Biological Forum – An International Journal **15(1): 720-727(2023)**

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Economics and Energetic Efficiency of Puddled Transplanted Rice (*Oryza sativa* L.) as Influenced by Residue and Nitrogen Management Options

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(Received: 08 December 2022; Revised: 29 December 2022; Accepted: 06 January, 2023; Published: 11 January, 2023)
(Published by Research Trend)

ABSTRACT: A field experiment was conducted during *kharif* seasons of 2020 and 2021 at Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India, to identify economic and energy-efficient residue and nitrogen management technology options with satisfactory productivity and profitability in transplanted rice, which was carried out in a split plot design, having six main plot treatments, consisting of rice residue management options viz., rice residue removal, *in-situ* burning of rice residues, *in-situ* incorporation of rice residues, *in-situ* incorporation of rice residues + 20 kg N ha^{-1} as starter, *in-situ* incorporation of rice residues + 20 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} as starter and *in-situ* incorporation of rice residues + waste decomposer; and four sub-plot treatments consisting soil test-based N, leaf colour chart based N, chlorophyll meter based N and integrated nitrogen management based N (75% N through inorganic + 25% N through FYM).The results of the experiment revealed the lowest input energy consumption with rice residue removal and LCC based N application resulted in the lowest input energy. With respect to output energy, the highest output energy was recorded with *in-situ* incorporation of rice residues along with starter application of N and P_2O_5, differing significantly with all other residue management options. Among the nitrogen management options, INM approach resulted in the highest output energy, differing significantly with all other N management options. The highest net energy return andenergy use efficiencywas recorded with *in-situ* incorporation of rice residues along with starter application of N and P_2O_5 and INM approach, differing significantly with all other residue management treatments. The lowest specific energy and highest energy productivity was observed with *in-situ* incorporation of rice residues along with waste decomposer, whereas, among nitrogen management options, INM approachand LCC based nitrogen management recorded the lowest specific energy and highest energy productivity, respectively. Among residue management options, maximum energy profitability was recorded with with *in-situ* incorporation of rice residues along with N as starter and LCC based nitrogen management. The highest net returns and B:C ratio was estimated with *in-situ* incorporation of rice residues along with 20 kg N ha^{-1} and 20 kg P_2O_5ha^{-1} and INM approach of N management. Thus, *in-situ* incorporation of rice residues along with starter application of N and P_2O_5 along with INM involving 75% inorganic and 25% organic can be practised for encashing highest net energy, energy use efficiency and economical return from transplanted rice.

Keywords: Residue incorporation, Nitrogen management, Energy efficiency, Economics, Transplanted rice.

INTRODUCTION

Energy has a significant impact on the development of key sectors of economic importance, such as industry, transport, and agriculture (Abbas, 2011). Agriculture itself is an energy user and energy supplier in the form of bioenergy; the agricultural sector requires energy as an essential input to production (Lal *et al.*, 2013), enhancing food security, adding value (Karimi *et al.*, 2008), and contributing to rural economic development (FAO, 2000). At present, the productivity and profitability of agriculture depends on energy consumption (Alam *et al.,* 2005; Esengun *et al.,* 2007). Continuously rising prices, increasing proportion of commercial energy in the total energy input to agriculture, and the growing scarcity of commercial energy sources, such as fossil fuels, have necessitated the more efficient use of these sources for different crops and cropping systems (Singh *et al.,* 1997).Rice (*Oryza sativa* L.) is the most important cereal food crop of India, occupying about 22% of gross cropped area, contributing 40% of total food grain production of the country. The cultivation of rice all over the world and India is facing acute crisis because of shrinking area, reduced water availability, escalating input cost, fluctuating production, stagnating yield in addition to high energy requirement for its production (Thakur *et al.*, 2016; Jat *et al.*, 2020). The production of rice incurs much higher inputs of commercial energy in India, mainly due to its high water and fertilizer requirements coupled with other practices like transplanting, harvesting and threshing (Khan and Hossain 2007; Rahman and Halder 2013).

India produces approximately 500 Mt of crop residues per year, while only Punjab state produces 23 Mt and 17 Mt of paddy and wheat straw, respectively, of which more than 80% of paddy straw are burnt in fields (Kumar *et al.*, 2015). In rice-rice cropping system, after harvesting, particularly rice straw was burned in the cultivated area and some was left as rice straw and stuff before incorporated into soil. Incorporation of rice straw for several years plays an importance role on soil fertility by adding considerable amount of various nutrients to the soil (Pomnamperuma, 1984). Application of inorganic fertilizer alone in large quantities over a long period of time results in imbalance in supply of other nutrients. Cassman and Pingali (1995) reported that the intensified rice mono-cropping for several years has begun to show a declining trend in rice yield. Imbalanced nutrient management and decreased soil organic matter are the key responsible factors for the observed declining trend in rice-based cropping systems (Reddy and Krishnaiah 1999). In this context residue incorporation holds a great promise in maintaining yield stability through correction of marginal deficiencies of secondary and micronutrients, enhancing efficiency of applied nutrients and providing favorable soil physical condition (Banerjee and Pal 2009).

The energy input-output relationship, energy productivity, and specific energy are useful parameters for designing a cleaner production system and in mitigation of GHGs emissions (Chaudhary *et al.,* 2017). Hence, energy balance studies are useful to identify the strategies that save energy and enhance its use efficiency in agricultural production systems and provide a basis for adopting low carbon footprint technologies while also supporting the sound management and policy decisions towards its adoption (Chaudhary *et al.,* 2006). Conventionally, crop residues are either burned or removed from the field and repeated tilling is practiced for a fine seed bed preparation, leading to increasing in GHGs emission (Kuotsu *et al.,* 2014). The energy consumed in agricultural operations contribute to global warming through emission of GHGs, mainly CO_2, CH_4 and N_2O (Ntinas *et al.*, 2017; Yadav *et al.*, 2017). Hence, there is an urgent need to increase the energy use efficiency and decrease the associated carbon footprint in crop production.

The productivity and sustainability of rice-based systems are threatened because of the inefficient use of inputs, increasing scarcity of resources, the emerging energy crisis and rising fuel prices, rising cost of cultivation and emerging socio-economic changes such as urbanization, migration of labour, preferences of non-agricultural work, concerns about farm-related pollution (Kumar and Ladha 2011). Therefore, the objective of this study was to identify economic and energy-efficient residue and nitrogen management technology options with satisfactory productivity and profitability in rice.

MATERIALS AND METHODS

The field experiment was conducted during *kharif* seasons of 2020 and 2021 at Agronomy Main Research Farm, Central Research Station, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India, having a latitude and the longitude of 20º15′ N and 85º52′E, respectively, with an altitude of 25.9 m above the mean sea level. The station comes under the East and South Eastern Coastal Plain Agro-Climatic Zone of Odisha. The climate of Bhubaneswar is characterized by hot, moist and sub-humid with hot summer and mild winter. The rainfall is monsoonal and unimodal. Soil of the experimental site was sandy loam in texture, with pH 5.67 and EC 0.11 ds m^{-1}, low in organic carbon (0.48 %), low in available nitrogen (228.0 kg ha^{-1}), medium in available phosphorus (20.4 kg ha^{-1}) and medium in available potassium (146.5 kg ha^{-1}). Hasanta rice variety was taken for this experimental work. The experiment was carried out in a split plot design having 24 treatment combinations and 3 replications. The main plot included six treatments consisting of rice residue management viz., C_1:Rice residue removal, C_2: *In-situ* burning of rice residues, C_3: *In-situ* incorporation of rice residues, C_4: C_3+ 20 kg N ha^{-1} as starter, C_5: C_3 + 20 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} as starter, C_6: C_3 + waste decomposer (500 L ha^{-1}), whereas in sub-plot, there were 4 treatments consisting of nitrogen management approaches for the system comprising of N_1: Soil test-based nitrogen, N_2: Basal dose + Leaf colour chart (LCC) based N management, N_3: Basal dose + Chlorophyll meter (SPAD meter) based N management, N_4: Integrated nitrogen management (75% N through inorganic source + 25% N through FYM).

The experimental plot was ploughed twice during April-May and before transplanting in the main field, about 5 t ha^{-1} crop residue of previous rice crop were taken and incorporated in the soil of main-plots of C_3, C_4, C_5 and C_6, by chopping into small pieces. In the mainplot C_1, residues were removed by cutting the plant above ground after maturity, whereas, entire amount of residues were burnt in the soil for the mainplot C_2. 20 kg N ha^{-1} was applied to mainplot C_4, while 20kg N ha^{-1} and 20kg P_2O_5 ha^{-1} were applied to the C_5. In the month June, the nursery bed was raised by wet bed nursery method. In the sub-plot, nitrogen management practices like soil test based nitrogen management (STBN), leaf colour chart (LCC), chlorophyll meter / SPAD meter and INM (inorganic N:organic N::75:25 %). The organic source was supplied through FYM. The experiment started with growing of rice under puddled condition in *kharif* seasons of 2020 and 2021.

Complete dose of P_2O_5 was applied during transplanting, whereas, K_2O was applied in two splits, i.e., during transplanting and at panicle initiation (PI) stage, while N was supplied at three splits i.e., ¼ at basal, ½ at tillering and ¼ at PI, which were supplied through urea, DAP and MOP and standard package of practices were followed to manage the pest and diseases and weeds in order to keep the crop healthy. The optimum soil moisture was maintained throughout the experimentation as and when required. Observations of SPAD meters and LCC were recorded at 10 days interval from 20 DAT to flowering and on the same day, leaf chlorophyll and leaf nitrogen was analyzed by collecting the upper fully expanded leaves. The crop was harvested plot wise leaving border and sampling areas.

Energy inputs and outputs of rice crop were estimated using crop management (machinery operations and amount of input used) and biomass production records. The amount of energy consumption per unit area of different inputs (human labour, machinery, implements, chemical fertilizers, diesel fuel, water, herbicides and rice seed) and outputs (grain and straw) was estimated by using energy equivalents (Table 1) (Devasenapathy *et al.,* 2009; Tuti *et al.,* 2012; Dhaka *et al.,* 2015; Sorokhaibam *et al.,* 2016; Negi *et al.,* 2016) and formulae used by Chaudhary *et al.,* (2006), Khan and Hussain (2007) and is given in Table 1. On the basis of energy input and output, cost of cultivation and yield, the energy indices like energy use efficiency, energy productivity, net energy, specific energy, energy profitability were calculated as per the following formula.

Net energy return=Total Output Energy (MJ ha^{-1}) - Total Input Energy (MJ ha^{-1}) (1)

Energy use efficiency=Total Output Energy (MJ ha^{-1})/Total Input Energy (MJha^{-1}) (2)

Specific Energy=Total Input Energy (MJ ha^{-1})/Total main product yield (kgha^{-1}) (3)

Energy productivity=Total main product yield (kg ha^{-1})/Total Input Energy (MJ ha^{-1}) (4)

Energy profitability = Net energy return (MJ ha^{-1})/Total Input Energy (MJ ha^{-1}) (5)

Table 1: Energy equivalents of inputs and outputs in agricultural production.

Components (unit)	Energy equivalent (MJ unit^{-1})
Input	
Labor (h)	1.96
Machinery (h)	62.7
Diesel (l)	56.31
Seed (kg)	14.7
Chemical fertilizers (kg)	
N	60.6
P_2O_5	11.1
K_2O	6.7
Pesticide (kg)	120
Output (kg)	
Grain	14.7
Straw	12.5

The cost of cultivation was calculated on the basis of local price of inputs, whereas, the price of output like price of grain was calculated on the basis of minimum support price of rice for the respective years and the price of straw was estimated on the basis of its local price. The data of two years for different energy indices and economics were calculated and pooled analysis was done using standard procedures of variance analysis and the significance of different source of variations was tested at 5% level of significance.

RESULTS AND DISCUSSION

A. Energy input-output analysis

Energy input-output relationships with respect to rice residue and nitrogen management are analysed and shown in Table 2. Among the residue management treatments, the lowest input energy consumption (11393 MJ ha^{-1})was estimated with rice residue removal, followed by *in-situ* burning of residues, whereas the highest input energy consumption (12905 MJ ha^{-1}) was recorded with *in-situ* incorporation of rice residues along with starter application of N and P_2O_5. Among the nitrogen management options, LCC based N application resulted in the lowest input energy (11102 MJ ha^{-1}), followed by SPAD based N application (11472 MJ ha^{-1}), whereas the highest value was estimated with INM approach (12664MJ ha^{-1}). With respect to output energy, among the residue management options, the highest output energy (159325MJ ha^{-1}) was recorded with *in-situ* incorporation of rice residues along with starter application of N and P_2O_5, differing significantly with all other residue management options. It was followed by *in-situ* incorporation of rice residues along with starter application of N only (153135 MJ ha^{-1}) and *in-situ* incorporation of rice residues along with application of waste decomposer.Among the nitrogen management options, INM approach resulted in the highest output energy (155224 MJ ha^{-1}), differing significantly with all other N management options. The use of maximum fertilizer application typically requires a higher input energy due to the energy-intensive production and transport of synthetic fertilizers, while organic nutrient management, i.e., INM and site-specific nutrient management typically involve more sustainable and environment friendly practices that require less energy input (Mondal *et al.*, 2021). The out-put energy was determined by the amount and quality of harvestable biomass (Gelfand *et al.*, 2010).

Table 2: Effect of residue and nitrogen management on input and output energy of rice (Pooled data).

Treatments	**Energy input (MJ ha^{-1})**	**Grain yield (kg ha^{-1})**	**Straw yield (kg ha^{-1})**	**Energy output (MJ ha^{-1})**
Residue Management				
C_1: Rice residue removal	11393	4019	4777	118786
C_2: *In-situ* burning of residues	11594	4259	4965	124667
C_3: *In-situ* incorporation of residues	11722	4363	5207	129228
C_4: C_3+ 20 kg N ha^{-1} as starter	12210	5185	6153	153135
C_5: C_3 + 20 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} as starter	12905	5299	6515	159325
C_6: C_3 + waste decomposer (500 L ha^{-1})	11812	5038	6070	149922
SEm (±)		65.3	70.3	1271.8
CD (P=0.05)		192.5	207.5	3751.3
Nitrogen Management				
N_1: Soil test based N application	12552	4356	5049	127143
N_2: LCC based N application	11102	4582	5521	136380
N_3: SPAD based N application	11472	4620	5603	137961
N_4: INM (Inorganic N:Organic N::75:25)	12664	5216	6283	155224
SEm (±)		43.9	64.3	979.2
CD (P=0.05)		123.8	181.3	2760.2

B. Energy indices of rice as influenced by residue and nitrogen management options

The pooled data of net energy return revealed the highest net energy return, amongresidue management options(146421MJ ha^{-1}), recorded with *in-situ* incorporation of rice residues along with starter application of N and P_2O_5, differing significantly with all other residue management treatments, which was due to higher production of output energy bysuch treatment, whereas, among the sub plot treatments, the highest value was estimated with INM approach (142560MJ ha^{-1}), which differed significantly with all other treatments. This might be due to highly productive gross yield brought about high energy output associated with these treatments was earlier reported by Menia *et al.* (2022). The highest energy use efficiency among residue management options (11.30) was estimated with *in-situ* incorporation of rice residues along with 20 kg N ha^{-1} and 20 kg P_2O_5 ha^{-1}, while among nitrogen management options, INM approach recorded the highest energy use efficiency (11.88), differing significantly with all other options. This might be due to production of higher output energy mainly attributed to higher yield production with lesser utilization of input energy with residue and nitrogen treatments. With respect to specific energy, significant difference was observed due to residue and nitrogen treatment combinations. The lowest specific energy (2.38MJ kg^{-1}) was observed with *in-situ* incorporation of rice residues along with waste decomposer, which was at par with *in-situ* incorporation of rice residues along with N as starter (2.39). Among the nitrogen management treatments, lowest specific energy (2.47MJ kg^{-1}) was observed with INM approach, being at par with LCC based N application. Thehighest energy productivity (0.428kg MJ^{-1}) was observed with with *in-situ* incorporation of rice residues along with waste decomposer, whereas, among the nitrogen management treatments, LCC based nitrogen management recorded highest energy productivity (0.412kg MJ^{-1}). This might be due to higher utilization of resources with maximum output energy in terms of higher crop yield. Among residue management options, maximum energy profitability (11.59 MJ MJ^{-1}) was recorded with *in-situ* incorporation of rice residues along with N as starter, which was statistically at par with *in-situ* incorporation of rice residues along with starter application of N and P_2O_5(11.41MJ MJ^{-1}), whereas, among the nitrogen management treatments, LCC based nitrogen management recorded highest energy profitability (11.26 MJ MJ^{-1}). Similar type of findings were earlier reported by Das *et al.* (2013).

Table 3: Energy indices of rice as influenced by residue and nitrogen management options (Pooled data).

Treatments	Net energy return (MJ ha^{-1})	Energy use efficiency	Specific energy (MJ kg^{-1})	Energy productivity (kg MJ^{-1})	Energy Profitability (MJ MJ^{-1})
Residue Management					
C_1: Rice residue removal	107393	10.15	2.85	0.353	9.44
C_2: *In-situ* burning of residues	113073	10.32	2.77	0.367	9.75
C_3: *In-situ* incorporation of residues	117456	10.53	2.73	0.371	9.99
C_4: C_3+ 20 kg N ha^{-1} as starter	140925	11.29	2.39	0.427	11.59
C_5: C_3 + 20 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} as starter	146421	11.30	2.47	0.412	11.41
C_6: C_3 + waste decomposer (500 L ha^{-1})	138110	11.20	2.38	0.428	10.65
SEm (±)	1271.8	0.11	0.03	0.006	0.11
CD (P=0.05)	3751.3	0.3	0.1	0.02	0.3
Nitrogen Management					
N_1: Soil test based N application	114592	9.32	2.91	0.346	9.12
N_2: LCC based N application	125278	11.23	2.47	0.412	11.26
N_3: SPAD based N application	126489	11.17	2.54	0.402	11.01
N_4: INM (Inorganic N:Organic N::75:25)	142560	11.47	2.47	0.411	11.23
SEm (±)	979.2	0.08	0.02	0.004	0.08
CD (P=0.05)	2760.2	0.2	0.1	0.01	0.2

Table 4: Economics of rice as influenced by crop residue and nitrogen management (Pooled data).

Treatment	CoC (Rs/ha)	Gross Return (Rs/ha)	NMR (Rs/ha)	B:C ratio
Residue Management				
C_1: Rice residue removal	57,325	82,263	24,937	1.43
C_2: *In-situ* burning of residues	57,368	87,097	29,728	1.51
C_3: *In-situ* incorporation of residues	61,803	89,337	27,534	1.44
C_4: C_3+ 20 kg N ha^{-1} as starter	62,031	1,06,130	44,099	1.71
C_5: C_3 + 20 kg N ha^{-1} + 20 kg P_2O_5 ha^{-1} as starter	62,950	1,08,656	45,706	1.72
C_6: C_3 + waste decomposer (500 L ha^{-1})	62,721	1,03,192	40,470	1.64
SEm (±)		1265.0	1265.0	0.02
CD (0.05)		3731.1	3731.1	0.06
Nitrogen Management				
N_1: Soil test based N application	59,665	89,052	29,387	1.49
N_2: LCC based N application	59,357	93,868	34,511	1.58
N_3: SPAD based N application	59,435	94,677	35,242	1.59
N_4: INM (Inorganic N:Organic N::75:25)	64,343	1,06,853	42,510	1.66
SEm (±)		848.1	848.1	0.01
CD (0.05)		2390.5	2390.5	0.04

The cost of cultivation, returns and benefit cost analysis of rice has been presented with respect to rice residue incorporation and nitrogen management practices in Table 4. Among the rice residue incorporation treatments, highest gross return was obtained with *in-situ* incorporation of rice residues along with 20 kg N ha^{-1} and 20 kg P_2O_5 (Rs. 1,08,656 ha^{-1}), being at par with *in-situ* incorporation of rice residues along with 20 kg Nha^{-1} (Rs. 1,06,130 ha^{-1}), but differed significantly with all other options. With respect to nitrogen management, highest gross return was resulted in integrated N management practice (Rs. 1, 06,853 ha^{-1}), which differed significantly with all other N management options. The highest net returns (Rs. 45,706 ha^{-1}) and B:C ratio (1.72) was estimated with *in-situ* incorporation of rice residues along with 20 kg N ha^{-1} and 20 kg $P_2O_5ha^{-1}$, which was at par with in-situ incorporation of rice residues along with 20 kg N ha^{-1}, but differed with all other treatments. With respect to nitrogen management, highest net returns (Rs. 42,510 ha^{-1}) and B:C ratio (1.66) was estimated with INM treatment, which differed significantly with all other N management options. Due to timely supply of nutrients, better mineralization, higher biomass production leading to increased yield and net return with *in-situ* incorporation of rice residues along with starter application of 20 kg N ha^{-1} and 20 kg $P_2O_5ha^{-1}$ and INM based nitrogen management, with optimum nitrogen fertilizer application in comparison to LCC, SPAD and soil test based N, delivered highest return per rupee spent. This was in conformity with Mohanty *et al.* (2015); Samant *et al.* (2021); Vijayaprabhakar *et al.* (2021).

CONCLUSIONS

In-situ incorporation of rice residues along with starter application of N and P_2O_5 and integrated nitrogen management involving 75% inorganic and 25% organic can be practised for encashing highest net energy, energy use efficiency and economical return from transplanted rice.

FUTURE SCOPE

The present work can be used for future references while studying the effect of residue and nitrogen management in rice as emerging challenges in agricultural resource management area. Effect of residue and nitrogen management on productivity, profitability and net energy return can also be studied for different crops and cropping systems.

Acknowledgement. I gratefully record my indebtedness to my advisor and all the faculty members of Department of Agronomy for valuable suggestions and constant guidance throughout the course of this research work.
Conflict of Interest. None.

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How to cite this article: Priyanka Nayak, Bama Shankar Rath, Rabindra Kumar Paikaray, Bijay Kumar Mohapatra, Sanat Kumar Dwibedi, Sabyasachi Sahoo and Shivasankar Acharya (2023). Economics and Energetic Efficiency of Puddled Transplanted Rice (*Oryza sativa* L.) as Influenced by Residue and Nitrogen Management Options. *Biological Forum – An International Journal*, *15*(1): 720-727.