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Impact of residue retention and incorporation rice-maize cropping system yield, nutrient uptake, and soil health

Mukesh Kumar Pandey and Ankita Singh

Abstract
Field experiments on rice-maize cropping systems were undertaken in Vertisols at IGKV, Raipur, during Kharif 2016-17 and Rabi 2017-18, to investigate the influence of residue management on yield, nutrient absorption, and soil health. Ten treatments of rice and maize were used in the rice-maize cropping system for nitrogen control in RDF and the incorporation of alternate crop residue in the soil. Six metrics were used to assess the system's performance: REY, ANR, AUE, PUE, PE, and SP. The study's findings suggested that the treatment T_5- 100% RDF [(N_{100} P_{60} K_{40}) Rice - Maize (N_{120} P_{60} K_{40}] was superior. T_1- F P - [(N_{103} $P_{57.5}$ K_{45}) Rice - Maize (N_{155} P_{115} K_{45})], T_3- 100% RDF [(N_{100} P_{60} K_{40}) Rice - Maize (N_{120} P_{60} K_{40})] generated the highest profitable yields of grain and straw, and this treatment was equivalent to T_1- F P - [(N_{103} $P_{57.5}$ K_{45}) Rice - Maize (N_{155} P_{115} K_{45})]. T_4-100% RDF [(N_{100} P_{60} K_{40}) Rice - Maize (N_{120} P_{60} K_{40})] [(N_{100} P_{60} K_{40}) Rice - Maize (N_{120} P_{60} K_{40}) *Trichoderma* was present during both years. The study's findings suggested that the treatment T_5- 100% RDF [(N_{100} P_{60} K_{40}) Rice - Maize (N_{120} P_{60} K_{40}] was superior. T_1- F P - [(N_{103} $P_{57.5}$ K_{45}) Rice - Maize (N_{155} P_{115} K_{45})], T_3- 100% RDF [($N_{10}0$ P_{60} K_{40}) Rice - Maize (N_{120} P_{60} K_{40})] generated the highest profitable yields of grain and straw, and this treatment was equivalent to T_1- F P - [(N_{103} $P_{57.5}$ K_{45}) Rice - Maize (N_{155} P_{115} K_{45})]. T_4-100% RDF [(N_{100} P_{60} K_{40}) Rice - Maize (N_{120} P_{60} K_{40})] [(N_{100} P_{60} K_{40}) Rice - Maize (N_{120} P_{60} K40) *Trichoderma* was present during both years Farmers typically utilize 258:172:90 kg ha^{-1} N: P: K in the rice-maize system, combined with residue incorporation in the soil. The current study with RDF 220:120:80 kg ha^{-1} N: P: K resulted in productivity comparable to farmers but with nutrient savings (38:52:10 kg ha^{-1} N: P: K) as well as maintaining and improving soil health in this system as compared to initial soil status as reflected by treatment T_5- 100% RDF [(N_{100} P_{60} K_{40})]. Rice (N_{120} P_{60} K_{40}) - Maize (N_{120} P_{60} K_{40}) 25% P_2O_5 at RI and 75% as basal + *Trichoderma*, with an increase in 13.5% N, 18.6% P, 9.6% K, and 17.54% organic carbon in the soil after completing a two-year cycle of rice-maize cropping system, with lowered pH and EC of soil.

Keywords: Residue-retention, residue-incorporation, nutrient uptake, rice-maize cropping system, RYE, system production, agronomic use efficiency, apparent nutrient recovery, physiological use efficiency

Introduction

Rice and maize residues in the soil are the main organic sources, supplemented with incorporation of straw/stover in the soil helps in enhanced grain yield by improving soil health, leading to sustainable crop production. Decomposition of crop residues is a microbial-mediated progressive propagation of organic matter (carbon and nutrients), however, there is immense need for its recycling and optimum use in the soil. Residues receive atmospheric (C, S and N) as well as earth elements (K, Ca, Mg, P, and trace elements) and if thoroughly digested, nutrients can cycle for a long time and can add in soil productivity.

Rice - maize cropping system is becoming popular and adopted in large area due to high economic return. However, this system is nutrient exhaustive, removing 262:79:311 kg ha^{-1} N: P: K (Mahto *et al*., 2018) [15], leading to declining fertility unless it is replaced from external source. The residues are considered an important source for replenish the nutrients in the soil. In rice-maize cropping system, residue of both the crops is generally removed from fields and thus declines soil fertility especially for potassium. The soil nutrient balance sheet is also affected adversely in the systems. Integrated plant nutrient supply system involving conjunctive use of chemical fertilizers and organic sources has great significance for improving crop productivity. The recommended dose of fertilizer (RDF) may optimally supply nutrients to the crops as and when needed for specific fields in a particular cropping season and improves yield and profitability of rice – maize cropping system.

In recent year, shortage of water has become an important issue. It can be addressed by including low water requirement crop such as maize in the system (Kumara *et al*., 2015) [12]. Rice crop normally absorbs 40% N, 30-35% P, 80-85% K and 40-50% S that remains in the plant on maturity. It is estimated that rice straw on dry weight basis contains 5-8 N, 0.7-1.2 P, 12-17 K, 05.- 1 S, 3 - 4 Ca, 1-3 Mg and 40-70 silica in kg ton^{-1} (Doberman and Witt, 2000). Similarly, maize stover contains 9.16, 2.08, 15.78, 5.17, 3.62 and 1.54 kg ton^{-1} of N, P, K, Ca, Mg and S respectively. Therefore, interventions are needed to incorporate stubbles of both the crops in soil for further decomposition leading to release of the nutrients to supplement inorganic fertilizers. Tillage implements facilitate this adequately, by properly mixing it in the soil.

The decaying of crop residues start as soon as it comes in contact with the soil. This process is controlled by the interaction of three processes, viz soil biological through organisms, physical through crop residues and chemical through environment. *Trichoderma* is one of the promising agents for this purpose.

Research findings related to the effect of crop residues in conjunction/combination with inorganic fertilizers on crop productivity and it's economically feasibility over a longer period in rice- maize cropping system is limited. Therefore, it is imperative to explore the effects of crop residues, nutrient manipulation and application of *Trichoderma* on decomposition process leading to enhanced productivity of the system.

Methodology Adopted

The field experiments were carried out in two subsequent years, 2016-17 and 2017-18, covering kharif (rice) and rabi (maize) under the rice - maize cropping system at Indira Gandhi Krishi Vishwavidyalaya's Research-cum-Instructional Farm, Raipur (21016' N latitude and 810 36' E longitude, altitude 298.56 m). The research area's climate was hot and humid. It got average annual rainfall of 1200-1400 mm (87% during the monsoon). January was the coldest month (8.60C), and May was the warmest (40.80C). Residue incorporation (RI) was carried out in all ten treatments, with three replications each in the RBD design. In both harvests, seeds were planted using an inclined plate planter. For rice and maize, the test varieties were IGKV R-1 (Rajeshwari-1) and Monsanto 9081, respectively. Rice spacing was set at 20 cm X 8 cm, whereas maize spacing was set at 60 cm X 20 cm, as indicated.

Residue incorporation and nutrient management

In order to prepare the field, one summer ploughing in the field was made before start of the experiment. During first season of rice (*Kharif* 2016), maize residues @ 5 t ha^{-1} (*ex-situ*) was applied 25 days before sowing in all the treatments. The disc harrow was then used to cut the stubbles/straw of rice and maize incorporated in the soil in alternate seasons. Subsequently, these residues were mixed properly in the soil using operation of disc plough followed by cultivator supplemented with light irrigation. This process of residue incorporation was used for both the crops and both the seasons.

In-situ residues (stubbles and straw of previous crop) were incorporated in the soil under rice – maize cropping system. *Trichoderma* and 25% P_2O_5 of 100 RDF or 75% RDF were applied and when required according to need of the treatments. One of the treatments (T_{-1}) was farmer's practice (rice - N_{103} $P_{57.5}$ $K_{45,}$ maize - N_{155} P_{115} K_{45}), wherein nutrients were applied in the form of DAP, urea and potash (MOP). While in other treatments SSP, urea and MOP was applied as per treatments. The whole amount of K and 1/3rd dose of N was applied as basal dose and remaining N was applied in two equal splits ***i.e.*** tillering/ knee height and panicle initiation/ tussling stages in rice and maize crops respectively.

The recommended dose of fertilizers (RDF) for rice (100:60:40 kg N: P_2O_5: K_2O ha^{-1}) and maize (120:60:40 kg N: P_2O_5: K_2O ha^{-1}) was used in the experiment. The nutrient application was made as per the treatments. The application of 25% P_2O_5 of RDF or 75% of RDF under the treatments of T_3, $T_{5,}$ T_7 and T_9 was made through SSP at the time of residue incorporation *i.e.* 25 days before sowing. The remaining amount of P and full dose of K was applied as basal dose. In farmers practice, whole amount of P was applied through DAP and K through MOP as basal dose. While, remaining amount of N under farmers practice was also applied through urea at tillering/ knee height and panicle initiation/ tussling stages in rice and maize crops respectively.

The *Trichoderma* was applied at the time of residue incorporation (15 days before sowing) under different treatments *i.e.* T_4, T_5, T_8 and T_9. To apply *Trichoderma,* 12.5 kg ha^{-1} *CG Trichome* (10% *Trichoderma* culture in varmibase) mixed with FYM in the ratio of 1:12 and broadcasted on the experimental soil previously mixed with residues. The residue was incorporated in all the treatments including control during ploughing.

Details of treatments as applied to rice – maze cropping system

T_1- F P – [(N_{103} $P_{57.5}$ K_{45}) Rice–Maize (N_{155} P_{115} K_{45})]

T_{2-} 100% RDF [(N_{100} P_{60} K_{40}) Rice-Maize (N_{120} P_{60} K_{40})]

T_3- 100% RDF [(N_{100} P_{60} K_{40}) Rice-Maize (N_{120} P_{60} K_{40})] 25% P_2O_5 at RI and 75% as basal

T_4- 100% RDF [(N_{100} P_{60} K_{40}) Rice-Maize (N_{120} P_{60} K_{40})] *Trichoderma*

T_5- 100% RDF [(N_{100} P_{60} K_{40}) Rice-Maize (N_{120} P_{60} K_{40})] 25% P_2O_5 at RI and 75% as basal + *Trichoderma*

T_6- 75% RDF [(N_{75} P_{45} K_{30}) Rice-Maize (N_{90} P_{45} K_{30})]

T_7- 75% RDF [(N_{75} P_{45} K_{30}) Rice-Maize (N_{90} P_{45} K_{30})}] 25% P_2O_5 at RI and 75% as basal

T_7- 75% RDF [(N_{75} P_{45} K_{30}) Rice-Maize (N_{90} P_{45} K_{30})] *Trichoderma*

T_9- 75% RDF [(N_{100} P_{60} K_{40}) Rice-Maize (N_{120} P_{60} K_{40})] 25% P_2O_5 at RI and 75% as basal + *Trichoderma*

T_{10}- Control (no fertilizer both the crop)

Various formulae used to work out various parameters were as under:

Apparent nutrient recovery (ANR) %

$$ANR\% = \frac{\text{Nutrient uptake kg ha}^{-1}\text{ in treated plot} - \text{uptake kg ha}^{-1}\text{control plot } X \text{ } 100}{\text{Nutrient applied kg ha}^{-1}}$$

Agronomic use efficiency (AUE)

$$\text{AUE} = \frac{\text{Grain yield kg ha}^{-1}\text{ of treated plot} - \text{grain yield kg ha}^{-1}\text{control plot}}{\text{Nutrient added (kg ha}^{-1})}$$

Physiological use efficiency (PUE)

$$\text{PAU} = \frac{\text{Grain yield kg ha}^{-1}\text{ of treated plot} - \text{grain yield kg ha}^{-1}\text{control plot}}{\text{Nutrient uptake kg ha}^{-1}\text{ in treated plot} - \text{contrlo } plot \text{ uptake}}$$

Rice equivalent yield (REY, q ha^{-1})

$$\text{REY (qha}^{-1}) = \frac{\text{Yield of maize (q ha}^{-1}\text{) X Price of maize (Rs q}^{-1}\text{)}}{\text{Nutrient uptake kg in treated plot} - \text{contrlo plot uptake}}$$

System productivity (SP, q ha^{-1})

SP (q ha^{-1}) = Rice equivalent yield (q ha^{-1}) + Rice yield (q ha^{-1})

Production efficiency (PE)

$$\text{PE (qha}^{-1}) = \frac{\text{System productivity of crop}}{\text{Total duration of the crop}}$$

Results and Discussion

The different nutrient and residue management practices significantly influenced various yield attributes (grain and straw) of rice is shown Table 1. The application of T_5 – 100% RDF {N_{100} P_{60} (25% P_2O_5 at RI and 75% as basal) K_{40}} +*Trichoderma* significantly increased effective tillers, grains panicle^{-1}, and test weight of rice due to adequate nutrient supply to the soil and its uptake by plants. Significantly the highest grain yield was recorded under this treatment during both the years (5.46 and 5.87 t ha^{-1}) with mean yield of 5.67 t ha^{-1}. Almost similar trend was noticed for straw yield during both the years (7.91 and 8.11 t ha^{-1}) with mean yield of 8.01 t ha^{-1}.

In maize during first year 2016-17, significantly the highest grain (7.98 t ha^{-1}) and stover (13.36 t ha^{-1}) yields were recorded under farmer's practice {T_1 - F P (N_{155} P_{115} K_{45})} as compared to other treatments while, during second year 2017-18 treatment T_5- 100% RDF [N_{120} P_{60} (25% P_2O_5 at RI and 75% as basal) K_{40}] + *Trichoderma* produced significantly the highest grain (8.37 t ha^{-1}) and stover (14.0 t ha^{-1}) yields. On considering the mean of the two years the treatment T_5 was found to be significantly superior in terms of both grain (8.13 t ha^{-1}) and stover yields (13.61 t ha^{-1}).

Table 1: Yield of Rice and maize as influenced by nutrient and residue management in rice – maize cropping system

Treatment	Rice yield (t ha^{-1})						Maize yield (t ha^{-1})					
	Grain			Straw			Grain			Stover		
	2016	2017	Mean	2016	2016-17	2017-18	Mean	2017	Mean	2016-17	2017-18	Mean
T_1 (F P)	5.06	5.32	5.19	7.54	7.73	7.63	7.98	8.06	8.02	13.36	13.58	13.47
T_2	5.15	5.47	5.31	7.32	7.69	7.50	7.5	7.55	7.53	12.4	12.76	12.58
T_3	5.30	5.59	5.44	7.69	7.85	7.77	7.63	8.07	7.85	12.9	13.61	13.26
T_4	5.36	5.70	5.53	7.83	8.05	7.94	7.73	8.28	8.00	12.93	13.79	13.36
T_5	5.47	5.88	5.67	7.91	8.11	8.01	7.89	8.37	8.13	13.22	14.00	13.61
T_6	4.55	4.72	4.64	6.88	6.94	6.91	6.79	6.96	6.88	11.82	11.68	11.75
T_7	4.62	4.93	4.78	6.97	7.01	6.99	6.82	7.07	6.94	12.24	11.96	12.1
T_8	4.81	5.11	4.96	7.09	7.34	7.22	6.96	7.20	7.08	12.3	12.47	12.38
T_9	4.99	5.26	5.13	7.27	7.59	7.43	7.14	7.44	7.29	12.14	12.55	12.34
T_{10}- Control	2.79	2.90	2.74	4.56	4.74	4.65	5.36	5.42	5.39	8.85	8.93	8.89
SEm±	0.17	0.17	0.17	0.16	0.22	0.15	0.14	0.17	0.18	0.32	0.29	0.31
C.D (P=0.05)	0.49	0.52	0.51	0.47	0.67	0.54	0.41	0.51	0.54	0.95	0.85	0.9

System's, Rice Equivalent Yield (REY): As per the result shown on Table 2 total grain yield of the rice maize cropping system was found to be highest in both the years under treatment T_5- 100% RDF [(N_{100} P_{60} K_{40}) Rice - Maize (N_{120} P_{60} K_{40})] 25% P_2O_5 at RI and 75% as basal + *Trichoderma* (2016-17: 13.36 t ha^{-1} and 2017-18: 14.25 t ha^{-1}). However, the system productivity is expressed as rice equivalent yields (REY), needs to be work out in order to compare the system performance by converting the yield of non-rice crop into equivalent rice yield on a price basis (Ahirvar and Khan, 2019). Under the present study the highest REY during first year 2016-17 was recorded under farmer's practice (T_1) 7.73 Rs. t h^{-1}. However, it was at par with treatments T_2, T_3, T_4 and T_5. On the other hand, during second year 2017-18 the treatment T_5 recorded significantly highest REY (7.57 Rs t h^{-1}). Considering the mean of the 2 years, treatment T_5 recorded the highest (7.60 Rs t ha^{-1}) REY. It was comparable to treatm*ents* T_1, T_2, T_3 and T_4.

Table 2: Rice Equivalent Ratio, System productivity and Production efficiency as influenced by nutrient and residue management practices under rice -maize cropping system

Treatments	Production Parameters								
	REY (t ha^{-1})			System Productivity (t ha^{-1})			Production efficiency (t ha^{-1} day^{-1})		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
T_1 (F P)	7.73	7.29	7.51	12.79	12.61	12.70	0.053	0.053	0.053
T_2	7.26	6.83	7.04	12.41	12.39	12.40	0.052	0.052	0.052
T_3	7.38	7.30	7.34	12.68	12.89	12.78	0.053	0.054	0.053
T_4	7.48	7.49	7.48	12.83	13.28	13.06	0.053	0.055	0.054
T_5	7.64	7.57	7.60	13.18	13.54	13.36	0.055	0.056	0.056
T_6	6.58	6.29	6.43	11.13	11.01	11.07	0.046	0.046	0.046
T_7	6.60	6.39	6.50	11.22	11.33	11.27	0.047	0.047	0.047
T_8	6.74	6.51	6.62	11.55	11.62	11.59	0.048	0.048	0.048
T_9	6.91	6.72	6.82	11.90	11.99	11.95	0.050	0.050	0.050
T_{10} (Control)	5.19	4.90	5.05	7.98	7.60	7.79	0.033	0.032	0.032
SEm±	0.234	0.187	0.154	0.136	0.274	0.213	0.001	0.001	0.001
C.D (P=0.05)	0.69	0.555	0.458	0.404	0.814	0.629	0.003	0.004	0.004

System productivity

System productivity of rice –maize system is the sum of REY and rice yield is shown in Table 2. In Chhattisgarh State rice-rice system is prevalent in irrigated areas. This system is not very much economical. This system is also discouraged by the State Government due to its water intensive character. In a study conducted at IIRR Cuttack (IIRR, 2021) [8] it was found that rice –maize system resulted in higher REY (10.2 t ha^{-1}) and higher gross profit (Rs 59,110 ha^{-1}) as compared to rice-rice system (7.8 t ha^{-1}, Rs 45,124 ha^{-1}). In the present study of rice - maize cropping system, the highest system productivity was recorded mean both the year under treatment T_5 (13.36 t ha^{-1}) as shown in Table 3, but it was statistically similar to treatments T_3 (12.78 t ha^{-1}) and T_4 (13.05 t ha^{-1}).

Production efficiency

The measurement of production efficiency is vital as it gives pertinent information for making management decision, resource allocation for planning cropping system. The results of production efficiency of rice - maize cropping system in present study is shown in Table 2. It revealed that higher values (0.056 t ha^{-1} day^{-1}) were obtained under treatment of T_5, however, it was found to be closely similar to treatments T_1, T_3 and T_4 (0.053 t ha^{-1} day^{-1}) individual years as well as mean of 2 years. These treatments were significantly superior over T_{10} (control) as well as T_2, T_6, T_7, and T_9.

Physiological use efficiency (PUE) Rice: The physiological use efficiency reflects the utilization of absorbed nutrients by crop to produce grain and biomass (Devika, *et al*., 2018). Following this PUE was calculated from the mean grain yield and total nutrient uptake by rice and is shown in Fig. 1. Its value varied from 44.60 - 52.74 kg grains kg^{-1} nutrient uptake. The best performing treatment has lowest PUE (44.60 kg grains kg^{-1}nutrient uptake) was obtained under T_5, followed by T_4 (46.86 kg grains kg^{-1}nutrient uptake) and T_3 (48.62 kg grains kg^{-1}nutrient uptake). The maximum value of PUE indicates that lowest performance for nutrient uptake was obtained under T_6 (52.74 kg grains kg^{-1}nutrient uptake).

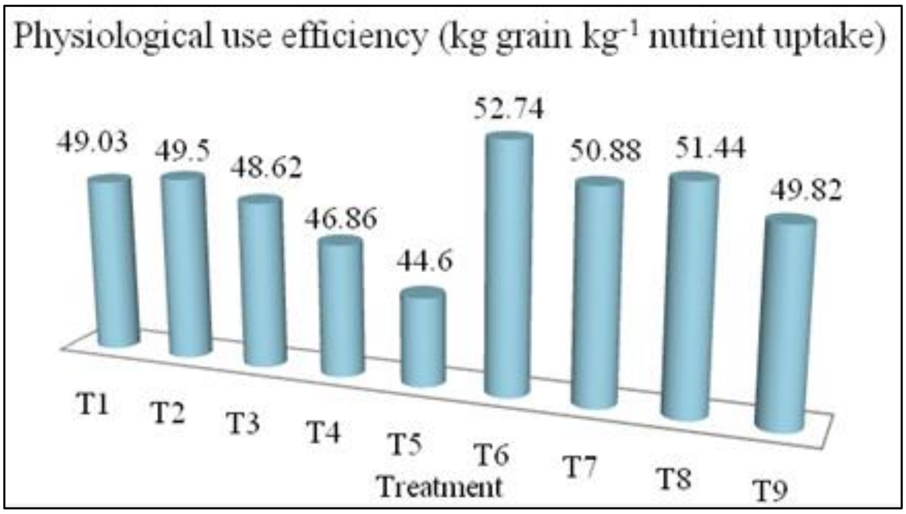


Fig 1: Physiological use efficiency of rice as influenced by nutrient and residue management practices in rice – maize cropping system

Maize: PUE was calculated from the mean grain yield and total nutrient uptake by maize and results are shown in Fig. 2. Its value varied from 30.95 - 43.34 kg grains kg^{-1} nutrient uptake. The best performing treatment T_5 recorded the lowest PUE (30.95 kg grains kg^{-1} nutrient uptake), followed by T_1 (32.14 kg grains kg^{-1}nutrient uptake) and T_4 (32.45 kg grains kg^{-1}nutrient uptake). The maximum value of PUE indicates that the lowest performance for nutrient uptake was obtained under T_6 (43.34 kg grains kg^{-1} nutrient uptake). Thus, it is apparent that the combined application of inorganic nutrients alongwith appropriate residue management enhanced nutrient uptake leading to increased crop productivity. As a result improved agronomical, physiological, and apparent recovery of nutrients was materialized. These findings are closely in agreement with those reported by Prasad and Sharma (2000) [16], Kumar and Goh (2000) [13], Singh, *et al*. (2007) [19], Jat, *et al*. (2012) [9] and Ghosh, *et al*. (2012) [12].

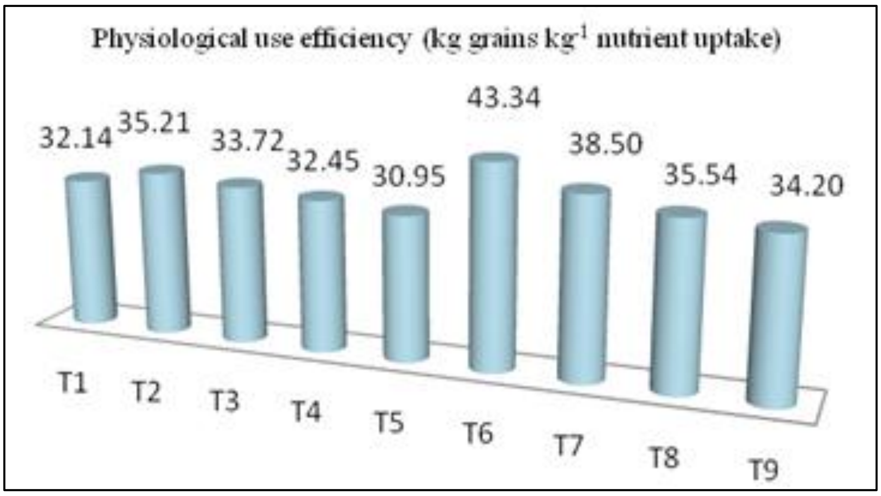


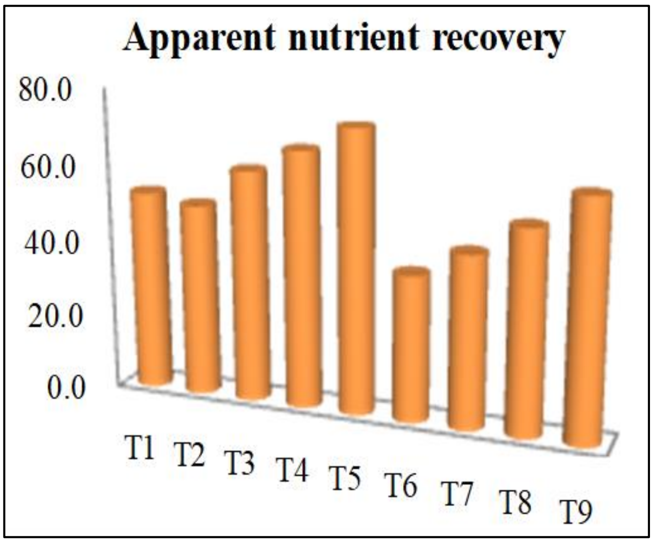
Fig.2: Physiological use efficiency of maize as influenced by nutrient and residue management practices in rice – maize cropping system

Apparent Nutrient Recovery (ANR)

Rice: Apparent nutrient recovery can be defined as the difference in nutrient uptake in above-ground parts of the crop between the fertilized and unfertilized plot relative to the quantity of nutrient applied (Fixen *et al.*, 2014) [5]. Following this concept the apparent nutrient recovery was worked out from the nutrient uptake and quantity of nutrient applied to rice. It is depicted in Fig. 3. The result revealed that it varied from 45% to 64%. The highest ANR (64%) was observed under followed by T_9 (50%) and T_4 (53%). On the other hand the lowest ANR (45%) was observed under the treatment T_6.

Maize: Similarly, the ANR of maize was also worked out from the mean nutrient uptake and amount of nutrient applied as depicted in Fig. 4. The results indicated that it varied from 38% to 74%. The highest value (74%) was recorded in T_5 followed by T_4 (62%) and T_9 (59%). The lowest value (38%) was found under T_6.

Agronomic use efficiency (AUE)



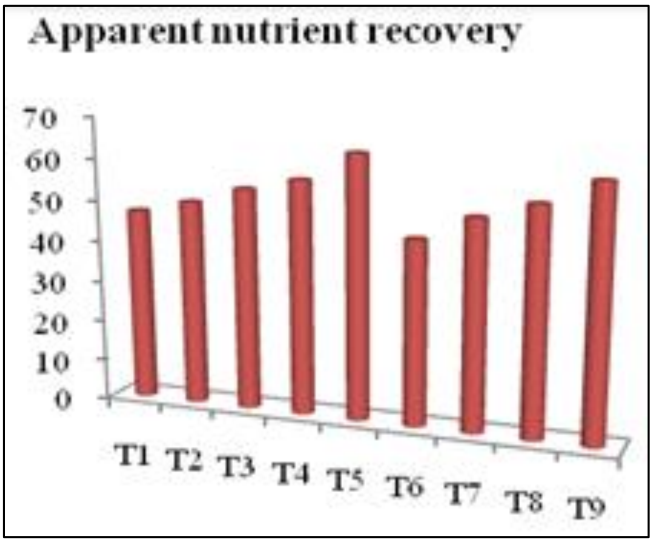


Fig. 3: Apparent nutrient recovery of rice and maize as influenced by nutrient and residue management practices in rice – maize cropping system

Rice: Agronomic use efficiency in general reflects the direct production impact of an applied fertilizer and it relates directly to economic return. It is calculated in units of yield increase per unit of nutrient applied (Fixen *et al.*, 2014) [5]. Accordingly AUE was calculated from the grain yield of rice and applied nitrogen as shown in Fig. 3. It varied from 22.83-30.47 kg grain kg^{-1} nutrient added. However, the highest value (30.47 kg grains kg^{-1}nutrient) was recorded under the treatment T_9 followed by T_5 (25.22 kg grains kg^{-1}nutrient) and T_8 (24.56 kg grains kg^{-1}nutrient). The lowest value (22.83 kg grains kg^{-1} nutrient) was recorded under the treatment T_1.

Maize: Results of the AUE between grain yield and applied nutrient in maize is shown in Fig. 4. It varied from 16.50 -

22.83 kg grains kg^{-1} nutrient added. However, the highest value (22.83 kg grains kg^{-1} nutrient) was observed under T_5 followed by T_4 (20.10 kg grains kg^{-1} nutrient) and T_9 (18.30 kg grains kg^{-1} nutrient). The lowest value (16.50 kg grains kg^{-1} nutrient) was recorded under the treatment T_1.

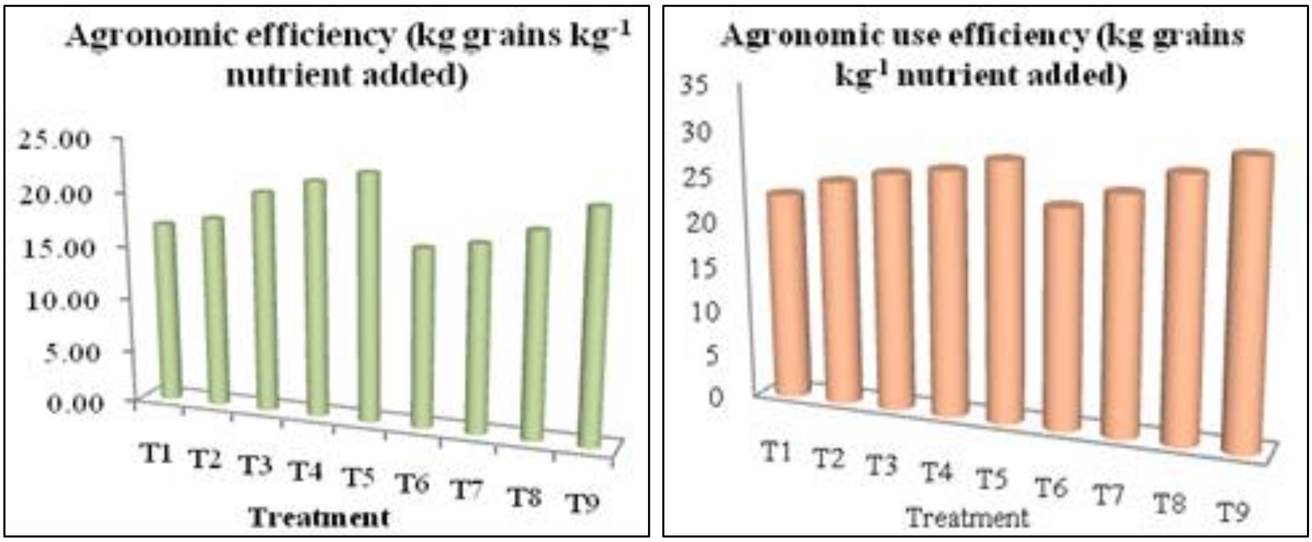


Fig. 4: Agronomic efficiency of rice and maize in a rice-maize cropping system as impacted by nutrient and residue management.

Higher agronomic indices for nutrient utilization appear to be attributable to improved nutrient management as a result of mineralization and loss reduction. Crop leftovers serve a significant role in increasing the efficiency with which native and additional inputs are utilized, as well as in ensuring correct demand-supply balance. In general, input efficiency was shown to be greater at low levels of supply; however, application of inputs under diverse treatments resulted in balanced nutrition, leading to an improvement in the value of agronomic indices such as ANR, AUE, and PUE under maize crop, which reacts favorably to nutrients. These findings corroborate those of Prasad and Sinha *et al*. (1995) [17], Tittonell *et al*. (2008) [21], Ramalaxmi *et al*. (2012) [18], and Jat *et al*. (2013) [10].

Nutrient uptake rice - maize cropping system

The nutrient demand of rice - maize system is high due to use of high yielding varieties/hybrids. The nutrient demand is related with the high productivity. However, soil fertility of this system is declining very fast, as the crop residues are usually removed from fields. The results of nutrient (NPK) uptake of this system are presented in Table 3. Accordingly, the maximum nutrient (NPK) uptake was recorded under treatment T_5, closely followed by treatments T_1- F P, T_3 and T_4 during both the years and on mean basis. The trend is similar to that of productivity of the system, as the higher nutrient uptake is directly associated with system's productivity.

Table 3: Nutrient uptake (kg ha^{-1}) as influenced by nutrient and residue management practices under rice -maize cropping system

Treatments	Nutrient uptake (kg ha^{-1})								
	N			P			K		
	2016-17	2017-18	Mean	2016-17	2017-18	Mean	2016-17	2017-18	Mean
T_1 (F P)	305.4	319.3	312.4	97.7	103	100.4	338.7	352.4	346.1
T_2	281.8	298.7	290.2	76.6	82.2	79.4	297	316.5	307.3
T_3	293.6	316.9	305.2	90.1	98.1	94.1	316.2	346.6	331.4
T_4	300.2	328.6	314.4	91.5	103.1	97.3	333.7	366.6	350.2
T_5	319.7	348.5	334.1	97.8	107.6	102.7	347.9	378.8	363.9
T_6	242.5	248.4	245.4	61.5	64.3	62.9	261.1	277.3	269.2
T_7	252.9	261.9	257.4	65	68.4	66.8	271.9	286.1	279
T_8	262.2	277.6	269.9	68.9	74.1	71.5	276.1	299.2	288.2
T_9	271.1	288.3	279.7	72.3	78.5	75.3	285	305.8	295.4
T_{10} (Control)	166.1	171.4	168.7	42.7	45.9	44.4	168.7	178.5	174.1
SEm±	9.69	11.25	9.61	4.7	4.6	4.5	15.5	17.4	16.1
C.D (P=0.05)	28.5	32.5	28.6	14.6	13.8	13.5	45.9	51.1	48.3

The effect of split doses: The effect of split doses of P can be seen by the difference in nutrient uptake and system productivity under the treatments T_5 and T_4. Accordingly, nutrient uptake was enhanced (by 19.7 N, 5.4 P and 13.7 K kg ha^{-1} under treatment T_5 (with 2 split doses of P) as compared to T_4. This resulted in higher system productivity under T_5 (13.36 t ha^{-1}) as compared to T_4 (13.06 t ha^{-1}) with relative advantage of 0.30 t ha^{-1} by just splitting P dose.

The effect of Trichoderma: The effect of *Trichoderma* can also be workout by comparing the treatments T_5 and T_3. Accordingly, the use of *Trichoderma* resulted in enhanced nutrient uptake (by 28.9 N, 8.6 P and 32.5 K kg ha^{-1}) under treatment T_5 (with application of *Trichoderma*) as compared to T_3. This resulted in higher system productivity under T_5 (13.36 t ha^{-1}) as compared to T_3 (12.784 t ha^{-1}) with relative advantage of 0.576 t ha^{-1} use of *Trichoderma*.

Chemical properties of soil

Application of nutrient and residue management practices maintained soil fertility status in rice - maize cropping system. Similar results were obtained in varied soils of India under this system. Organic manures or fertilizers on residue decomposition solubilize soil nutrients, thus leading to improvement in available nutrient status of soil including pH, EC and organic carbon (Behera and Nand Ram, 2004, Bajapai *et al.*, 2002, and Laxminarayana, 2006) [3, 2, 14].

The results of the study are shown in Table 4 and 5. It indicated that after two years of study the soil organic carbon and available N, P, K was significantly influenced by nutrient and residue management practices resulting in improved soil fertility status, while pH was non-significant.

The maximum available soil nutrients NPK and organic carbon after two years study was found to be highest under treatment T_5 (N 261, P 23.6, K 455 kg ha^{-1} and OC – 0.67%), that was statistically at par to T_4, T_1- F P and T_3 compared to initial.

Table 4: Soil characteristics status (kg ha^{-1}) after 2 year cycle of rice- maize cropping system as influenced by nutrient and residue management practices

Treatment	pH		EC (dSm^{-1})		Organic carbon (%)	
	Value	% change	Value	% change	Value	% change
T_1 (F P)	7.53	-2.33	0.22	-4.35	0.64	+12.28
T_2	7.41	-3.89	0.21	-8.70	0.63	+10.53
T_3	7.44	-3.50	0.21	-8.70	0.64	+12.28
T_4	7.42	-3.76	0.21	-8.70	0.65	+14.04
T_5	7.46	-3.24	0.22	-4.35	0.67	+17.54
T_6	7.28	-5.58	0.21	-8.70	0.60	+5.26
T_7	7.39	-4.15	0.21	-8.70	0.61	+7.06
T_8	7.43	-3.63	0.21	-8.70	0.62	+8.77
T_9	7.4	-4.02	0.21	-8.70	0.63	+10.53
T_{10}- Control	7.38	-4.28	0.21	-13.04	0.59	+3.51
SEm±	0.22	-	0.8	-	0.01	-
C.D (P=0.05)	NS	-	NS	-	0.04	-

Initial Chemical composition of soil (pH 7.71, EC -0.23 dSm^{-1} and OC- 0.57%)

Table 5: Available nutrient status (kg ha^{-1}) after 2 year cycle of rice- maize cropping system as influenced by nutrient and residue management practices

Treatment	N		P		K	
	Value	% change	Value	% change	Value	% change
T_1 (F P)	254	10.4	22.4	12.6	452	8.9
T_2	247	7.4	21.6	8.8	444	7.0
T_3	253	10.0	22.3	12.1	448	7.9
T_4	257	11.7	23.1	16.1	450	8.4
T_5	261	13.5	23.6	18.6	455	9.6
T_6	239	4.5	20.8	4.9	437	5.3
T_7	242	5.2	20.9	5.3	439	5.8
T_8	244	6.1	21.4	7.5	440	6.0
T_9	247	7.4	21.8	9.5	443	6.7
T_{10}- Control	238	3.5	19.3	3.0	423	1.9
SEm±	3	-	0.6	-	3	-
C.D (P=0.05)	8	-	1.7	-	9	-

Initial available nutrient status (N- 230, P-19.9 and K-415 in kg ha^{-1})

These findings are consistent with those of (Karki and Kumar, 2005) [11], who found a significant residual effect of conjunctive usage of residue and fertilizer on subsequent crop and system production in a rice-based cropping system. The good effect of appropriate nutrient levels resulted in improved growth and yield characteristics, which resulted in greater grain and stover yields of maize, and hence higher returns. Thus, emphasizing the importance of nutrients in rice-based cropping systems, (Gupta *et al.*, 2006) [6] asserted that in India, 45% of inferior yields attained in lowland rice production systems may be traced to a single cause, namely poor nutrient management.

The rice-maize farming system is extremely productive and economically successful, but it is a large system; soil fertility may be maintained through smart integration of organic and inorganic sources of plant nutrients. Rice and maize straw are the most important organic material sources, and incorporating crop straw and stubble into the soil restores most of the nutrients and helps to sustain crop output over time. Crop residue decomposition is a microbial-mediated gradual breakdown of organic materials with the ultimate end result being carbon and different nutrients released into the biological circulation in the ecosystem on both a local and global scale. Trichoderma is the most prevalent creature, and it plays a significant part in the breakdown of organic materials. Similarly, solitary superphosphate has been shown to accelerate straw breakdown (Singh and Charya, 2010) [20]. It has also been shown that straw retention reduces phosphate concentrations in soil solutions, particularly before planting (Yan *et al.*, 2016) [22]. Taking the aforementioned factors into account, the current experiment was carried out to control nutrients and residue in the rice-maize cropping system.

Conclusion
Under treatment T5, residue retention and incorporation in soil, along with inorganic fertilizers, had a positive impact on the rice-maize cropping system in terms of REY, system productivity, production efficiency, available N, P, and K (13.5% N, 18.6% P, 9.6% K, and 17.54% OC) in soil, and total nutrient uptake (13.5% N, 18.6% P, 9.6% K, and 17.54% OC). Split P dosages increased nutrient absorption (by 19.7 N, 5.4 P, and 13.7 K kg ha-1), resulting in 0.30 t ha-1 improved system productivity. Similarly, the application of Trichoderma increased nutrient absorption (by 28.9 N, 8.6 P, and 32.5 K kg ha-1), resulting in 0.576 t ha-1 greater system productivity.

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