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Effect of Paddy Residue and Nutrient Management Approaches on Growth, Yield and Nutrient Uptake by Paddy in Paddy-Paddy Cropping System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

An investigation on the efficacy of paddy residue and nutrient management approaches on growth, yield and nutrient uptake by paddy was conducted during *kharif* and *rabi-summer* seasons of 2019-20 and 2020-21 at Gabbur village, Raichur, Karnataka, India. The experiment was laid out in split plot design with three replications, which consisted of four residue management in main plots and five nutrient management approaches in sub plots. The treatment with residue incorporation + compost culture gave significantly taller plants (84.40 and 84.53 cm), higher number of tillers hill^{-1} (20.06 and 20.09), grain yield (65.37 & 65.34 q ha^{-1}), straw yield (80.01 & 80.04 q ha^{-1}) and total N, P, K, S, Zn & Fe uptake over residue incorporation alone, residue burning and residue removal. Similarly, application of nutrients through SSNM targeted yield of 80 q ha^{-1} gave significantly higher plant height (90.51 and 90.50 cm), higher number of tillers hill^{-1} (23.02 and 22.95), grain yield (75.19 & 75.26q ha^{-1}), straw yield (92.17 & 92.14 q ha^{-1}) and total N, P, K, S, Zn & Fe uptake

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followed by STCR targeted yield of 80 q ha^{-1} > STL method > recommended NPK > absolute control. Interaction effect showed that, residue incorporation + compost culture with SSNM targeted yield of 80 q ha^{-1} recorded significantly higher plant height (95.95 and 96.13), number of tillers hill^{-1}(25.50 and 25.56), grain yield (77.25 and 77.45 q ha^{-1}), straw yield (94.83 and95.32 q ha^{-1}) and nutrient uptake by paddy over other combinations.

Keywords: Paddy; growth; yield; nutrient uptake.

1. INTRODUCTION

Sustainability of natural resources such as soil and water for crop production is a major challenge with burgeoning population pressure. There is a need to balance between increasing crop production without compromising soil health and environmental sustainability**.** In Asia, rice is the principal staple crop where ~90 percent of the global rice being grown and consumed. In India, it occupies ~43.8 m ha of cultivable area with production of ~118.87 mt [1]. Intensive mono-cropped system of rice cultivation has commenced to show declining trend in rice yield, where imbalance nutrient management and decreasing soil organic matter are the major accountable factors for the declining the rice yield [2].

Crop residue is a kind of energy materials that is rich in carbon. Returning of crop residues in field has great significance in maintaining soil fertility and developing sustainable agriculture. After the green revolution, the introduction of high input technologies and high yielding varieties led to higher crop residue generation in India. Billions of tonns of crop residue now become trash due to the promotion of crop yield and the mechanical harvest. The disposal of such huge amount of residue is a major concern, particularly in the region where rice-rice/rice-wheat cropping system is extensively followed. Hence, the abundant crop residues are often burnt by farmers in harvest seasons, resulting in not only a waste of organic fertilizer resource but also environmental pollutions and negative effects on soil ecosystem [3]. Crop residue contains considerable quantity of carbons (C), nitrogen (N), phosphorus (P), potassium (K) and other nutrients. In addition, crop residue can also improve soil properties and increase yield of crop.

In nature, the bioconversion rate of paddy straw is slow and natural micro flora participates in degradation of the crop waste. Therefore, bio-augmentation of paddy straw with efficient microbes may improve and/or accelerate the decomposition process and fasten nutrient release by creating a suitable environment for degradation. Fungi are an important component of soil micro-biota in soil constituting more of the soil biomass than bacteria, depending on depth and nutrient conditions of soil. Fungi being filamentous in nature have an advantage in the decomposition of lignocellulosic waste as they possess ability to produce prolific spores that can quickly invade substrates. They play an important role in the degradation of rice straw. Moreover, mixed cultures can have greater influence on substrate colonization because of the higher production of enzymes and resistance to contaminant microbes compared to pure cultures. A compatible consortium of lignocellulolytic fungal might play an important role in the rapid degradation of paddy straw.

In recent years with the development of chemical fertilizer, use of the organic fertilizers has dramatically reduced. The effect of the incorporation of crop straws on the fertility of soil as well as yield response of the crop was well documented. However, the residue incorporation along with different nutrient management approaches *viz*., site specific nutrient management (SSNM), soil test and crop response (STCR), soil test laboratory method (STL) on yield and nutrient uptake has been rarely reported in paddy-paddy cropping system. Keeping in view of harmful effect of residue burning and excess fertilizer application rates, the present study was undertaken.

2. MATERIALS AND METHODS

2.1 Experimental Site and Soil

The field experiments were conducted during *kharif* and *rabi-summer* season of 2019-2020 and 2020-2021 under transplanted condition in progressive farmer field at Gabbur village, Raichur situated in the North Eastern Dry Zone (Zone 2) of Karnataka at 16° 18'Nlatitude 77° 06' E longitude with an altitude of 393 m above mean sea level.

The soil of the experimental site was clay in texture with neutral pH (7.95), medium EC (1.13 dS m^{-1}) and high in OC (15.00 g kg^{-1}). The soil was low in available nitrogen (168.00kg ha^{-1}), high in available phosphorus (188.99 kg ha^{-1}) & potassium (520.12 kg ha^{-1}) and medium in available sulphur (16.30 mg kg^{-1}). The DTPA extractable Zn and Fe were in sufficient range with values 2.08 and 5.05, mg kg^{-1}, respectively. The variety used in the study was BPT-5204, which matures in about 145-150 days with an average yield potential was 5.0 - 6.0 t ha^{-1}.

2.2 Experimental Details

The experiment was laid out in split plot design having four residue management (M) and five nutrient management approaches (T) with three replications as detailed in Table 1.

During *kharif* 2019, the required amount of paddy residue of 94 q ha^{-1} with nutrient composition of 0.42, 0.12 and 1.3 % of N, P and K, respectively was determined based on the straw generated in the farmer's field. In the subsequent seasons, immediately after harvest, above-ground residues from the individual plots were either completely removed/ retained/ retained & inoculated/ burnt and incorporated into about 15 cm depth using a tractor drawn rotovator. The fungal culture used in the study was "Compost culture" developed by Institute of Organic Farming, University of Agricultural Sciences Dharwad, Karnataka, India, which is a mixture of four microorganisms *i.e*., *Aspergillu*s sps., *Trichoderma* sps., *Phaenerochaete* sps. and *Pleurotus* sps was applied @ 1 kg per tonne of paddy residue.

2.3 Fertilizer Calculations

The quantity of fertilizer dose for soil test laboratory (STL) method was calculated on the basis of low, medium and high fertility ratings for N, P_2O_5 and K_2O. Furthermore, the quantity of fertilizers for STCR treatment was calculated by using standardized equation developed for *Vertisols* of Siruguppa for rice cultivation [4] as detailed below:

$FN = 3.45\ T - 0.29\ SN$ ($KMnO_4$ - N)
$FP_2O_5 = 2.82\ T - 1.70\ SP_2O_5$ (Olsen's - P_2O_5)
$FK_2O = 2.00\ T - 0.09\ SK_2O$ (NH_4OAC - K_2O)

Where,

T = Targeted yield (q ha^{-1})
FN = Nitrogen supplied through fertilizer (kg ha^{-1})
FP_2O_5 = Phosphorus supplied through fertilizer (kg ha^{-1})
FK_2O = Potassium supplied through fertilizer (kg ha^{-1})

Similarly for SSNM, the quantity of N, P_2O_5 and K_2O required were calculated based on the nutrient removal by paddy crop per tonne. In the first season, the average nutrient removal of N, P_2O_5 and K_2O by rice crop per tonne grain production considered was 17.81, 16.67 and 25.86 kg ha^{-1} [5]. In the subsequent seasons nutrient removal of N, P and K considered was on the basis of previous crop results.

2.4 Growth and Yield Measurements

The plant height and number of tillers $hill^{-1}$of paddy in each season was recorded at crop harvest. In each season, the above ground biomass of all plants was manually harvested separately from the net plot, threshed and dried in sun. The grains were cleaned and weight was recorded in quintals hectare (q ha^{-1}).

2.5 Nutrient Uptake by Paddy

The collected plant samples (grain and straw) at the time of harvest from each plot were thoroughly washed with deionized water and oven dried at 60 °C to obtain constant weight, cut to pieces, powdered and used for analysis of total N, P, K, S and micronutrients using standard procedures and workout for total uptake.

Table 1. Treatment details

Main plot: Residue management	Subplot: Nutrient management
M_1: Residue removal	T_1: Absolute control
M_2: Residue incorporation (RI)	T_2: Recommended NPK
M_3: RI + Compost culture	T_3: Fertilizer based on STL
M_4: Residue burning	T_4: Fertilizer based on STCR for yield target of 80 q ha^{-1}
	T_5: Fertilizer based on SSNM for yield target of 80 q ha^{-1}

2.6 Statistical Analysis

The experimental data were subjected to statistical scrutiny to find out the influence of treatments on growth, yield and nutrient uptake by paddy. Further the effects were tested at 5% level of significance [6].

3. RESULTS AND DISCUSSION

The data on growth, yield and nutrient uptake paddy are furnished in Tables 2 to 7. There was a slight difference in these parameters during both *kharif* and *rabi-summer* experiments, but the pattern of response were similar. Hence, only pooled data of the two years are used to emphasize the results.

3.1 Growth Attributes of Paddy

Pooled results showed that, among the residue management options, RI + compost culture registered significantly higher plant height (84.40 and 84.53 cm) and number of tillers hill^{-1} (20.06 and 20.09) over residue incorporation alone, residue burning & residue removal during *kharif* and *rabi-summer* season, respectively (Table 2). The results obtained in performances probably due to better decomposition of the paddy straw by added microbial inoculants, which led to enhanced nutrients availability and good soil condition to the crop growth resulted in quantitative increase in growth attributes with increased cell division, cell enlargement, photosynthesis and protein synthesis. The beneficial role of microbial inoculants on plant height was also reported by Singh et al. [7] in rice crop.

During *kharif* and *rabi-summer* season, application of fertilizers based on SSNM targeted yield of 80 q ha^{-1} (T_5) recorded significantly higher plant height (90.51 and 90.50 cm) and number of tillers hill^{-1} (23.02 and 22.95) followed by STCR targeted yield of 80 q ha^{-1} > STL method > recommended NPK > absolute control (Table 2). Improved plant height and number of tillers hill^{-1} under SSNM targeted yield of 80 q ha^{-1} was accrued due to sufficient nutrients supply as per crop demand and indigenous soil nutrient supplying capacity as compared to STL method, recommended NPK and absolute control. The results are also in conformity with the findings of Raghavendra et al. [8], who reported higher plant height of 72.8 cm with the application of site specific nutrients (150: 43: 115 kg NPK kg ha^{-1}) in dry-DSR. A similar result for plant height was also noticed in rice [9].

Significantly higher plant height of 95.95 & 96.13 cm and number of tillers hill^{-1} of 25.50 & 25.56 was noticed under RI + compost culture with SSNM targeted yield of 80 q ha^{-1} (M_3T_5; Table 2) in comparison to other combinations which might be due to enhanced availability of both macro and micro nutrients besides improvement in soil microbial activity. The enhanced uptake of these nutrients might have resulted in increased vegetative growth of plant. In parallel, Vijayaprabhakar et al. [10] reported that the incorporation of harvested rice residue with 25 kg additional N ha^{-1} as basal + bio-mineralizer (2 kg t^{-1} of rice residue) and cow dung slurry (5 %) recorded higher plant height and number of tillers hill^{-1}over incorporation of straw alone and removal of straw.

3.2 Yield of Paddy

Among the different residue managements, RI + compost culture (M_3) registered significantly higher grain yield of 65.37 & 65.34 q ha^{-1} and straw yield of 80.01 & 80.04 q ha^{-1} during both *kharif* and *rabi-summer* season, respectively over residue incorporation alone, residue burning and residue removal (Table 3).The impact of straw application on crop yield varies depending on straw application timing, straw incorporation method, the amount of crop residue, soil characteristics and the amount of fertilizer applied [11]. Crop residues upon decomposition releases essential nutrients slowly throughout the growth period, which will result in better plant growth and yield as noticed in our study. While the incorporation of paddy straw with compost culture enhanced this process and resulted in higher grain & straw yield when compared to straw incorporation alone, residue burning and residue removal, possibly due to microbial load, which can accelerate the decomposition of crop straws. These findings were in support of Jayadeva et al. [12].

Application of nutrients through SSNM targeted yield of 80 q ha^{-1} showed significantly higher grain (75.19 & 75.26q ha^{-1}) and straw (92.17 & 92.14 q ha^{-1}) yield followed by STCR targeted yield of 80 q ha^{-1} (T_4) > STL method (T_3) > recommended NPK (T_2) over absolute control (T_1) during *kharif* and *rabi-summer,* respectively (Table 3).The prerequisite for getting higher yield in any crop is due to higher total dry matter production and it's partitioning into various plant parts coupled with maximum translocation of photosynthates to the sink. Growth and yield attributes could have been promoted by sufficient and balanced availability of the nutrients for a prolonged period during crop growth and development stages and evidenced through higher uptake of nutrients *viz.,* nitrogen, phosphorous and potassium. The increase in the grain yield under T_5 was 12.72 & 13.05 per cent over recommended NPK during *kharif* and *rabi-summer,* respectively. Raghavendra et al. [8] reported significantly higher grain yield of 54.73 q ha^{-1} and straw yield of 68.55 q ha^{-1} in SSNM approach targeted yield of 55 q ha^{-1} which resulted from increased growth and yield attributes in the same treatment. Similar result was also reported by Rajesh et al. [13].

It is evident from the data that interaction effect on grain & straw yield differed significantly with values varied from 33.02 to 77.25 q $ha^{-1}$and 40.52 to 94.83q ha^{-1}, respectively during *kharif* season; 32.18 to 77.45 q $ha^{-1}$and 39.71 to 95.32 q ha^{-1}, respectively during *rabi-summer* season. Wherein, significantly higher values were recorded under residue incorporation + compost culture with SSNM targeted yield of 80 q ha^{-1} (M_3T_5) as compared to other treatment combinations (Table 3). It was very clear that residue incorporation in combination with inorganic fertilizers (SSNM) increased the vegetative growth of plants as observed earlier and thereby increased yield of paddy [14]. Similar to our findings, Patra [15] reported enhanced grain and straw yield with increase in N level (180 kg ha^{-1}) under residue incorporation over residue removal and burning.

3.3 Nutrient Uptake by Paddy

During both *kharif* and *rabi-summer* season of the study, residue incorporation along with compost culture (M_3) significantly enhanced total N (141.11 & 140.51 kg ha^{-1}), P (40.51 & 40.36 kg ha^{-1}), K (148.18 & 148.39 kg ha^{-}1), S (19.95 & 20.04 kg ha^{-1}), Zn (316.83 & 318.91 g ha^{-1}) and Fe (3829.58 & 3836.63 g ha^{-1}) uptake by paddy followed by residue incorporation alone, residue burning and residue removal (Table 4, 5, 6 & 7). Straw incorporation has been shown to enhance nutrient recycling and provide soil fertility benefits [16]. In the present study, the incorporation of the microbial inoculated straw recorded higher total N, P, K, S, Zn and Fe uptake (grain + straw) over other three residue management as it is supported by increase in biomass as well as increased availability of these nutrients during both *kharif* and *rabi-summer.* The *in-situ* decomposition of paddy straw in combination with cow dung slurry (5 %) + *Trichoderma harizianum* (5 kg ha^{-1}) + *Pleurotus sajorcaju* (5 kg ha^{-1}) enhanced N, P and K uptake by paddy grain and straw [12]. It might be due to increase in rate of crop residue decomposition in soil and easy availability of plant nutrient from the soil solution, which favored higher degree of vegetative growth. The better availability of Zn through organic & inorganic $ZnSO_4$ and increased Fe concentrations in the soil solution through reduced redox potential might have helped in better absorption and translocation of these nutrients from the soil solution, which resulted in higher dry matter production, inturn increased total Zn & Fe uptake by paddy [17].

Among the different nutrient management approaches, the application of fertilizers through SSNM targeted yield of 80 q ha^{-1} (T_5) recorded significantly higher total N, P, K S, Zn and Fe (172.22 & 169.67 kg ha^{-1}, 51.61 & 51.20 kg ha^{-1}, 186.69 & 186.20 kg ha^{-1}, 24.72 & 24.49 kg ha^{-1}, 397.35 & 395.16 g ha^{-1} and 5179.08 & 5111.15 g ha^{-1} during *kharif* and *rabi-summer*, respectively). Whereas, lower uptake values were recorded under absolute control (Tables 4, 5, 6 & 7). Higher uptake of these nutrients under SSNM might be due to balanced fertilization as per crop need which is well reflected in terms of higher grain and straw yield. The increased availability of P, K and S from the native soil also facilitated better nutrient uptake by paddy from rhizoshpere. Raghavendra et al. [5] and Rajesh et al. [13] also noticed higher nutrient uptake (grain + straw) by dry DSR through SSNM approach as compared to RDF, farmer's practice and other soil test methods. The results are in line with the findings of Ravi et al. [18].

The data pertaining to interaction effect on total N, P, K, S, Zn and Fe uptake by paddy differed significantly. Wherein, the residue incorporation + compost culture with SSNM targeted yield of 80 q ha^{-1} recorded significantly higher total N (186.82 & 185.83 kg ha^{-1}) P (56.01 & 55.96 kg ha^{-1}) K (196.21 & 196.97 kg ha^{-1}), S (26.93 & 27.17 kg ha^{-1}), Zn (432.29 & 435.67 g ha^{-1}) and Fe (5641.58 & 5636.46 g ha^{-1}) in comparison to other combinations during *kharif* and *rabi-summer*, respectively. Whereas, lower values were recorded under residue removal with absolute control (Tables 4, 5, 6 & 7). The combined application of organic and inorganic sources of nutrients (residue incorporation + compost culture with SSNM targeted yield of 80 q ha^{-1}; M_3T_5) helped in higher translocation of macro & micro nutrients to straw and grain, which resulted for higher total uptake by paddy. This might be due to the fact that the number of

Table 2. Plant height and number of tillers hill^{-1} of paddy as influenced by residue and nutrient management

Treatment	Plant height (cm)						Number of tiller hill^{-1}					
	Kharif			***Rabi-summer***			***Kharif***			***Rabi-summer***		
	2019	**2020**	**Pooled**	**2019-20**	**2020-21**	**Pooled**	**2019**	**2020**	**Pooled**	**2019-20**	**2020-21**	**Pooled**
Residue management (M)												
M_1: Residue removal	77.86	78.10	77.98	76.39	77.58	76.98	16.75	17.22	16.98	16.22	16.88	16.55
M_2: Residue incorporation (RI)	80.28	81.80	81.04	80.76	80.99	80.88	18.26	19.18	18.72	18.59	18.85	18.72
M_3: RI + Compost culture	83.31	85.50	84.40	84.40	84.66	84.53	19.44	20.68	20.06	19.89	20.29	20.09
M_4: Residue burning	78.16	78.69	78.42	76.78	77.92	77.35	16.93	17.58	17.25	16.51	17.21	16.86
S.Em.±	0.49	0.64	0.40	0.42	0.44	0.33	0.20	0.25	0.15	0.17	0.16	0.11
C.D. at 5%	1.69	2.20	1.40	1.44	1.52	1.16	0.70	0.87	0.52	0.59	0.56	0.39
Nutrient management (T)												
T_1: Absolute control	66.43	64.23	65.33	64.52	63.91	64.21	11.48	11.06	11.27	11.09	10.91	11.00
T_2: Recommended NPK	77.32	79.14	78.23	77.12	78.37	77.74	16.67	17.57	17.12	16.68	17.27	16.97
T_3: STL	81.08	83.11	82.09	81.05	82.19	81.62	17.98	18.98	18.48	17.87	18.64	18.26
T_4: STCR of 80 q ha^{-1}	85.20	87.10	86.15	84.96	86.24	85.60	20.73	22.03	21.38	20.63	21.57	21.10
T_5: SSNM of 80 q ha^{-1}	89.50	91.52	90.51	90.27	90.73	90.50	22.36	23.67	23.02	22.74	23.16	22.95
S.Em.±	0.43	0.59	0.39	0.40	0.43	0.33	0.19	0.21	0.13	0.16	0.19	0.13
C.D. at 5%	1.24	1.69	1.13	1.14	1.23	0.95	0.55	0.60	0.38	0.47	0.56	0.39
Interaction (M × T)												
M_1T_1	65.99	63.79	64.89	63.87	63.45	63.66	11.22	10.61	10.91	10.67	10.51	10.59
M_1T_2	75.15	75.85	75.50	73.26	75.40	74.33	15.60	16.15	15.87	14.99	15.82	15.41
M_1T_3	78.78	79.66	79.22	77.11	79.07	78.09	16.74	17.53	17.13	16.00	17.17	16.58
M_1T_4	82.67	83.62	83.14	80.82	82.83	81.83	19.29	20.16	19.73	18.51	19.69	19.10
M_1T_5	86.72	87.57	87.15	86.88	87.16	87.02	20.89	21.65	21.27	20.93	21.20	21.07
M_2T_1	66.66	64.37	65.51	64.85	64.15	64.50	11.69	11.36	11.53	11.40	11.17	11.29
M_2T_2	77.78	80.11	78.95	78.76	79.20	78.98	16.97	18.06	17.52	17.63	17.80	17.72
M_2T_3	81.44	84.05	82.74	82.73	82.90	82.81	18.46	19.44	18.95	18.81	19.14	18.98
M_2T_4	85.63	87.92	86.77	86.50	87.03	86.76	21.30	22.71	22.00	21.72	22.30	22.01
M_2T_5	89.90	92.54	91.22	90.97	91.65	91.31	22.86	24.31	23.58	23.40	23.86	23.63
M_3T_1	66.83	64.71	65.77	65.38	64.44	64.91	11.75	11.60	11.67	11.56	11.36	11.46
M_3T_2	80.85	84.14	82.50	82.72	83.22	82.97	18.34	19.61	18.98	18.84	19.36	19.10
M_3T_3	85.04	88.38	86.71	86.87	87.40	87.14	19.77	21.07	20.42	20.33	20.74	20.54
M_3T_4	89.56	92.61	91.09	91.19	91.83	91.51	22.76	24.70	23.73	23.46	24.14	23.80
M_3T_5	94.25	97.65	95.95	95.84	96.41	96.13	24.56	26.44	25.50	25.25	25.86	25.56
M_4T_1	66.22	64.04	65.13	63.98	63.58	63.78	11.25	10.69	10.97	10.73	10.62	10.68
M_4T_2	75.49	76.45	75.97	73.72	75.67	74.69	15.76	16.46	16.11	15.24	16.09	15.67
M_4T_3	79.05	80.36	79.70	77.49	79.40	78.45	16.96	17.88	17.42	16.33	17.52	16.93
M_4T_4	82.94	84.26	83.60	81.31	83.28	82.30	19.56	20.56	20.06	18.85	20.13	19.49
M_4T_5	87.11	88.33	87.72	87.40	87.68	87.54	21.13	22.29	21.71	21.41	21.71	21.56
S.Em.±	0.86	1.18	0.78	0.79	0.85	0.66	0.38	0.42	0.26	0.33	0.39	0.27
C.D. at 5%	2.48	3.39	2.25	2.29	2.46	1.90	1.11	1.20	0.76	0.95	1.11	0.77

Table 3. Grain and straw yield of paddy as influenced by residue and nutrient management

Treatment	Grain yield (q ha^{-1})						Straw yield (q ha^{-1})					
	Kharif			*Rabi-summer*			*Kharif*			*Rabi-summer*		
	2019	2020	Pooled	2019-20	2020-21	Pooled	2019	2020	Pooled	2019-20	2020-21	Pooled
Residue management (M)												
M_1: Residue removal	62.88	63.01	62.94	62.57	62.61	62.59	76.88	77.05	76.97	76.52	76.51	76.51
M_2: Residue incorporation (RI)	64.01	64.41	64.21	64.16	63.79	63.98	78.41	78.76	78.58	78.53	78.06	78.30
M_3: RI + Compost culture	64.86	65.88	65.37	65.43	65.25	65.34	79.22	80.79	80.01	80.32	79.75	80.04
M_4: Residue burning	63.03	63.30	63.17	62.77	62.96	62.86	77.00	77.38	77.19	76.71	76.89	76.80
S.Em.±	0.14	0.21	0.12	0.17	0.18	0.14	0.17	0.25	0.19	0.30	0.28	0.25
C.D. at 5%	0.49	0.73	0.40	0.59	0.62	0.48	0.60	0.88	0.66	1.03	0.98	0.86
Nutrient management (T)												
T_1: Absolute control	34.79	31.98	33.38	34.10	30.97	32.53	42.65	39.15	40.90	42.12	38.04	40.08
T_2: Recommended NPK	66.27	67.13	66.70	66.27	66.87	66.57	81.19	82.34	81.77	81.33	81.98	81.66
T_3: STL	69.97	71.07	70.52	70.02	70.70	70.36	85.85	87.24	86.54	86.00	86.76	86.38
T_4: STCR of 80 q ha^{-1}	73.16	74.48	73.82	73.35	74.11	73.73	88.63	90.47	89.55	88.86	89.75	89.30
T_5: SSNM of 80 q ha^{-1}	74.28	76.09	75.19	74.93	75.60	75.26	91.07	93.27	92.17	91.78	92.50	92.14
S.Em.±	0.13	0.17	0.14	0.17	0.17	0.15	0.16	0.20	0.17	0.27	0.27	0.24
C.D. at 5%	0.38	0.48	0.42	0.49	0.50	0.43	0.46	0.57	0.48	0.79	0.77	0.69
Interaction (M × T)												
M_1T_1	34.47	31.58	33.02	33.74	30.62	32.18	42.37	38.66	40.52	41.65	37.78	39.71
M_1T_2	65.56	66.11	65.84	65.21	65.92	65.56	80.32	81.15	80.73	79.98	80.88	80.43
M_1T_3	69.13	69.79	69.46	68.69	69.54	69.12	84.74	85.53	85.13	84.16	85.20	84.68
M_1T_4	72.18	73.03	72.60	71.73	72.73	72.23	87.46	88.66	88.06	87.00	88.08	87.54
M_1T_5	73.05	74.52	73.78	73.48	74.21	73.85	89.54	91.23	90.38	89.82	90.60	90.21
M_2T_1	34.91	32.04	33.48	34.21	31.16	32.68	42.80	39.29	41.05	42.42	38.24	40.33
M_2T_2	66.35	67.52	66.94	66.50	66.99	66.75	81.51	82.50	82.00	81.68	82.12	81.90
M_2T_3	70.23	71.36	70.80	70.53	70.94	70.74	86.46	87.77	87.11	86.74	87.22	86.98
M_2T_4	73.64	74.77	74.21	74.07	74.24	74.15	89.24	90.76	90.00	89.49	90.03	89.76
M_2T_5	74.90	76.33	75.61	75.50	75.62	75.56	92.02	93.46	92.74	92.31	92.70	92.51
M_3T_1	35.23	32.45	33.84	34.58	31.40	32.99	42.98	39.74	41.36	42.65	38.29	40.47
M_3T_2	67.49	68.62	68.06	67.91	68.34	68.13	82.51	84.33	83.42	83.48	83.70	83.59
M_3T_3	71.22	73.05	72.13	71.93	72.31	72.12	87.45	89.80	88.63	88.72	88.84	88.78
M_3T_4	74.46	76.72	75.59	75.69	76.30	76.00	90.20	93.40	91.80	91.73	92.32	92.02
M_3T_5	75.93	78.58	77.25	77.02	77.88	77.45	92.97	96.69	94.83	95.02	95.62	95.32
M_4T_1	34.54	31.86	33.20	33.86	30.71	32.28	42.44	38.89	40.67	41.77	37.86	39.81
M_4T_2	65.70	66.27	65.98	65.44	66.25	65.85	80.41	81.39	80.90	80.20	81.23	80.72
M_4T_3	69.31	70.06	69.69	68.90	70.02	69.46	84.75	85.84	85.30	84.38	85.76	85.07
M_4T_4	72.35	73.39	72.87	71.93	73.14	72.54	87.63	89.06	88.34	87.21	88.56	87.88
M_4T_5	73.26	74.93	74.09	73.71	74.67	74.19	89.75	91.71	90.73	89.96	91.07	90.52
S.Em.±	0.27	0.33	0.29	0.34	0.35	0.30	0.32	0.39	0.34	0.55	0.54	0.48
C.D. at 5%	0.77	0.96	0.83	0.99	1.00	0.86	0.93	1.13	0.97	1.58	1.55	1.38

Table 4. Effect of residue and nutrient management on nitrogen, phosphorus and potassium uptake by paddy during *kharif*season

Treatment	N (kg ha^{-1})			P (kg ha^{-1})			K (kg ha^{-1})		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
Residue management (M)									
M_1: Residue removal	122.91	128.27	125.59	35.27	36.32	35.79	136.95	138.52	137.73
M_2: Residue incorporation (RI)	129.38	136.90	133.14	37.22	39.24	38.23	141.69	144.36	143.03
M_3: RI + Compost culture	135.31	146.91	141.11	38.95	42.07	40.51	145.23	151.13	148.18
M_4: Residue burning	124.18	130.23	127.21	35.51	36.84	36.18	137.70	139.93	138.82
S.Em.±	0.64	0.70	0.51	0.11	0.25	0.14	0.39	0.82	0.39
C.D. at 5%	2.21	2.43	1.77	0.39	0.88	0.50	1.33	2.84	1.36
Nutrient management (T)									
T_1: Absolute control	52.64	46.48	49.56	13.12	11.42	12.27	61.50	55.86	58.68
T_2: Recommended NPK	126.15	132.32	129.23	35.95	37.42	36.68	135.57	139.22	137.39
T_3: STL	141.20	150.33	145.77	40.43	42.93	41.68	145.57	149.90	147.73
T_4: STCR of 80 q ha^{-1}	155.59	168.46	162.03	44.61	47.67	46.14	176.25	182.14	179.19
T_5: SSNM of 80 q ha^{-1}	164.14	180.29	172.22	49.56	53.65	51.61	183.08	190.31	186.69
S.Em.±	0.63	0.79	0.50	0.22	0.24	0.18	0.49	0.60	0.47
C.D. at 5%	1.81	2.28	1.44	0.62	0.70	0.51	1.40	1.72	1.35
Interaction (M × T)									
M_1T_1	51.70	45.40	48.55	12.72	11.09	11.90	60.84	55.04	57.94
M_1T_2	121.39	126.71	124.05	34.58	35.46	35.02	132.43	134.73	133.58
M_1T_3	135.54	142.21	138.87	38.87	40.50	39.69	141.84	144.41	143.13
M_1T_4	149.20	158.41	153.81	42.79	44.73	43.76	171.82	175.59	173.70
M_1T_5	156.73	168.59	162.66	47.38	49.79	48.58	177.84	182.81	180.32
M_2T_1	52.89	46.71	49.80	13.21	11.37	12.29	61.69	56.06	58.87
M_2T_2	127.41	133.69	130.55	36.24	38.18	37.21	136.38	140.33	138.36
M_2T_3	143.06	152.05	147.56	40.84	43.77	42.31	146.94	151.37	149.15
M_2T_4	157.32	170.15	163.74	45.34	48.42	46.88	178.00	183.01	180.51
M_2T_5	166.20	181.89	174.05	50.49	54.45	52.47	185.45	191.02	188.24
M_3T_1	53.89	47.78	50.84	13.57	11.98	12.78	62.21	56.78	59.49
M_3T_2	133.34	141.14	137.24	38.24	40.34	39.29	140.46	146.19	143.32
M_3T_3	149.41	162.73	156.07	42.96	46.54	44.75	150.91	158.12	154.52
M_3T_4	164.97	184.20	174.59	47.24	52.18	49.71	182.38	192.30	187.34
M_3T_5	174.96	198.68	186.82	52.72	59.30	56.01	190.16	202.26	196.21
M_4T_1	52.09	46.01	49.05	12.98	11.23	12.11	61.26	55.56	58.41
M_4T_2	122.46	127.74	125.10	34.76	35.68	35.22	133.01	135.63	134.32
M_4T_3	136.81	144.33	140.57	39.06	40.88	39.97	142.58	145.68	144.13
M_4T_4	150.88	161.08	155.98	43.09	45.33	44.21	172.79	177.65	175.22
M_4T_5	158.66	172.01	165.33	47.66	51.08	49.37	178.87	185.14	182.00
S.Em.±	1.26	1.58	1.00	0.43	0.48	0.35	0.97	1.20	0.94
C.D. at 5%	3.62	4.57	2.87	1.25	1.40	1.02	2.80	3.45	2.71

Table 5. Effect of residue and nutrient management on nitrogen, phosphorus and potassium uptake by paddy during *rabi-summer* season

Treatment	N (kg ha^{-1})			P (kg ha^{-1})			K (kg ha^{-1})		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
Residue management (M)									
M_1: Residue removal	121.74	124.05	122.89	34.43	35.20	34.82	135.47	137.15	136.31
M_2: Residue incorporation (RI)	131.27	132.06	131.66	37.76	38.00	37.88	142.54	142.64	142.59
M_3: RI + Compost culture	139.98	141.03	140.51	40.12	40.61	40.36	148.24	148.53	148.39
M_4: Residue burning	122.86	125.54	124.20	34.90	36.03	35.47	136.65	138.58	137.61
S.Em.±	0.94	0.79	0.81	0.28	0.35	0.25	0.34	0.54	0.37
C.D. at 5%	3.26	2.75	2.80	0.97	1.20	0.87	1.18	1.87	1.28
Nutrient management (T)									
T_1: Absolute control	50.72	45.16	47.94	12.51	10.87	11.69	60.27	54.20	57.24
T_2: Recommended NPK	126.98	129.38	128.18	35.89	36.61	36.25	135.73	138.13	136.93
T_3: STL	142.00	145.10	143.55	40.39	41.70	41.04	145.96	148.57	147.26
T_4: STCR of 80 q ha^{-1}	157.64	161.83	159.74	44.84	46.12	45.48	176.99	180.02	178.50
T_5: SSNM of 80 q ha^{-1}	167.47	171.87	169.67	50.40	52.00	51.20	184.69	187.71	186.20
S.Em.±	0.87	0.78	0.76	0.26	0.31	0.23	0.64	0.62	0.57
C.D. at 5%	2.52	2.24	2.18	0.75	0.89	0.66	1.84	1.78	1.63
Interaction (M × T)									
M_1T_1	49.64	44.16	46.90	12.02	10.68	11.35	59.51	53.71	56.61
M_1T_2	120.12	123.13	121.63	33.62	34.49	34.06	130.87	133.88	132.37
M_1T_3	134.38	138.11	136.25	37.72	39.03	38.37	139.88	143.38	141.63
M_1T_4	147.69	152.75	150.22	41.74	43.10	42.42	169.82	173.94	171.88
M_1T_5	156.85	162.08	159.47	47.07	48.69	47.88	177.26	180.86	179.06
M_2T_1	50.86	45.46	48.16	12.57	10.93	11.75	60.63	54.49	57.56
M_2T_2	129.06	130.86	129.96	36.80	37.28	37.04	137.16	139.08	138.12
M_2T_3	144.93	147.07	146.00	41.51	42.46	41.98	148.25	149.94	149.10
M_2T_4	160.63	163.83	162.23	46.15	46.79	46.47	179.55	181.03	180.29
M_2T_5	170.84	173.09	171.97	51.76	52.57	52.16	187.11	188.67	187.89
M_3T_1	52.21	46.47	49.34	13.13	11.13	12.13	61.08	54.66	57.87
M_3T_2	137.41	139.15	138.28	39.10	39.60	39.35	142.96	144.50	143.73
M_3T_3	153.37	155.63	154.50	44.09	45.20	44.64	154.47	155.81	155.14
M_3T_4	173.10	176.08	174.59	49.12	50.35	49.74	187.22	189.22	188.22
M_3T_5	183.82	187.84	185.83	55.16	56.76	55.96	195.49	198.46	196.97
M_4T_1	50.15	44.56	47.36	12.32	10.74	11.53	59.84	53.96	56.90
M_4T_2	121.31	124.37	122.84	34.03	35.05	34.54	131.92	135.06	133.49
M_4T_3	135.33	139.62	137.47	38.22	40.12	39.17	141.23	145.14	143.18
M_4T_4	149.14	154.68	151.91	42.32	44.25	43.28	171.38	175.87	173.63
M_4T_5	158.35	164.49	161.42	47.62	49.99	48.81	178.89	182.86	180.88
S.Em.±	1.75	1.56	1.52	0.52	0.62	0.46	1.28	1.24	1.13
C.D. at 5%	5.03	4.49	4.37	1.50	1.77	1.33	3.68	3.56	3.26

Table 6. Effect of residue and nutrient management on sulphur, zinc and iron uptake by paddy during *kharif*season

Treatment	S (kg ha^{-1})			Zn (g ha^{-1})			Fe (g ha^{-1})		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
Residue management (M)									
M_1: Residue removal	17.15	17.77	17.46	272.39	279.07	275.73	3231.11	3326.74	3278.92
M_2: Residue incorporation (RI)	18.05	19.44	18.75	290.32	307.52	298.92	3463.03	3708.89	3585.96
M_3: RI + Compost culture	18.81	21.10	19.95	302.23	331.43	316.83	3638.66	4020.50	3829.58
M_4: Residue burning	17.24	18.05	17.64	274.23	283.52	278.87	3289.53	3386.10	3337.81
S.Em.±	0.11	0.18	0.13	1.67	3.62	1.95	30.35	53.38	39.76
C.D. at 5%	0.39	0.62	0.46	5.77	12.52	6.73	105.03	184.71	137.58
Nutrient management (T)									
T_1: Absolute control	7.45	5.92	6.68	124.32	109.24	116.78	1169.95	956.79	1063.37
T_2: Recommended NPK	16.78	18.38	17.58	267.81	285.40	276.61	3006.92	3216.97	3111.95
T_3: STL	19.67	21.49	20.58	300.19	322.44	311.31	3528.16	3791.83	3659.99
T_4: STCR of 80 q ha^{-1}	21.64	23.75	22.69	348.20	373.60	360.90	4357.43	4694.48	4525.96
T_5: SSNM of 80 q ha^{-1}	23.53	25.92	24.72	383.45	411.24	397.35	4965.46	5392.71	5179.08
S.Em.±	0.13	0.14	0.11	1.43	2.52	1.40	21.47	33.10	22.65
C.D. at 5%	0.37	0.40	0.33	4.11	7.27	4.03	61.84	95.35	65.26
Interaction (M × T)									
M_1T_1	7.34	5.82	6.58	122.75	107.39	115.07	1136.45	920.07	1028.26
M_1T_2	16.20	17.15	16.67	255.26	263.56	259.41	2837.18	2945.92	2891.55
M_1T_3	18.92	19.96	19.44	286.63	297.33	291.98	3344.40	3457.36	3400.88
M_1T_4	20.76	21.97	21.36	332.44	345.96	339.20	4125.67	4313.61	4219.64
M_1T_5	22.55	23.95	23.25	364.88	381.12	373.00	4711.85	4996.73	4854.29
M_2T_1	7.48	5.94	6.71	125.07	109.63	117.35	1193.06	963.64	1078.35
M_2T_2	16.94	18.72	17.83	273.43	293.54	283.48	3054.69	3325.02	3189.86
M_2T_3	19.94	21.90	20.92	305.82	331.17	318.50	3577.47	3922.12	3749.79
M_2T_4	21.99	24.20	23.09	355.11	382.58	368.85	4441.65	4834.67	4638.16
M_2T_5	23.91	26.46	25.18	392.18	420.68	406.43	5048.29	5499.00	5273.64
M_3T_1	7.60	6.05	6.83	126.19	111.57	118.88	1204.26	1009.86	1107.06
M_3T_2	17.68	20.28	18.98	285.92	316.98	301.45	3235.01	3589.90	3412.45
M_3T_3	20.85	23.78	22.32	319.81	358.90	339.36	3783.23	4259.45	4021.34
M_3T_4	22.96	26.47	24.71	370.31	414.05	392.18	4676.07	5254.87	4965.47
M_3T_5	24.98	28.89	26.93	408.95	455.64	432.29	5294.72	5988.44	5641.58
M_4T_1	7.35	5.87	6.61	123.26	108.35	115.80	1146.01	933.58	1039.80
M_4T_2	16.29	17.36	16.82	256.65	267.54	262.09	2900.79	3007.06	2953.92
M_4T_3	18.98	20.30	19.64	288.49	302.36	295.43	3407.54	3528.38	3467.96
M_4T_4	20.87	22.35	21.61	334.93	351.82	343.38	4186.34	4374.78	4280.56
M_4T_5	22.70	24.36	23.53	367.80	387.53	377.66	4807.00	5086.67	4946.83
S.Em.±	0.25	0.28	0.23	2.85	5.05	2.80	42.94	66.20	45.31
C.D. at 5%	0.73	0.81	0.65	8.22	14.55	8.07	123.69	190.70	130.51

Table 7. Effect of residue and nutrient managementon sulphur, zinc and iron uptake by paddy during *rabi-summer* season

Treatment	S (kg ha^{-1})			Zn (g ha^{-1})			Fe (g ha^{-1})		
	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled	2019-20	2020-21	Pooled
Residue management (M)									
M_1: Residue removal	16.56	17.26	16.91	266.96	274.66	270.81	3104.77	3263.18	3183.98
M_2: Residue incorporation (RI)	18.48	18.84	18.66	294.84	299.03	296.94	3530.73	3628.08	3579.41
M_3: RI + Compost culture	19.76	20.32	20.04	315.88	321.94	318.91	3787.90	3885.36	3836.63
M_4: Residue burning	16.69	17.60	17.15	269.23	279.66	274.45	3153.57	3327.36	3240.46
S.Em.±	0.24	0.19	0.17	2.26	3.36	2.46	53.91	54.69	52.57
C.D. at 5%	0.82	0.65	0.59	7.83	11.64	8.51	186.57	189.24	181.91
Nutrient management (T)									
T_1: Absolute control	6.92	6.03	6.48	120.49	107.52	114.00	1105.76	971.57	1038.67
T_2: Recommended NPK	16.89	17.77	17.33	270.04	280.26	275.15	2973.55	3145.98	3059.76
T_3: STL	19.79	20.83	20.31	302.96	314.88	308.92	3513.93	3721.32	3617.62
T_4: STCR of 80 q ha^{-1}	21.80	22.89	22.34	351.48	364.80	358.14	4364.30	4582.48	4473.39
T_5: SSNM of 80 q ha^{-1}	23.97	25.00	24.49	388.67	401.66	395.16	5013.68	5208.63	5111.15
S.Em.±	0.18	0.17	0.15	2.24	2.52	2.08	32.83	36.10	31.59
C.D. at 5%	0.53	0.48	0.42	6.44	7.26	5.99	94.58	104.00	91.01
Interaction (M × T)									
M_1T_1	6.80	5.96	6.38	118.64	106.19	112.41	1068.85	927.57	998.21
M_1T_2	15.64	16.61	16.12	249.25	260.37	254.81	2681.79	2891.16	2786.48
M_1T_3	18.23	19.37	18.80	279.96	292.86	286.41	3185.58	3415.80	3300.69
M_1T_4	20.04	21.21	20.62	325.69	339.81	332.75	3965.84	4215.63	4090.73
M_1T_5	22.11	23.12	22.61	361.28	374.08	367.68	4621.82	4865.76	4743.79
M_2T_1	6.96	6.08	6.52	121.23	108.24	114.73	1129.82	1001.56	1065.69
M_2T_2	17.47	18.06	17.76	278.95	286.49	282.72	3102.38	3259.32	3180.85
M_2T_3	20.53	21.24	20.89	312.20	320.90	316.55	3683.06	3850.44	3766.75
M_2T_4	22.62	23.33	22.98	362.01	371.11	366.56	4560.34	4730.62	4645.48
M_2T_5	24.84	25.48	25.16	399.82	408.43	404.13	5178.08	5298.45	5238.27
M_3T_1	7.06	6.12	6.59	122.76	108.97	115.87	1141.09	1017.12	1079.10
M_3T_2	18.73	19.54	19.14	301.01	310.08	305.55	3368.62	3475.58	3422.10
M_3T_3	22.02	22.87	22.44	336.98	346.79	341.89	3955.58	4117.45	4036.52
M_3T_4	24.37	25.36	24.86	389.44	401.70	395.57	4913.93	5104.01	5008.97
M_3T_5	26.64	27.70	27.17	429.19	442.15	435.67	5560.29	5712.63	5636.46
M_4T_1	6.85	5.98	6.42	119.32	106.69	113.00	1083.30	940.04	1011.67
M_4T_2	15.74	16.85	16.29	250.96	264.11	257.53	2741.40	2957.87	2849.63
M_4T_3	18.38	19.83	19.11	282.70	298.97	290.84	3231.50	3501.57	3366.54
M_4T_4	20.19	21.63	20.91	328.79	346.57	337.68	4017.10	4279.65	4148.37
M_4T_5	22.31	23.69	23.00	364.40	381.96	373.18	4694.53	4957.68	4826.10
S.Em.±	0.37	0.33	0.29	4.47	5.04	4.16	65.67	72.21	63.18
C.D. at 5%	1.06	0.96	0.85	12.88	14.51	11.99	189.17	208.00	182.01

soil microorganism can increase rapidly to decompose the residue to humus and release the nutrient components. The results are in line with Guo-Wei et al. [19] who indicated that both residue incorporation and SSNM increased N, P and K translocation from vegetative organs and grains of rice related to enhancement of enzyme activity in root surface [20]. Furthermore, improvements in total S, Zn and Fe uptake by paddy under M_3T_5 treatment is possibly due to improved fertility status as well as enhanced biomass production by the crop.

4. CONCLUSION

Disposal of paddy straw has become a major problem in paddy growing area resulting in frequent fires initiated by farmers as a time saving option. Our study suggests that paddy straw could be managed successfully with the supply of additional microbial inoculants. The results of the study showed that among the varied residue and nutrient management practices, residue incorporation + compost culture (M_3), SSNM targeted yield of 80 q ha^{-1} (T_5) and their combination (M_3T_5) was found to be ideal in increasing the growth, yield and nutrient uptake by paddy as compared to other combinations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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