton, J.D., Havlin, J.L., 1995. Soil fertility and fertilizers, 5th edition, pp. 62–75. Prentice Hall of India Pvt. Ltd., New Delhi.

Yadav, R.L., 2004. Enhancing efficiency of fertilizer N use in rice-wheat systems of indo-gangetic plains by intercropping *Sesbania aculeata* in direct-seeded upland rice for green manuring. Bioresource Technology 93, 213−215.