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Research Paper

Influence of microbial consortia mediated *in-situ* rice straw management options on yield, economics and energetics in rice-wheat cropping system

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ABSTRACT

A field experiment was carried out during rainy and winter seasons of 2019–20 and 2020–21 at ICAR-IARI, New Delhi to study the effect of crop establishment methods and microbial consortia (*Pusa* decomposer) mediated *in-situ* rice straw management options on yield, economics and energetics of rice (*Oryza sativa* L) (cv. *Pusa* Basmati 1509) and wheat (*Triticum aestivum* L.) (cv. HD 2967). The experiment was laid out in split-plot design with three replications. The main plot consisted of two treatments *viz*., aerobic rice (AR) and conventional transplanted (CT) rice in wet season and seven sub-plot treatments *viz.* clean cultivation (removal of paddy straw), paddy straw incorporation (PSI), paddy straw mulching (PSM), PSI + *Pusa* decomposer (PD), PSM + PD, PSI + urea @ 20 kg/ha, PSI + PD + urea @ 10 kg/ha in dry season. In rice, results showed that grain yield (4.23 and 4.42 t/ha), net return (₹69,470 and ₹71,682/ha) and energy output (157361 and 160950 MJ/ha) were significantly superior in CT rice than AR in main plots during both the years of experiment. However, sub-plot treatments showed a non-significant difference on these parameters. In wheat, among *in-situ* rice straw management options, paddy straw incorporation+ *Pusa* decomposer + urea @ 10 kg/ha treatment significantly resulted in higher grain yield (4.86 and 4.92 t/ha), net return (₹62697 and ₹64801 /ha) and energy output (174951 and 176730 MJ/ha) compared to other treatments and control (clean cultivation). However, in main plots, statistically similar results were obtained with AR-wheat and CT-wheat. Thus, conventional rice transplanting resulted in significantly higher productivity and profitability over aerobic rice, however, AR consumed less energy (18.95%) and water (31.73%). Whereas, paddy straw incorporation+ *Pusa* decomposer + Urea @ 10 kg/ha was found effective *in-situ* rice management options with higher productivity and energy output compared to control.

Key words: Aerobic rice, Economics, Energetics, Paddy Straw, *Pusa* decomposer, Yield

Rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping system (RWCS) is a nutrient exhaustive cropping system. Crop residue serves as a valuable organic resource of essential plant nutrients, accessible to the majority of rice-growing farmers. It also plays a crucial role in preserving the stability of agricultural ecosystems (Dotaniya. 2013). Rice is the major staple crop worldwide. Each year, a considerable quantity of straw is generated from rice cultivation as a by-product, which accounts to 50% of the total dry weight of the rice plant. In India, ~686 million tonnes (MT) of dry matter is produced annually from different crops, of which 234.5 MT is surplus crop residue (Hiloidhari *et al*., 2014; Cardoen *et al*., 2015). Rice residues alone contribute to 34% of the total crop residues in India. Many farmers across India use rice residue for soil mulching, composting, and livestock feed. In a rice-wheat sequence that yields 7 t/ha of rice and 4 t/ha of wheat, over 300 kg N, 30 kg P, and 300 kg K/ha are removed from the soil. If this residue is not returned, it can cause major nutrient depletion in the soil, leading to a net negative balance and multi-nutrient deficiencies in crops. This is one of the reasons for the yield decline in the rice-wheat system. In the RWCS of India, wheat residue is often fed to animals, but rice residue is considered poor animal feed due to its high silica content, so it is often burned by farmers (Mandal *et al*., 2004). Farmers often go for open field burning to dispose of rice straw rather than incorporating it into the field due to its slower rate of degradation, pest and disease infestation, unstable nutrients in the soil, and negative impact on growth and yield caused by short-term

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nitrogen immobilization (Pandey *et al*., 2009). Microbial decomposition is an eco-friendly promising solution for rice straw recycling. The process relies on specific microbes capable of breaking down the different components of rice straw, such as cellulose, holocellulose, and lignin (Kausar *et al*., 2016). Thus, it is imperative to assess the efficacy of these microbial inoculants in the field conditions to evaluate their potential for rice residue management. Future management of rice straw under transplanted and aerobic cultivation systems will largely depend on economically feasible technologies such as *in-situ* residue management, breeding crop varieties with shorter maturation times and lower straw-to-paddy ratios, crop diversification, and the use of microbial inoculants. Therefore, this research work get insights into the impact of crop establishment methods and microbial consortia (*Pusa* decomposer) mediated *in-situ* rice straw management options on yield, economics and energetics of rice-wheat cropping system.

MATERIALS AND METHODS

A field experiment was carried out at the ICAR–Indian Agricultural Research Institute, New Delhi, India (28° 38′ N, 77° 10′ E and 228.6 m above mean sea level (MSL). The total amounts of rainfall (RF) received during the first (2019–2020) and second (2020–2021) cropping cycle of RWCS were 907.2 mm and 757 mm. During the initial two rice cropping periods, there was a reception of 603.3 mm and 685.9 mm RF, respectively. For the wheat season, 303.9 mm and 71.1 mm RF were received. The experimental field had sandy clay-loam soil (15 cm depth), with pH 7.97 and 0.42% organic carbon. Alkaline $KMnO_4$-extractable N, $NaHCO_3$-extractable P, and 1 N ammonium acetate-extractable K were 183 kg/ha, 16.6 kg/ha, and 262 kg/ha, respectively. The fertilizer dose of 120 kg N, 60 kg P_2O_5, and 60 kg K_2O was applied as per treatment. The experiment was conducted in split-plot design with three replications with the use of aromatic rice variety '*Pusa Basmati* 15092 and wheat variety 'HD 2967'. The treatments consisted of two main plot treatments, *viz*. aerobic rice (AR) [M1] and conventional transplanted rice (CTR) [M2] rice and seven sub-plot treatments, *viz.* clean cultivation (removal of paddy straw) [S1], paddy straw incorporation (S2), paddy straw mulching (S3), paddy straw incorporation + *Pusa* decomposer (S4), paddy straw mulching + *Pusa* decomposer (S5), paddy straw incorporation + urea @ 20 kg/ha (S6), paddy straw incorporation + *Pusa* decomposer + Urea @ 10 kg/ha (S7). The aerobic rice (AR) is a new production system in which rice is grown under non-puddled, non-flooded and non-saturated soil conditions as other upland crops (Prasad, 2011). Thus in AR, soils are kept aerobic almost throughout the rice-growing season. For, AR system the field was ploughed with tractor drawn disc plough. Harrowing was done to achieve the desired tilth with rotavator. Seeds were sown (on 5th and 3rd July of 2019 and 2020) with a zero tilled seed driller at the depth of 4 cm with the row spacing of 22.5 cm and light irrigation was applied to facilitate germination. For CTR, the field was given with pre-irrigation, ploughed twice with disc plough followed by ploughing with cultivator. The soil was levelled with laser land leveller. Puddling was done twice by using tractor drawn puddler. Transplanting of rice (CTR) in puddled condition was taken on 10th & 8th July of 2019 and 2020, respectively. The effects of these treatments were observed in seed drill (straw incorporated and clean cultivation plots) and zero till sown wheat (straw mulched plots) in *Rabi* seasons (sowing was done on 20th and 22nd November of 2020 and 2021, respectively). The 6 t/ha straw was incorporated/mulched and the recommended dose of *Pusa* decomposer was sprayed @ 25 L /ha (liquid formulation). ICAR-Indian Agricultural Research Institute, New Delhi has developed a technology called *Pusa* decomposer (both in liquid and capsule forms) for rapid decomposition of paddy straw. Four capsules of this product can be scaled up to 25 L liquid formulation which can be applied *in-situ* to 1.0 ha of rice field having 5- 6 tonnes of paddy straw. *Pusa* decomposer plays an important role in *in-situ* and *ex-situ* decomposition of paddy straw. For *in-situ* management, harvesting paddy with combine followed by chopper plus mulcher and spraying *Pusa* decomposer followed by rotavator and light irrigation to keep the field moist has shown accelerated decomposition of the paddy straw and enabled the farmer to do timely wheat sowing. Observations on grain and biological yield were recorded at harvest stages of the crop. The economics of cultivation of rice, viz. cost of cultivation, net return and B: C ratios were recorded on the basis of prevailing market prices of inputs and outputs. Energetics were calculated based on the energy equivalents values taken from various literatures given by Devasenapathy *et al.* (2009); Kaur *et al*., 2023. The data obtained from the experiment were statistically analysed using the F-test.

RESULTS AND DISCUSSION

Effect on yield and economics of rice and wheat

The grain (4.23 and 4.42 t/ha) and biological yields in transplanted rice were significantly higher than aerobic rice (3.48 and 3.67 t/ha of grain yield; 10.21 t/ha and 10.46 t/ha of biological yield) in both the years of rice cultivation (Table 1). The adequate availability of water and nutrients and weed free conditions under CT-rice might have favoured good crop growth and ultimately led to higher yield in conventional transplanted rice (Gouda *et al.,* 2021). The grain (4.86 and 4.92 t/ha) and biological yield of wheat were also significantly higher in paddy straw in-

Table 1. Effect of crop establishment methods and microbial consortia (Pusa decomposer) mediated *in-situ* rice straw management options on yield and economics of rice

Treatment	Grain yield (t/ha)		Biological yield (t/ha)		Cost of cultivation (× 10³ ₹/ha)		Net return (× 10³ ₹/ha)		Benefit: cost ratio	
	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21
Rice establishment methods (REM)										
M_1	3.48	3.67	10.21	10.46	39.29	43.02	65.38	67.22	1.35	1.66
M_2	4.23	4.42	11.84	12.10	56.60	58.45	69.47	71.68	1.10	1.23
SEm±	0.01	0.01	0.08	0.08	-	-	0.36	0.37	0.005	0.01
CD (P=0.05)	0.06	0.08	0.49	0.47	-	-	2.20	2.24	0.029	0.04
In-situ rice residue management options (IRM)										
S_1	3.72	3.91	10.70	10.94	47.95	50.73	63.58	65.53	1.15	1.36
S_2	3.81	4.00	10.85	11.13	47.95	50.73	66.14	68.14	1.19	1.41
S_3	3.85	4.05	10.95	11.20	47.95	50.73	67.33	69.35	1.22	1.45
S_4	3.92	4.11	11.08	11.32	47.95	50.73	69.09	71.14	1.26	1.48
S_5	3.87	4.06	11.01	11.25	47.95	50.73	67.71	69.74	1.23	1.45
S_6	3.83	4.03	10.96	11.19	47.95	50.73	66.76	68.77	1.21	1.43
S_7	4.00	4.19	11.38	11.62	47.95	50.73	71.37	73.46	1.30	1.53
SEm±	0.06	0.06	0.07	0.06	-	-	1.57	1.60	0.03	0.03
CD (P=0.05)	0.16	0.16	0.19	0.19	-	-	4.59	4.67	0.10	0.10
I (REM × IRM)	NS	NS	NS	NS	-	-	NS	NS	NS	NS

M_1, Aerobic rice (AR); M_2, conventional transplanted rice (CTR); S_1, clean cultivation (removal of paddy straw); S_2, paddy straw incorporation; S_3, paddy straw mulching; S_4, paddy straw incorporation + Pusa decomposer; S_5, paddy straw mulching + Pusa decomposer; S_6, paddy straw incorporation + urea @ 20 kg/ha; S_7, paddy straw incorporation+ Pusa decomposer + urea @ 10 kg/ha; straw incorporated/mulched @ 6 t/ha; recommended dose of Pusa compost inoculant/decomposer @ 25 litres/ha (liquid formulation); I, interaction

corporation + *Pusa* decomposer + urea @10 kg/ha – wheat treatment compared to other treatments (Table 2). The improvement in the soil fertility status with incorporation of rice residue and better decomposition of straw with *Pusa* decomposer led to improved physical, chemical and biological conditions available to the succeeding crop (IARI, 2022; Manu *et al.,* 2023). These improvements took place in terms of higher organic carbon, more available NPK, enhanced nutrient uptake and microbial activity. The improved soil structure also led to minimum crop stress (Manu *et al*., 2023). The economics of rice cultivation was significantly influenced by the planting methods and *in-situ* rice residue management options. The significantly higher cost of cultivation was recorded in CT rice (₹56,609 and ₹58,449/ha) compared to AR cultivation (₹39,297 and ₹43,017/ha) as it involved puddling operation, transplanting and more number of irrigation. Similarly, higher net returns were obtained in CT rice (₹69,470 and ₹71,682/ha) than in AR cultivation (₹65,380 and ₹67,216/ha). However, BC ratio was higher in AR (1.35 and 1.66) than CT rice (1.10 and 1.23). In sub-plot treatment Paddy straw incorporation+ Pusa decomposer + urea @ 10 kg/ha (PSI+PD+Urea) which showed higher net returns and BC ratio compared to other treatments (Table 1). The results were in conformity with other researchers, viz. Saha *et al*. 2017; Poornima *et al*. 2020; Mitra and Patra. 2023. In wheat, among *in-situ* rice residue management options, a significant improvement in higher net return (₹62,697 and ₹64,801 /ha) and net B: C (₹1.70 and 1.80) were recorded in paddy straw incorporation+*Pusa* decomposer + urea @ 10 kg/ha treatment over control, which was followed by paddy straw incorporation + *Pusa* decomposer. An additional cost of ₹2,386/ha has been also involved for application of PSI+PD+Urea. However, it has long-term benefits to farmers including soil management, water conservation, and reduced fertilizer demand due to nutrients' recycling and higher crop yields. It might be due to positive effect of residue application/incorporation and faster decomposition of rice residue by *Pusa* decomposer that created more favourable condition for growth and development which resulted in higher yield in this treatment as discussed by Meena (2015). The net returns and B:C for wheat was not affected significantly under different crop establishment methods. The plots of aerobic rice

Table 2. Effect of crop establishment methods and microbial consortia (Pusa decomposer) mediated *in-situ* rice straw management options on yield and economics of wheat

Treatment	Grain yield (t/ha)		Biological yield (t/ha)		Cost of cultivation (× 10³ ₹/ha)		Net returns (× 10³ ₹/ha)		Benefit cost ratio	
	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21	2019–20	2020–21
Crop establishment methods (CEM)										
M_1	4.64	4.70	12.57	12.70	35.84	34.96	59.23	61.37	1.65	1.75
M_2	4.52	4.58	12.25	12.37	35.84	34.96	56.76	58.98	1.58	1.69
SEm±	0.001	0.001	0.004	0.004	–	–	0.028	0.027	0.001	0.001
CD (P=0.05)	0.008	0.008	0.022	0.023	–	–	0.172	0.166	0.005	0.005
In-situ rice residue management options (IRM)										
S_1	4.33	4.38	11.75	11.83	34.77	33.89	53.95	55.95	1.55	1.65
S_2	4.48	4.54	12.15	12.27	35.95	35.07	55.83	58.03	1.55	1.65
S_3	4.43	4.49	12.01	12.12	34.77	33.89	55.99	58.19	1.61	1.72
S_4	4.76	4.83	12.88	13.04	36.71	35.83	60.78	63.09	1.66	1.76
S_5	4.64	4.71	12.56	12.72	35.53	34.65	59.61	61.82	1.68	1.78
S_6	4.56	4.62	12.36	12.49	36.30	35.42	57.11	59.31	1.57	1.67
S_7	4.86	4.92	13.14	13.27	36.84	35.96	62.69	64.80	1.70	1.80
SEm±	0.002	0.002	0.006	0.006	–	–	0.044	0.044	0.001	0.001
CD (P=0.05)	0.006	0.006	0.016	0.017	–	–	0.128	0.129	0.002	0.002
I (REM × IRM)	0.002	0.002	0.006	0.007	–	–	0.050	0.051	0.001	0.001

M_1, Aerobic rice (AR); M_2, conventional transplanted rice (CTR); S_1, clean cultivation (removal of paddy straw); S_2, paddy straw incorporation; S_3, paddy straw mulching; S_4, paddy straw incorporation + Pusa decomposer; S_5, paddy straw mulching + Pusa decomposer; S_6, paddy straw incorporation + urea @ 20 kg/ha; S_7, paddy straw incorporation+ Pusa decomposer + urea @ 10 kg/ha; straw incorporated/mulched @ 6 t/ha; recommended dose of Pusa compost inoculant/decomposer @ 25 litres/ha (liquid formulation); I, interaction

followed by wheat had comparatively higher net return (₹59,237 and ₹61,370/ha) and net B: C (1.65 and 1.75) as compared to transplanted rice followed by wheat.

Effect on energetics of rice and wheat

The energetics of rice cultivation, viz. energy input and energy output were significantly influenced by crop establishment methods (Fig 1). A significantly higher energy input (23354 and 25394 MJ/ha), energy output (157361 and 160950 MJ/ha) and net energy (134006 and 135556 MJ/ha), were recorded in CT rice than AR. However, AR consumed less energy (18.95%) over CT rice. It is because of higher energy consumption in CT rice in the process of nursery bed preparation, transplanting and irrigation as compared to AR. Similar findings were reported by Poornima *et al*. (2020) and Gouda (2020). In sub-plot treatment paddy straw incorporation+ *Pusa* decomposer + urea @ 10 kg/ha (PSI+PD+Urea) showed higher energy output (157361 and 160950 MJ/ha) and net energy (134006 and 135556 MJ/ha) compared to other treatments (Fig 1). Treatment having aerobic rice-wheat had comparatively higher output energy (167289 and 169059 MJ/ha) and net energy (103283 and 105679 MJ/ha) as compared to transplanted rice-wheat system. Sub-pots, *in-situ* rice residue management practices recorded significantly higher output energy than control. Paddy straw incorporation+ *Pusa* decomposer + urea @ 10 kg/ha was significantly higher output energy (174951 and 176730 MJ/ha) in succeeding wheat as compared control (clean cultivation) in both the years (Fig 2).

It is concluded that a higher rice productivity was recorded under conventional transplanted condition than aerobic rice in respect of yield, net returns and energy output. However, cost of cultivation and consumption of energy was significantly lower in aerobic rice than conventional transplanting of rice. In case of *in-situ* rice residue management options, paddy straw incorporation + *Pusa* decomposer + urea @ 10 kg/ha–wheat was found effective *in-situ* rice management options with higher yield, net returns and energy output compared to control. It can be recommended for farmers to get higher productivity, profitability and energy values in rice–wheat cropping system, however location-specific study under varied ecologies may be carried out for wider adoption.

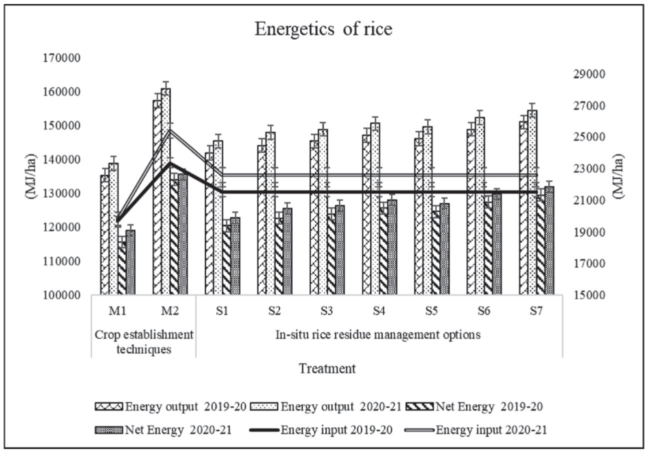

Fig. 1. Energetics of rice as influenced by crop establishment methods and microbial consortia (Pusa decomposer) mediated *in-situ* rice straw management options

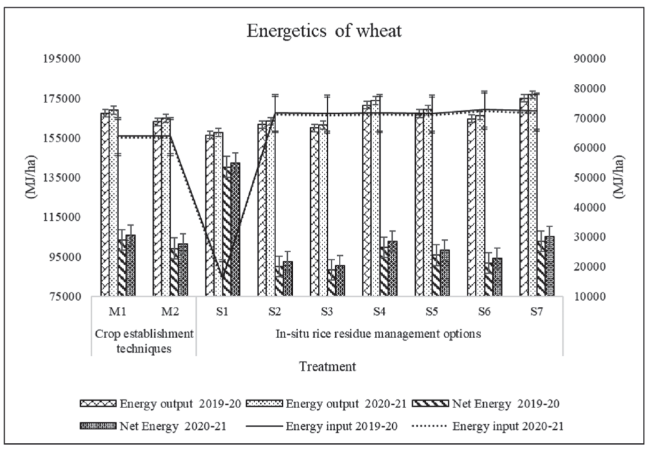

Fig. 2. Energetics of wheat as influenced by crop establishment methods and microbial consortia (Pusa decomposer) mediated *in-situ* rice straw management options

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