Journal of Agricultural Science and Technology B 5 (2015) 297-308
doi: 10.17265/2161-6264/2015.05.001

Effect of Integrated Nutrient Management on Growth and Productivity of Hybrid Rice

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Abstract: Sustaining rice (*Oryza sativa* L.) productivity at high level is a great challenge, particularly in areas where rice productivity declines in spite of following recommended nutrient management practices. Nutrient management by integrating organic manures, inorganic fertilizers and biofertilizers may play an important role in improving and sustaining rice productivity. In this study, the authors tried to evaluate the suitable proportion of organic manures and inorganic fertilizers along with biofertilizer to maximize growth and productivity of hybrid rice on sandy-loam lateritic soils of West Bengal, India. The crop having 50% recommended dose of fertilizer (RDF) + 50% recommended dose of nitrogen (RDN) through mustard oil cake (MOC) and 75% RDF + 25% RDN through MOC + biofertilizer significantly increased plant height, number of tillers/m^2, leaf area index (LAI), dry matter accumulation (DMA) and crop growth rate (CGR) at initial and vital period of grain growth over those of 25% RDF + 75% RDN through MOC and 100% RDN through MOC. The former two treatments also increased number of panicles/m^2 and number of grains/panicle over those of only organic manuring (100% RDN) or only chemical fertilization (100% RDF) or 25% RDF + 75% RDN through MOC. Crop with 75% RDF + 25% RDN through MOC + biofertilizer or 50% RDF + 50% RDN through MOC produced 20.2%-33.8% higher grain yield and 11.0%-33.3% greater straw yield, and paid higher gross and net returns over other treatments. This study suggests growing hybrid rice with 75% RDF + 25% RDN through MOC + biofertilizer or 50% RDF + 50% RDN through MOC for better growth, higher productivity and greater profit.

Key words: Hybrid rice, biofertilizer, integrated nutrient management.

1. Introduction

Rice is the staple food crop of the world, cultivated in about 163.2 million ha with a production of 719.7 million tons of grains. India is the second most populous nation and the largest producer of rice in the world after China. India produces about 152.6 million tons from 42.5 million ha with an average productivity of 3.57 tons/ha; while, China produces 204.3 million tons from 30.3 million ha with an average productivity of 6.73 tons/ha [1]. China's increased rice productivity is propelled with hybrid rice. China had extended hybrid rice cultivation over half of its total rice land by 1990 to emerge as the world's largest rice producer. Hybrid rice cultivation technology was fully utilized in China, where its exploitation has paid rich dividend to alleviate hunger and poverty [2]. The hybrid rice produces 6.0-7.0 tons/ha with 30% yield advantage over conventional varieties [3].

Enhancing the rice productivity through the improvement of yield potential of genotypes and appropriate nutrient management has been the main thrust of Indian rice policy. Inorganic fertilizer is one of the key factors to increase the rice productivity. Rice yield and biomass increased rapidly due to increased use of chemical fertilizers [4-6]. In the recent years, crop productivity has stagnated or decreased in spite of consumption of increased rate of chemical fertilizers [7-9]. As a result, agricultural ecosystems remain in a state of chemical nutrient saturation, leading to huge nutrient losses through leaching, runoff, volatilization, emissions, immobilization

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and subsequent low nutrient use efficiency [10]. It is high time to search for innovative practices, which can guarantee higher yields with minimal deterioration of natural resources. Integrated nutrient management has been shown to considerably improve rice yields by minimizing nutrient losses to the environment and managing the nutrient supply, and thereby results in high nutrient use efficiency [11-13]. Recent field experiments have demonstrated that integrated nutrient management can lead to significant increase in crop yields while substantially reducing nutrient losses [14-16].

Most studies on optimizing nutrient management in hybrid rice were conducted with temperate hybrid rice in China [17-20]. These strategies cannot be adopted directly for tropical hybrid rice. Physiology-based management strategies need to be developed for maximizing the yield of tropical hybrid rice [20-22]. Recognizing the potential of hybrid rice to enhance production and productivity, the strategies to be taken are exploitation of local hybrids and improving nutrient management practices by integrating organic and inorganic fertilizers for sustaining supply of plant nutrients, particularly NPK [5, 23, 24]. The nutrients, their sources, method and time of application form an important component of fertilizer management strategies [16, 25-27]. Oil cake is considered as the concentrated organic manure due to its high amount of nutrients content. In addition to N, P and K, it also supplies considerable amount of secondary and micronutrients, and causes the improved growth and high yield of various crops. Information regarding integrated use of organic and inorganic sources of plant nutrients to hybrid rice is limited in Indian subtropics. The response of recent rice hybrids to various proportions of organic and inorganic sources of nutrients has to be attempted to elicit information on the optimum proportion of organic and inorganic nutrients to rice hybrid. With this view, the present investigation was carried out in Eastern Indian subtropics to have a better understanding of improving nutrient management in hybrid rice for better growth, greater productivity and higher profit.

2. Materials and Methods

2.1 Experimental Site

A Field experiment was conducted at the Agricultural Farm of the Institute of Agriculture (Palli Siksha Bhavana), Visva-Bharati, Sriniketan, West Bengal (23°39′ N latitude, 87°42′ E longitude and an altitude of 58.9 m above sea level), during the kharif (rainy) season of 2011 and 2012 to study the effect of nutrient management practices on growth, productivity and economics of hybrid rice (PHB 71). The experimental soil is fragile, lateritic and sandy-loam in texture (60% sand, 23.2% silt and 16.3% clay). The initial properties of the soil collected at the beginning of the field experiment were 142.0 kg/ha available N (Kjeldahl), 8.2 kg/ha available P (Bray-1), 112.2 kg/ha available K (1 N NH_4-acetate) and 5.5 pH (1:2.5 of soil:water). The climate is classified as sub-humid subtropical, characterized by hot summer, hot-humid rainy and mild winter. The weather condition of the experimental area varied considerably between the two crop seasons. Normally, the experimental area receives 991 mm rainfall during the crop season (July to October) as long term average (LTA) rainfall of the area; but the crop received 32.2% and 19.6% less rainfall in 2011 (672.3 mm) and 2012 (796.6 mm), respectively, as compared to LTA (Fig. 1). The advantage of higher rainfall in 2012 was reflected by increased grain yield (10.2%) over those of 2011 in spite of protected irrigation. The temperature and relative humidity (RH) during the crop growing period of both the years did not deviate much from their LTA. The maximum temperature ranged from 30.0 °C to 34.7 °C; while, the minimum temperature varied from 17.5 °C to 26.9 °C during the cropping season (July to October). The average RH during the cropping season varied from 73.4% to 91.2%.

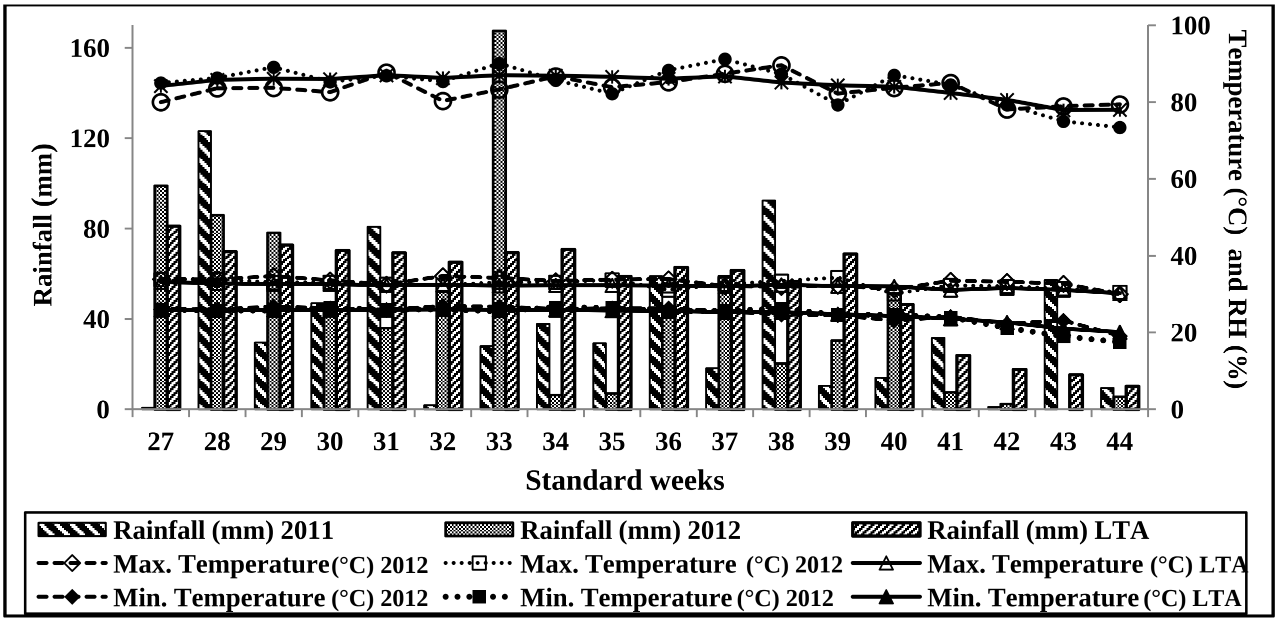

Fig. 1 Weather condition of the experimental area during the two cropping seasons.

2.2 Experimental Design and Treatments

The experiment was laid out in randomized complete block design with eight nutrient management practices: T_1 = 100% recommended dose fertilizer (RDF), T_2 = 75% RDF + 25% recommended dose of nitrogen (RDN) through mustard oil cake (MOC), T_3 = 50% RDF + 50% RDN through MOC, T_4 = 25% RDF + 75% RDN through MOC, T_5 = 100% RDN through MOC, T_6 = 100% RDF + 25% RDN through MOC, T_7 = 75% RDF + 25% RDN through MOC + biofertilizer and T_8 = 100% RDF + 25% RDN through MOC + biofertilizer. Each treatment was replicated thrice in 5 m × 3 m plots. RDF for hybrid rice was 120 kg/ha N, 26.7 kg/ha P, 50 kg/ha K and RDN was 120 kg/ha N. The experiment was conducted in two successive years in the same layout.

2.3 Crop Management Practices

Rice (PHB 71) seedlings were raised in dry nursery beds. The main field was prepared by two crosswise ploughing by tractor drawn plough, followed by puddling with power tiller. The manures and fertilizers were applied in the form of MOC, urea, single super phosphate and muriate of potash as per treatments. Full dose of MOC, P and K and one-thirds dose of N were applied as basal before planting. The remaining N fertilizer was applied in two equal splits at mid-tillering and heading stages. The crop was transplanted on the 4th week of July during both the years at 20 cm × 15 cm spacing with 21-days-old seedling one in each hill. Azotobactor biofertilizer of 0.5 kg/ha was applied after mixing thoroughly with 5.0 kg/ha vermicompost as per treatments at 30 days after planting (DAT). In addition to rainfall, the crop received four irrigations at early tillering (14 DAT), panicle initiation (48 DAT), grain formation (70 DAT) and grain filling (85 DAT) stages in 2011 and three irrigations at maximum tillering (35 DAT), flowering (63 DAT) and grain filling (85 DAT) stages in 2012 for maintaining the field under saturated condition from planting to 25 days after flowering (DAF). Spraying of dimethoate 30 EC of 0.03% was done at heading stage to protect the crop against the attack of gundhi bug (*Leptocorisa varicornis*) during both the years.

2.4 Observations Recorded

The observation on plant height was recorded from 10 hills, which were randomly selected from each plot at different stages, and average number of tillers from the same hills was also recorded at 45 DAT. Plant samples for biomass was collected from five hills of ear-marked area in each plot and fresh weights were recorded. The plant samples were then separated into stem (leaf sheath + culm), green leaves (lamina) and panicles, and kept in separate paper packets, which were put in an oven for drying at 65-70 °C till constant weights were obtained. The dry weight of leaves, stems and panicles were noted and converted into g/m^2. The sum of the dry weights was taken as the total dry matter accumulation (DMA). The dry weight of leaves was used for determining leaf area index (LAI) as suggested by Watson [28]. DMA at different stages was used for determining crop growth rate (CGR). Yield components, like number of panicles/m^2 and panicle length (cm), were recorded from 10 hills selected randomly in each plot at maturity. Filled grains/panicle was recorded from 10 panicles of the selected hills at maturity. The test weight (1,000-grain weight) was estimated by Eq. (1):

$$\text{Test weight of grain (g)} = \frac{\text{Dry weight of grains of the above 10 panicles}}{\text{Numberof grains of the above 10 panicles}} \times 1000 \quad (1)$$

The crop was hand-harvested from 8 m^2 area in each plot at maturity. Grain and straw yields were estimated after threshing, cleaning and drying of grain and straw. The harvest index was computed as Eq. (2):

$$\text{Harvest index } (\%) = \frac{\text{Grain yield} \times 100}{\text{Grain + straw yield}} \quad (2)$$

2.5 Economic and Statistical Analysis

The cost of cultivation and gross returns for different treatments were calculated, taking into account the government approved rate and prevailing price of different inputs and outputs in the local markets. The authors have computed the cost of different cultural operations on the basis of fixed cost and variable cost. The cost of common cultural operations for all the treatments, such as seeds and seedling raising, uprooting, main field preparation, transplanting, irrigation, weeding and plant protection, are put under fixed cost, and those varying with treatments, like the costs of fertilizer and its application, harvesting and processing costs, are put under variable cost. The cost for harvesting and processing depends on the amount of yield. Therefore, cost per unit yield for harvest and processing was calculated using measured mean yield of rice under various treatments in combination with the published standard costs for harvesting and processing of the crop [29]. A summary of hybrid rice production cost is shown in Table 1. The gross return from each plot was calculated taking into account of grain and straw yield multiplied by their respective price. Net return was calculated by deducting the production cost from the gross value of the produce, including by-product value (gross return). The return per dollar invested was estimated dividing the gross return with respective cost of cultivation.

The data were statistically analyzed by standard analysis of variance technique for randomized complete block design as suggested by Gomez, K. A. and Gomez, A. A. [30], and the treatments means were compared based on the least significant difference (LSD) at 0.05 level of probability.

3. Results and Discussion

3.1 Growth Attributes

Nutrient management showed significant effect on increasing plant height, tillering, LAI, DMA and CGR of hybrid rice. The crop receiving only organic manure (100% RDN through MOC) or 25% RDF + 75% RDN through MOC produced dwarf plants at all the growth stages (tillering (25 DAT), flowering (65 DAT) and maturity (105 DAT)) and less number of tillers/m^2 as compared to those of all other fertility treatments under the study. The plant height at all the above stages and number of tillers/m^2, however, did not differ significantly among the other fertility treatments (Table 2). The LAI increased steadily up to flowering stage (65 DAT) and thereafter it decreased sharply towards maturity in all the treatments. Significantly

Table 1 Computation of production cost of hybrid rice.

Cultural operations	Cost ($/ha)
1. Fixed cost items	
Nursery bed management (0.1 ha for 1 ha transplanting)	
Bed preparation	4.0
Manures, fertilizers and application	2.4
Seeds and sowing in seed beds	33.0
Irrigation	4.0
Plant protection	2.0
Seedling uprooting and carrying	10.0
Subtotal	55.4
Main field management	
Field preparation	48.0
Transplanting	70.0
Irrigation	80.0
Weeding	90.0
Plant protection	10.0
Subtotal	298.0
2. Variable cost items	
Fertilizer and its application	As per treatment
Harvest and processing cost at *Y* ton yield	20*Y*

Table 2 Effect of integrated nutrient management on plant height and tillering of hybrid rice.

No.	Treatments	Plant height (cm)						Number of tillers/m^2	
		2011			2012				
		Tillering	Flowering	Maturity	Tillering	Flowering	Maturity	2011	2012
T1	100% RDF	62.0	118.5	137.2	65.1	131.0	137.9	379	391
T2	75% RDF + 25% RDN (MOC)	61.4	118.3	136.0	64.5	130.1	136.6	380	386
T3	50% RDF + 50% RDN (MOC)	59.7	117.1	134.6	62.4	129.4	135.7	374	382
T4	25% RDF + 75% RDN (MOC)	53.4	109.9	125.1	56.1	120.3	125.7	338	336
T5	100% RDN (MOC)	51.6	107.7	124.6	54.1	118.5	124.9	330	317
T6	100% RDF + 25% RDN (MOC)	60.5	118.4	137.3	62.8	131.0	138.6	380	390
T7	75% RDF + 25% RDN (MOC) + biofertilizer	60.7	117.9	135.8	63.8	130.7	137.2	378	383
T8	100% RDF + 25% RDN (MOC) + biofertilizer	62.3	119.5	137.5	65.4	131.4	138.9	382	395
SEM (±)		1.9	2.2	2.8	1.8	2.9	3.1	10.9	13.4
LSD at 5%		5.8	6.7	8.5	5.5	8.9	9.4	33.1	40.5

RDF = 120 kg/ha N, 26.7 kg/ha P and 50 kg/ha K; RDN = 120 kg/ha N through MOC; SEM = standard error of mean.

greater values of LAI were recorded in crop with 50% RDF + 50% RDN through MOC, 75% RDF + 25% RDN through MOC + biofertilizer, 100% RDF + 25% RDN through MOC and 100% RDF + 25% RDN through MOC + biofertilizer than those of other nutrient management practices at all the growth stages, except maturity during both the years (Table 3). However, the LAI did not differ much among the above treatments in all the cases. Similarly, the other treatments (100% RDF, 75% RDF + 25% RDN through MOC, 25% RDF + 75% RDN through MOC and 100% RDN through MOC) did not cause much variation in LAI of hybrid rice at all the growth stages during both the years. The results showed that replacement of higher amount of N through organic manure (75%-100% through MOC) was not helpful in increasing plant height, tiller production and LAI of hybrid rice; rather it reduced the plant height, tiller production and LAI values. This might be due to its inability to supply nutrients as per demand of hybrid rice because of its slow release particularly at the early vegetative stages. The duration of LAI maintaining above 5.0 is more important than the maximum LAI on influencing the crop productivity [17, 31]. In this study, the former four nutrient management practices (T1-T4) maintained LAI values over 5.0 from panicle initiation (45 DAT) to flowering (65 DAT) that might lead to high productivity of hybrid rice. Increasing 25% N application through MOC over 100% RDF was found not beneficial for increasing LAI of hybrid rice over that of the crop having 50% RDF + 50% RDN through MOC under the study. The results concur with Huang et al. [19] and Shah and Kumar [32].

Positive and significant effects of nutrient management practices were also noticed on DMA in hybrid rice. DMA increased gradually and steadily as the crop progressed towards its maturity, and the highest DMA was recorded at maturity. DMA increased steadily due to replacing fertilizer N up to 50% by MOC. Further increase in replacement of N by

Table 3 Effect of integrated nutrient management on LAI of hybrid rice.

No.	Treatments	LAI at different DAT									
		2011					2012				
		25	45	65	85	105	25	45	65	85	105
T1	100% RDF	1.55	4.36	5.07	1.87	0.60	1.84	4.66	5.19	2.02	0.57
T2	75% RDF + 25% RDN (MOC)	1.71	4.47	5.18	1.94	0.65	1.90	4.71	5.30	2.12	0.62
T3	50% RDF + 50% RDN (MOC)	2.06	5.09	5.88	2.51	0.68	2.21	5.72	6.15	2.49	0.65
T4	25% RDF + 75% RDN (MOC)	1.65	4.41	5.11	1.77	0.64	1.77	4.52	5.16	1.96	0.60
T5	100% RDN (MOC)	1.48	4.29	4.96	1.64	0.65	1.71	4.35	5.10	1.85	0.62
T6	100% RDF + 25% RDN (MOC)	2.07	5.15	5.90	2.55	0.72	2.21	5.60	6.08	2.48	0.68
T7	75% RDF + 25% RDN (MOC) + biofertilizer	2.13	5.13	5.86	2.52	0.71	2.27	5.68	6.15	2.51	0.67
T8	100% RDF + 25% RDN (MOC) + biofertilizer	2.08	5.10	5.91	2.54	0.67	2.26	5.64	6.18	2.47	0.64
SEM (±)		0.08	0.12	0.11	0.11	0.05	0.11	0.13	0.17	0.11	0.04
LSD at 5%		0.25	0.35	0.32	0.34	NS	0.33	0.41	0.51	0.33	NS

RDF = 120 kg/ha N, 26.7 kg/ha P and 50 kg/ha K; RDN = 120 kg/ha N through MOC; SEM = standard error of mean; NS = not significant.

Table 4 Effect of integrated nutrient management on DMA in hybrid rice.

No.	Treatments	DMA (g/m^2) at different DAT									
		2011					2012				
		25	45	65	85	105	25	45	65	85	105
T1	100% RDF	190	396	816	1,263	1,522	188	468	833	1,342	1,575
T2	75% RDF + 25% RDN (MOC)	201	420	822	1,292	1,553	219	483	862	1,399	1,636
T3	50% RDF + 50% RDN (MOC)	246	489	912	1,469	1,744	260	589	932	1,581	1,823
T4	25% RDF + 75% RDN (MOC)	193	418	816	1,293	1,560	214	497	850	1,349	1,616
T5	100% RDN (MOC)	171	383	777	1,247	1,526	183	457	811	1,285	1,543
T6	100% RDF + 25% RDN (MOC)	245	497	921	1,449	1,757	268	594	948	1,602	1,833
T7	75% RDF + 25% RDN (MOC) + biofertilizer	249	504	915	1,454	1,755	263	591	939	1,593	1,844
T8	100% RDF + 25% RDN (MOC) + biofertilizer	259	517	925	1,462	1,771	275	606	953	1,609	1,846
SEM (±)		10.2	19.9	26.5	48.3	57.2	12.8	21.6	21.1	48.7	54.7
LSD at 5%		31	60	80	146	173	39	65	64	148	166

RDF = 120 kg/ha N, 26.7 kg/ha P and 50 kg/ha K; RDN = 120 kg/ha N through MOC; SEM = standard error of mean.

MOC (75%-100% MOC) was not helpful in increasing DMA of hybrid rice; rather it had adverse effect of reducing the DMA of this crop (Table 4). The DMA recorded in crop receiving 50% RDF + 50% RDN through MOC, 100% RDF + 25% RDN through MOC, 75% RDF + 25% RDN through MOC + biofertilizer and 100% RDF + 25% RDN through MOC + biofertilizer was significantly greater than those of the crop having other nutrient management practices (100% RDF, 75% RDF + 25% RDN through MOC, 25% RDF + 75% RDN through MOC and 100% RDN through MOC) at all the growth stages during both the years. But, the DMA did not vary significantly among the above treatments. Similarly, the DMA did not differ significantly among the other nutrient management practices at all the growth stages of both the years. The CGR of hybrid rice did not vary significantly among the different nutrient management practices during all the growth periods of both the years, except for the period of grain filling (65-85 DAT) in 2012, while the crop with 50% RDF + 50% RDN through MOC, 100% RDF + 25% RDN through MOC, 75% RDF + 25% RDN through MOC + biofertilizer and 100% RDF + 25% RDN through MOC + biofertilizer recorded significantly higher CGR values than those of the crop with 25% RDF + 75% RDN through MOC and 100% RDN through MOC (Table 5). The above treatments, however, had a tendency of producing higher CGR values than other treatments during most of the periods of both the years. As the rate of DMA followed almost a similar trend in most of the nutrient management practices, it nullified the response of CGR to the different treatments. High DMA and LAI at vegetative stage enhanced tillering that caused further increase in DMA during the reproductive period leading to greater spikelet formation, better grain development and higher crop productivity [6, 14, 33]. The results of this study also showed that integrated use of 50% RDF + 50% RDN through MOC and/or 75% RDF + 25% RDN through MOC + biofertilizer enhanced DMA that ultimately helped in increasing the productivity of hybrid rice.

3.2 Yield Components

The yield components, like number of panicles/m^2, panicle length and number of grains/panicle varied significantly among the different nutrient management practices; but, the test weight of grain did not vary much among them. Crop receiving 50% RDF + 50% RDN through MOC, 100% RDF + 25% RDN through MOC, 75% RDF + 25% RDN through MOC + biofertilizer and 100% RDF + 25% RDN through MOC

Table 5 Effect of integrated nutrient management on CGR of hybrid rice.

No.	Treatments	CGR (g/m^2/d) at different DAT							
		2011				2012			
		25-45	45-65	65-85	85-105	25-45	45-65	65-85	85-105
T1	100% RDF	10.3	21.0	22.3	13.0	14.0	18.2	25.5	11.7
T2	75% RDF + 25% RDN (MOC)	10.8	20.1	23.5	13.1	13.2	18.9	26.9	11.8
T3	50% RDF + 50% RDN (MOC)	12.2	21.1	27.8	13.8	16.5	17.1	32.5	12.1
T4	25% RDF + 75% RDN (MOC)	11.3	19.9	23.8	13.4	14.1	17.6	25.0	13.4
T5	100% RDN (MOC)	10.6	19.7	23.5	14.0	13.7	17.7	23.7	12.9
T6	100% RDF + 25% RDN (MOC)	12.6	21.2	26.4	15.4	16.3	17.7	32.7	11.5
T7	75% RDF + 25% RDN (MOC) + biofertilizer	12.8	20.6	26.9	15.1	16.4	17.4	32.7	12.5
T8	100% RDF + 25% RDN (MOC) + biofertilizer	12.9	20.4	26.8	15.4	16.6	17.4	32.8	11.5
SEM (±)		1.1	1.4	3.0	1.3	1.0	1.6	2.4	1.3
LSD at 5%		NS	NS	NS	NS	NS	NS	7.2	NS

RDF = 120 kg/ha N, 26.7 kg/ha P and 50 kg/ha K; RDN = 120 kg/ha N through MOC; SEM = standard error of mean; NS = not significant.

Table 6 Effect of integrated nutrient management on yield components of hybrid rice.

No.	Treatments	Numbers of panicles/m^2		Panicle length (cm)		Filled grains /panicle		Test weight (g)	
		2011	2012	2011	2012	2011	2012	2011	2012
T1	100% RDF	305	325	28.4	28.9	127	125	22.5	23.3
T2	75% RDF + 25% RDN (MOC)	311	324	28.6	29.3	130	126	22.7	23.4
T3	50% RDF + 50% RDN (MOC)	343	360	30.7	32.5	136	134	22.5	23.2
T4	25% RDF + 75% RDN (MOC)	308	323	28.4	29.7	129	122	22.5	23.2
T5	100% RDN (MOC)	304	319	28.2	29.5	125	121	22.1	22.8
T6	100% RDF + 25% RDN (MOC)	342	351	30.6	31.5	138	135	22.4	23.1
T7	75% RDF + 25% RDN (MOC) + biofertilizer	345	366	30.5	32.3	136	134	22.8	23.5
T8	100% RDF + 25% RDN (MOC) + biofertilizer	338	355	30.7	32.0	137	136	22.7	23.4
SEM (±)		8.5	8.1	0.5	0.6	1.6	2.2	0.27	0.28
LSD at 5%		26	24	1.5	1.7	5.0	6.7	NS	NS

RDF = 120 kg/ha N, 26.7 kg/ha P and 50 kg/ha K; RDN = 120 kg/ha N through MOC; SEM = standard error of mean; NS = not significant.

+ biofertilizer produced significantly higher number of panicles/m^2, longer panicles and greater number of grains/panicle than those obtained with the other treatments during both the years (Table 6). Only organic manuring (100% RDN through MOC), only chemical fertilization (100% RDF), combination of 75% RDF + 25% RDN through MOC and 25% RDF + 75% RDN through MOC were found less efficient in improving yield components of hybrid rice. Test weight is a very stable varietal character and does not vary much among the nutrient management practices. High LAI functioning over the period of panicle formation and grain filling of hybrid rice under the above nutrient management practices was mainly responsible for producing longer panicles, greater number of panicles/m^2 and higher number of grains/panicle in hybrid rice. The results are in conformity with the findings of Acharya and Mondal [34] and Dass et al. [35]. Only organic manuring recorded the lowest values of these yield components of hybrid rice, indicating its inability of supplying plant nutrients in accordance with the demand of hybrid rice.

3.3 Crop Productivity

Nutrient management showed significant effect on grain and straw yield of hybrid rice, but did not affect the harvest index of the crop. Crop receiving 75% RDF + 25% RDN through MOC + biofertilizer produced the highest grain (8.81, 9.64 and 9.23 ton/ha in 2011, 2012 and pooled data, respectively) and straw (9.18 ton/ha and 9.95 ton/ha in 2011 and 2012, respectively) yields, which was closely followed by the crop having 50% RDF + 50% RDN through MOC (8.66, 9.62 and 9.14 ton/ha grain, and 8.94 ton/ha and 9.74 ton/ha straw, respectively), 100% RDF + 25% RDN through MOC + biofertilizer (8.25, 8.95 and 8.50 ton/ha grain, and 8.98 ton/ha and 9.71 ton/ha straw, respectively) and 100% RDF + 25% RDN through MOC (8.26, 8.96 and 8.51 ton/ha grain, and 8.86 ton/ha and 9.47 ton/ha straw, respectively). The above fertility treatments recorded significantly higher grain and straw yields over those of other treatments except 75% RDF + 25% RDN through MOC during both the years and also in pooled analysis (Table 7). The crop with only organic manuring (100% RDN through MOC) or only chemical fertilization (100% RDF) or 25% RDF + 75% RDN through MOC produced very low grain and straw yields as compared to other fertility treatments during both the years. The results showed that replacement of 25% N by organic (75% RDF + 25% RDN through MOC + biofertilizer) and/or replacement of 50% N by organic (50% RDF + 50% RDN through

MOC) were most conducive for obtaining high grain and straw yield of hybrid rice. Crop receiving these treatments recorded high LAI functioning over the vital period of panicle initiation to grain filling, increased CGR during the periods of panicle initiation to flowering and flowering to grain filling that helped in increasing plant height and panicle production and ultimately improved crop productivity. It was reflected by very strong and positive correlations between LAI at 65 DAT and plant height at 65 DAT and 85 DAT, between CGR during 45-65 DAT and plant height at 65 DAT and 85 DAT, between LAI at 65 DAT and CGR during 45-65 DAT, between LAI at 85 DAT and CGR during 65-85 DAT and between CGR during 65-85 DAT and panicles/m^2 (Table 8). Grain yield also showed very strong and positive relations with plant height at 85 DAT (r^2 = 0.452*), CGR during both the periods of 45-65 DAT (0.598**) and 65-85 DAT (0.543**) and panicles/m^2 (0.527**) under the study. Integrated use of appropriate proportion of organic manures and chemical fertilizers increases N accumulation in the foliage, improves growth and controls senescence of the whole plant, causing more dry matter production to meet the need of larger sink in hybrid rice [8, 36, 37]. The above treatments increased grain yield by 27.1% over that of only organic manuring (100% RDN through MOC) or chemical fertilization (100% RDF). It further noticed that application of 25% N through MOC in addition to 100% RDF did not help in increasing grain yield of hybrid rice over the above treatments. The results agree with the findings of Shah and Kumar [32], Perumal and Kalyanasundaram [38] and Kumar et al. [39].

Table 7 Effect of integrated nutrient management on productivity of hybrid rice.

No.	Treatments	Grain yield (kg/ha)			Straw yield (kg/ha)		Harvest index (%)	
		2011	2012	Pooled	2011	2012	2011	2012
T1	100% RDF	6.83	7.56	7.19	7.60	8.12	47.3	48.2
T2	75% RDF + 25% RDN (MOC)	7.61	8.45	8.03	8.48	9.22	47.3	47.8
T3	50% RDF + 50% RDN (MOC)	8.66	9.62	9.14	8.94	9.74	49.2	49.7
T4	25% RDF + 75% RDN (MOC)	6.91	7.71	7.31	7.52	8.06	47.9	48.9
T5	100% RDN (MOC)	6.88	7.64	7.26	7.43	7.94	48.1	49.0
T6	100% RDF + 25% RDN (MOC)	8.26	8.96	8.51	8.86	9.47	48.2	48.6
T7	75% RDF +25% RDN (MOC) + biofertilizer	8.81	9.64	9.23	9.18	9.95	49.0	49.2
T8	100% RDF + 25% RDN (MOC) + biofertilizer	8.25	8.95	8.50	8.98	9.71	47.9	48.0
SEM (±)		0.44	0.37	0.38	0.40	0.43	1.02	0.91
LSD at 5%		1.32	1.13	1.16	1.21	1.30	NS	NS

RDF = 120 kg/ha N, 26.7 kg/ha P and 50 kg/ha K; RDN = 120 kg/ha N through MOC; SEM = standard error of mean; NS = not significant.

Table 8 Correlation coefficients between grain yield and growth and yield attributes of hybrid rice.

Variables	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	Y
Plant height at 65 DAT (X_1)		0.576**	0.462*	0.027	0.563**	0.343	0.336	-0.049	0.330
Plant height at 85 DAT (X_2)			0.535**	0.110	0.605**	0.237	0.315	-0.013	0.452*
LAI at 65 DAT (X_3)				0.355	0.549**	0.229	0.122	0.049	0.257
LAI at 85 DAT (X_4)					-0.213	0.413*	0.088	0.167	-0.066
CGR at 45-65 DAT (X_5)						0.264	0.294	-0.048	0.598**
CGR at 65-85 DAT (X_6)							0.728**	0.027	0.543**
Panicles/m^2 (X_7)								0.016	0.527**
Grains/panicle (X_8)									-0.121
Grain yield (Y)	Number of observations = 24								

*Indicates the significant at 0.05 probability level and **indicates the significant at 0.01 probability level.

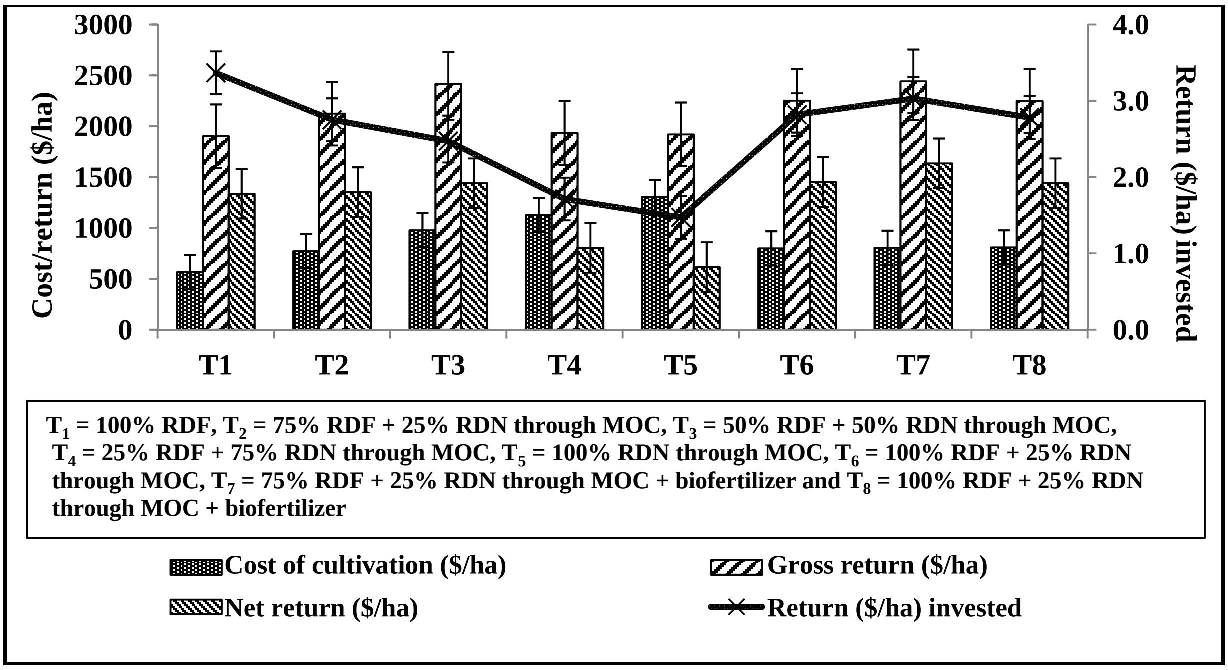

Fig. 2 Effect of integrated nutrient management on economics of hybrid rice.
The figures are the average of two years' data; vertical lines indicate standard error.

3.4 Economics of Hybrid Rice Cultivation

The economics of hybrid rice cultivation followed a trend similar to that of the crop productivity and did not vary between the two years. The average values of economic data over two years were presented in Fig. 2. The results showed very striking effect of nutrient management practices on economics of hybrid rice cultivation. The cost of cultivation increased steadily due to increase in the rate of MOC application, and the maximum cost involved with the use of 100% RDN through MOC ($1,304) was significantly greater than that of all other fertility treatments. Application of 75% RDN through MOC + 25% RDF through chemical fertilizers also recorded markedly higher cost of cultivation ($1,129) over the remaining fertility treatments. High cost of MOC and its high quantity to makeup recommended N dose were responsible for high cost of cultivation. Application of 100% RDF recorded the lowest cost ($565) of hybrid rice cultivation among all other fertility treatments.

The nutrient management practices showed significant effect on gross and net returns from hybrid rice cultivation. The highest gross ($2,314) and net ($1,517) returns were recorded from the crop with 75% RDF + 25% RDN through MOC + biofertilizer, and was followed by the crop receiving 50% RDF + 50% RDN through MOC ($2,289 gross and $1,321 net returns), 100% RDF + 25% RDN through MOC ($2,163 gross and $1,372 net returns) and 100% RDF + 25% RDN through MOC + biofertilizer ($2,165 gross and $1,363 net returns). The above treatments showed significantly higher gross return than that of only chemical fertilization ($1,813), only organic manuring ($1,823) and 25% RDF + 75% RDN through MOC ($1,837), and greater net return over only organic manuring through MOC ($526) and 25% RDF + 75% RDN through MOC ($722), which recorded very low gross and net returns under the study (Fig. 2). The results agree with the findings of Koch et al. [40]. Return per dollar invested followed an interesting trend. The crop at 100% RDF paid the highest return per dollar invested ($3.22) and followed by integrated use of 75% RDF +25% RDN through MOC + biofertilizer ($2.90). Only organic manuring gave the lowest return per dollar invested ($1.41) and was comparable to that of 25% RDF + 75% RDN through MOC ($1.65) due to high cost organic manure (MOC). Both the treatments paid significantly lower return per dollar invested than that of all other nutrient management practices in hybrid rice cultivation.

4. Conclusions

It may be concluded from the present study that integrated use of 75% RDF + 25% RDN through MOC + biofertilizer or 50% RDF + 50% RDN through MOC be required for improving growth attributes, yield components and productivity of hybrid rice. It also paid high gross and net returns with good return per dollar invested. The study recommends the integrated use of 75% RDF + 25% RDN through MOC + biofertilizer or 50% RDF + 50% RDN through MOC for better growth, higher productivity and greater profit from hybrid rice.

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