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Effect of Nutrient Management and Rice Establishment Methods on Biochemical and Physiological Attributes, Yield and Economics of Rice (*Oryza sativa* L.) in Rice-Groundnut Cropping System in Coastal Odisha

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A field experiment was conducted during 2019-20 and 2020-21 to study the effect of nutrient management and rice establishment methods on biochemical, physiological attributes, yield and economics of rice in rice–groundnut cropping system in coastal Odisha. The experimental field was laid out in factorial randomised block design during *Kharif* and in split-plot design during *Rabi* with three replications. Six treatment combinations comprising two rice establishment methods *viz*., direct seeded rice (DSR) and transplanted rice (TPR) and three nutrient management practices, *viz*., inorganic source, organic source and integrated nutrient management (INM) in rice during *Kharif* were allotted to the main-plots. Three nutrient management practices to groundnut *viz*., 75% soil test based fertiliser, STBF (inorganic), 100% STBF (inorganic) and INM during *Rabi* were allotted to the sub-plots. The results of the study revealed that DSR recorded significantly higher plant height, tillers m^{-2}, leaf temperature, net returns (Rs. 39121 ha^{-1}) and B:C ratio (1.68). The TPR was superior in terms of total chlorophyll content, dry matter production, panicles m^{-2}, panicle weight, grains panicle^{-1}, 1000-seed weight, leaf area index (LAI), light transmission ratio (LTR), relative growth rate (RGR) and net assimilation rate (NAR) resulting in yield improvement of 3.3% over DSR. The INM practice was superior to other nutrient management approaches in total chlorophyll content, dry matter production and its partitioning into panicle (62.5%), panicles m^{-2}, grains panicle^{-1}, 1000-seed weight, LAI and leaf temperature, which resulted in 13.3 and 15.2% higher grain yield than inorganic and organic source of nutrient management, respectively. The INM treatment also recorded higher plant height, tillers m^{-2}, crop growth rate (CGR), net assimilation rate (NAR), relative growth rate (RGR), net returns (Rs. 56246 ha^{-1}) and B:C ratio (1.89). Organic sources recorded higher NAR, RGR, panicle weight, but had the lowest dry matter accumulation and net returns.

(***Key words:*** *Chlorophyll, Dry matter partitioning, Economics, Nutrient management, Rice establishment,Yield*)

Rice and rice-based cropping systems form an integral part of agriculture whose spread and extent is predominant across the country and more precisely in eastern India. Inclusion of oilseeds and legumes in the cropping system has a close relationship between cropping system productivity, energy and environment (Deep *et al*., 2018). Rice (*Oryza sativa* L.) is one of the important staple food crops of the world and, India has the world's largest area under rice (44.5 Mha) and is the second highest producer (121.26 Mt) contributing 22% of global rice production (FAO, 2018).

Groundnut (*Arachis hypogaea* L.) is considered a unique and important legume oilseed crop and in India, it is grown over an area of 4.9 Mha with a total production of 10.14 Mt (DES, 2020). Rice-groundnut is an important cropping system in Odisha. Rice is also the predominant crop of Odisha covering about 10% of the total rice area in the country and 45% of the total cultivable area in the state with a productivity of 1.74 t ha^{-1}. Rice covers about 67% of the total cultivable area of the state in the *Kharif* season and groundnut is the major oilseed crop grown in 0.20 Mha, out of which *Rabi* groundnut accounts for about 67% area with a productivity of 1.98 t ha^{-1} (DA & FP, 2017-18). Both the crops in the system are nutrient exhaustive and sensitive to changing climate. Deterioration of soil properties due to improper crop and nutrient management has threatened the productivity and sustainability of the system in the state (Patra *et al*., 2019).

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The method of stand establishment influences the performance of rice and the effect of the method of seeding rice during *Kharif* has a great impact on field preparation and establishment of succeeding *Rabi* crops (Pandey *et al*., 2018). Rice is grown mostly through transplanting but due to scarcity of labour, irrigation water and soil degradation, farmers switch over to direct seeding. Rice yield during the rainy (*Kharif*) season in the coastal areas are highly variable mainly due to improper selection varieties, soil salinity and submergence by heavy water following transplanting which also deteriorates the soil structure and creates problem in tillage and establishment of subsequent rabi crop (Sarangi *et al*., 2017). Transplanting in rice is detrimental to the succeeding non-rice crop due to deterioration of soil physical condition and the formation of a hard pan at shallow depth through puddling (Bandyopadhyay *et al*., 2019).

Nutrient management practices play an important role in enhancing the production of rice. Continuous use of imbalanced inorganic fertilizers is subject to various losses and might be converted into different gas emissions, leading to global warming (Ravikumar *et al*., 2021). Efficient nutrient management is essential to achieve higher and sustained crop yield and integration of all possible sources of nutrients can fulfil the phasic requirement of crops improving the use efficiency of applied nutrients. An integrated approach of nutrient supply with the use of organics and inorganic fertilizers is gaining importance, as it not only reduces the use of costly inorganic fertilizers but also is an eco-friendly approach (Kamble *et al*., 2018; Suryawanshi *et al*., 2019) and is the best option for sustaining crop yield and improving soil health (Mondal *et al*., 2019). It also ensures the supply of all the essential nutrients to the crops in sufficient amounts and makes the nutrients readily available during crop growth as required (Das *et al*., 2015). Organic manures and biofertilizers have a carry-over effect on the succeeding crops in rice-based cropping systems. The low productivity of groundnut is mainly due to low consumption of fertilizer in spite of prominent nutrient deficiencies and the application of manures and fertilizers affects the availability of soil nutrients and soil physical properties of groundnut (Patil *et al*., 2017; Mondal *et al*., 2019). Keeping these facts in view, the present investigation was undertaken to find out the effect of different nutrient management and rice establishment methods on biochemical and physiological attributes, yield and economics of rice in rice–groundnut cropping system in coastal Odisha.

MATERIALS AND METHODS

The field experiment was conducted for two consecutive years during the *Kharif* and *Rabi* seasons of 2019-20 and 2020-21 at Agronomy Main Research Farm, Odisha University of Agriculture and Technology, Bhubaneswar (20° 15′ N, 85° 52′ E, 25.9 m above MSL) under East and South-Eastern Coastal Plain Agro-Climatic Zone of Odisha. The soil of the experimental site was acidic (pH-5.28), loamy sand in texture with medium organic carbon (0.57%), phosphorus (15.4 kg ha^{-1}) and potassium (189.4 kg ha^{-1}) and low in nitrogen (187.5 kg ha^{-1}). Six treatment combinations comprising two establishment methods [direct seeded rice (DSR) and transplanted puddled rice (TPR)] and three nutrient management practices [inorganic-100% soil test based fertilizers (STBF) from inorganic source; organic-green manuring with *dhaincha* + 1/3rd soil test based nitrogen, STBN (vermicompost) + 1/3rd STBN (neem oil cake) and integrated nutrient management (INM) with integration of both organic and inorganic sources-green manuring with *dhaincha* + 50% STBN + 100% P_2O_5 + 100% K_2O] to rice during *Kharif* were allotted to the main-plots. Three nutrient management practices viz., 75% STBF (inorganic), 100% STBF (inorganic) and INM [75% STBN + 25% STBN (FYM) + lime 0.2 LR + biofertilisers *viz*., *Rhizobium* and PSB + 100% P_2O_5 + 100% K_2O] to groundnut during *Rabi* were allotted to the sub-plots in a split-plot design replicated three times at the same site during both the years in rice–groundnut cropping system. Rice (cv. Maudamani-CR DHAN 307) and groundnut variety (cv. Devi-ICGV 91114) were grown with the recommended package of practices. The N content of vermicompost and neem oil cake used was 1.62%, 3.85% during 2019-20 and 1.56%, 3.82% during 2020-21, respectively. Vermicompost @ 2.0 t ha^{-1} and neem oil cake @ 0.87 t ha^{-1} were applied immediately after the layout of the experiment as per treatments. Inorganic nutrient management practices in crops were 100% of soil test based fertilizers (STBF) @ 100:40:40 kg $N:P_2O_5:K_2O$ ha^{-1} through inorganic fertilisers. In DSR, rice was sown with *dhaincha* (*Sesbania aculeata*) and in TPR, rice was transplanted after incorporation of *dhaincha* at 42 days stage. After *dhaincha* incorporation, the land of the individual plot was again puddled and levelled before transplanting. *Dhaincha* in DSR was also brown manured by knocking down *dhaincha* with the spraying of 2,4-D ethyl ester at the same stage.

Total chlorophyll content in the leaves was determined by using the method stated by Arnon (1949) and the growth indices were calculated as per standard formulae (Radford, 1967). All the growth, yield attributes and yield were recorded and the economic analysis was done by calculating the cost of cultivation, gross returns, net returns and B:C ratio. Available soil nutrient contents were determined following the standard procedures (Jackson, 1973). The data collected from the experiment on various observations of rice crop were subjected to pooled analysis over two years following the standard ANOVA technique as prescribed by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Biochemical attributes

Chlorophyll is an important molecule associated with photosynthesis in plant leaves that directly affects the growth and yield of rice. Chlorophyll content at different growth stages of the crop (Table 1) indicated that the concentration of chlorophyll in the leaf gradually increased from 30 to 90 DAS. Rice establishment method and nutrient management had a significant effect on chlorophyll content. The data in Table 1 revealed that the total chlorophyll content of direct seeded rice (DSR) was found to be higher (1.62 mg g^{-1}) than transplanted rice (TPR) at 30 DAS, but the trend was reversed in favour of transplanted rice with higher chlorophyll (4.10 mg g^{-1}) at 90 DAS resulting in significantly higher SPAD value and leaf temperature. Leaf area index (LAI) and light transmission ratio (LTR) were at par in both establishment methods in conformity with that reported by Das *et al*. (2015).

Among the nutrient management practices, better chlorophyll content was found in INM (3.02 and 4.10 mg g^{-1} at 60 DAS and 90 DAS, respectively) over organic or 100% STBF owing to prolonged availability of nitrogen due to the slow release of N from the organic source, closely matching the N supply with rice N demand that increased the rate of leaf expansion leading to better interception of solar radiation by the canopy, enhanced photosynthesis, nitrogen metabolism, transformation of carbohydrates and oxidation-reduction process in plants. Singh (2013) reported similar findings in chlorophyll content of hybrid rice with 75% RDF + green manuring. Organic source of nutrient management recorded significantly higher LTR (0.08) might be due to slow availability of the available form of N to plant feeding with organic source and *vice versa* whereas numerically better LAI (5.12) and leaf temperature (23.30°C) was observed in INM practice.

Table 1. *Chlorophyll content, chlorophyll index, leaf area index, leaf temperature and light transmission ratio of rice as influenced by nutrient management and rice establishment methods (Pooled data of 2 years)*

Treatment	Chlorophyll-total (mg g^{-1}) 30 DAS	Chlorophyll-total (mg g^{-1}) 60 DAS	Chlorophyll-total (mg g^{-1}) 90 DAS	SPAD value 90 DAS	Leaf area index 90 DAS	Leaf temperature (°C) 90 DAS	Light transmission ratio 90 DAS
Rice establishment methods							
DSR	1.62	2.51	3.26	18.59	4.63	23.20	0.06
TPR	0.98	2.92	4.10	22.61	4.74	22.90	0.07
SEm ±	0.067	0.002	0.150	0.749	0.298	0.20	0.01
C.D. at 5%	0.16	0.01	0.37	1.83	NS	0.65	NS
Nutrient management in rice							
Inorganic	1.43	2.51	3.42	17.89	4.82	22.90	0.06
Organic	1.15	2.61	3.53	19.29	4.11	22.90	0.08
INM	1.32	3.02	4.10	24.61	5.12	23.30	0.06
SEm ±	0.082	0.002	0.184	0.917	0.364	0.30	0.01
C.D. at 5%	0.20	0.01	0.45	2.24	0.89	0.80	NS

Physiological attributes

DSR recorded (Table 2) significantly higher plant height (127.3 cm) and tillers m^{-2} (412.6) over TPR which might be due to transplanting shock in TPR and greater intra-row competition as a result of higher plant density in DSR causing elongation of the stalk.

Integrated nutrient management (INM) in rice resulted in comparatively higher plant height and tillers m^{-2} than inorganic and organic management. The efficiency of crop canopy for utilizing the available solar radiation is a function of the rate and duration of photosynthesis and its subsequent translocation and storage in different plant parts during crop growth, which results in total dry matter accumulation. The data on accumulation of dry matter by rice crop as affected by nutrient management and rice establishment methods revealed that TPR significantly increased the dry matter production resulting in 10.0% increase over DSR. Nutrient management practices also influenced dry matter production and INM produced significantly higher dry matter of 1482.0 g m^{-2} followed by inorganic and organic management.

Dry matter accumulation in different plant parts at maturity showed a maximum in panicle followed by stem and leaf. TPR recorded a higher partition in the panicle (60.0%) over DSR. Among nutrient management practices, INM was observed to be superior with maximum dry matter accumulation and its partitioning into grain, 62.5% of total dry matter in panicle. The lowest dry matter was observed with inorganic practices having 54.7% of total dry matter in panicle. Inorganic resulted in a higher per cent of dry matter accumulation in leaf (11.8%) and stem (33.5%) over the organic source of nutrient management. The recommended dose of fertilizer through inorganic sources might have supplied an adequate quantity of nutrients as per as crop's requirement rapidly and additionally green-manuring can also play a good role as an organic source of fertilizer which can enhance dry matter production of the crop. These results are supported with that reported by Kumari *et al*. (2014).

Table 2. *Plant height, tillers m^{-2}, dry matter accumulation and partition of rice as influenced by nutrient management and rice establishment methods (Pooled data of 2 years)*

Treatment	Plant height (cm)	Tillers m^{-2}	Dry matter accumulation (g m^{-2})			
			Leaf	Stem	Panicle	Total
Rice establishment methods						
DSR	127.3	412.6	134.4 (11.4)	371.4 (31.7)	680.1 (56.9)	1213.5
TPR	118.4	335.6	138.9 (10.1)	400.7 (29.9)	822.9 (60.0)	1335.0
SEm ±	1.44	12.19	9.9	12.9	30.0	38.27
C.D. at 5%	3.5	29.7	24.0	NS	73.2	93.3
Nutrient management in rice						
Inorganic	123.0	367.7	139.0 (11.8)	382.5 (33.5)	643.4 (54.7)	1212.1
Organic	121.5	353.7	116.3 (9.9)	370.2 (32.0)	663.2 (58.1)	1128.7
INM	124.2	400.7	154.6 (10.4)	405.4 (27.1)	947.9 (62.5)	1482.0
SEm ±	1.77	14.93	12.1	15.8	36.8	46.87
C.D. at 5%	NS	36.4	29.6	NS	89.7	114.3

*Figures in parentheses are percentage of dry matter partitioning

The maximum crop growth rate (CGR) of 24.65-26.20 g m^{-2} day^{-1} was observed during 60-90 DAS irrespective of treatments (Table 3), thereafter it declined towards maturity. TPR outperformed at 30-60 DAS observation interval in other stages the DSR and TPR were at par. INM practice led to a significantly higher CGR after 30-60 DAS onwards. Net assimilation rate (NAR) was found to be non-significant, regardless of treatments imposed except at the initial growth stages. The trend of NAR was observed to be declining at advanced stages of growth. The relative growth rate (RGR) increased at successive growth stages up to 90 DAS, which is evident from RGR values at 30-60 and 60-90 DAS, respectively and then declined towards maturity. TPR showed a significantly higher RGR at 30-60 DAS, however, the effect of the establishment methods was not noticed afterwards. The higher growth rate with the combined use of organic and inorganic was due to rapid growth caused by adequate nutrient supply to the crops, which resulted in an increase in various metabolic processes and better mobilisation of synthesized carbohydrates in amino acids and proteins. This in turn stimulated the rapid cell division and cell elongation, thus allowing the plant to grow faster. These results are in agreement with Awan *et al*. (2000) and Parasuraman (2005).

TPR recorded (Table 4) higher panicle m^{-2} (288.3), panicle weight (4.16 g) and grains $panicle^{-1}$ (185.8) resulting in yield improvement of 3.3% over DSR whereas at par 1000-seed weight (24.37-24.46g) was observed in establishment methods. This could be due to better microclimatic conditions and improvement in soil physico-chemical properties for better water uptake as well as availability and utilization of nutrients in TPR (Bastola, 2020). Among the nutrient management practices, INM recorded higher panicles m^{-2} (321.0), grains $panicle^{-1}$ (190.2) and 1000-seed weight (24.53 g) than organic and inorganic, but panicles were heavier (4.26 g) in the organic source of nutrient management. The 1000-seed weight was at par for organic (24.81 g) and INM (24.53 g) treatments.

The INM practice in rice resulted in the highest grain yield (6060 kg ha^{-1}) and straw yield (7077 kg ha^{-1}), which outyielded both the inorganic and the organic practices by 13.2 and 15.2%, respectively. Integrated use of green manures and fertilizer N was more beneficial than their individual application even on an equal nutrient basis which might be because of improvement in soil physical conditions and soil microbial activity leading to increased availability and overall balanced nutrition (Ghosh *et al*., 2021). Better performance of rice crop with INM had led to an increase in plant growth resulting in higher grain yield due to *in situ* green manuring with *dhaincha* (Mankotia, 2007).

Table 3. *Crop growth rate, net assimilation rate and relative growth rate of rice as influenced by nutrient management and rice establishment methods (Pooled data of 2 years)*

Treatment	Crop growth rate (g m^{-2} day^{-1})			Net assimilation rate (g m^{-2} day^{-1})			Relative growth rate (mg g^{-1} day^{-1})		
	30-60 DAS	60-90 DAS	90-Maturity	30-60 DAS	60-90 DAS	90-Maturity	30-60 DAS	60-90 DAS	90-Maturity
Rice establishment methods									
DSR	5.09	24.65	5.04	1.84	6.11	4.62	25.2	41.9	5.4
TPR	7.52	26.20	4.70	2.97	6.07	4.76	39.3	40.5	5.9
SEm ±	0.498	1.161	0.270	0.170	0.364	0.47	2.29	1.83	0.24
C.D. at 5%	2.21	NS	NS	0.42	NS	NS	5.6	NS	NS
Nutrient management in rice									
Inorganic	6.16	24.47	4.34	2.26	5.76	3.93	30.9	40.6	5.1
Organic	6.47	21.55	4.38	2.99	5.98	5.02	38.8	38.2	6.0
INM	6.29	30.25	5.90	1.96	6.53	5.12	27.0	44.7	5.8
SEm ±	0.61	1.422	0.33	0.21	0.446	0.57	2.81	2.39	0.29
C.D. at 5%	NS	3.47	0.81	0.51	NS	NS	6.8	4.5	0.7

Table 4. *Yield attributes, yield and economics of rice as influenced by nutrient management and rice establishment methods (Pooled data of 2 years)*

Treatment	Panicles m^{-2}	Panicle weight (g)	Grains $panicle^{-1}$	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Net Return (₹ ha^{-1})	Benefit cost ratio
Rice establishment methods								
DSR	264.8	3.74	173.5	24.46	5469	6602	39121	1.68
TPR	288.3	4.16	185.8	24.37	5646	6944	34537	1.51
SEm ±	5.06	0.124	3.44	0.169	30	77	440	0.005
C.D. at 5%	12.3	0.30	8.4	NS	73	188	1072	0.01
Nutrient management in rice								
Inorganic	270.8	3.42	183.2	23.91	5352	6588	48776	1.85
Organic	237.7	4.26	165.5	24.81	5262	6653	5465	1.05
INM	321.0	4.17	190.2	24.53	6060	7077	56246	1.89
SEm ±	6.20	0.151	4.21	0.207	37	94	538	0.006
C.D. at 5%	15.1	0.37	10.3	0.51	90	230	1313	0.02

Economics

DSR recorded a higher net return value (₹ 39,121 ha^{-1}) and improved the B:C ratio to 1.68 as compared to TPR (Table 4), due to the relatively lower cost of cultivation resulting from lower labour requirement in direct seeding which conforms with the findings of Sarangi *et al*. (2017) and Bohra and Kumar (2015). INM in rice resulted in the higher net returns (₹ 56,246 ha^{-1}) and B:C ratio (1.89) over the organic and inorganic sources of nutrition which might be due to higher yield under INM. Organic sources of nutrients in rice resulted in the lowest net return owing to the higher cost of organic manures. The higher yield under INM might have negated the relatively higher cost of organic sources of nutrients as reported by Singh *et al*. (2006).

Thus, integrated nutrient management practice in conjunction with *dhaincha* green manuring + 50% STBN + 100% P_2O_5 + 100% K_2O under transplanted rice is the best option for improving the biochemical and physiological attributes, yield and economics of rice in rice–groundnut cropping system in coastal Odisha.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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