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Growth, Productivity and Economics of Hybrid Rice as Influenced by Fertility Level and Plant Density

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Abstract

A field experiment conducted during *kharif* 2010 and 2011 at the Institute of Agriculture, Visva Bharati, Sriniketan, West Bengal, India showed that application of 125 kg N, 62.5 kg P_2O_5 and 62.5 kg K_2O ha^{-1} (F_3) improved the growth attributes (plant height, number of tillers m^{-2}, leaf area index (LAI), dry matter accumulation, and crop growth rate) and increased yield components (number of panicles m^{-2}, panicle length, number of spikelets panicle^{-1}, number of grains panicle^{-1} and test weight) that led to high crop productivity of hybrid rice. Increase in plant density increased the plant height, tillers m^{-2}, LAI, dry matter production and CGR. Panicles m^{-2} increased with increasing plant density; but all other yield components like panicle length, spikelets panicle^{-1}, grains panicle^{-1} and test weight decreased with increasing plant density. Both grain and straw yield increased by increasing plant density. Crop at medium plant density (33 hills m^{-2}) with 125 kg N, 62.5 kg P_2O_5 and 62.5 kg K_2O ha^{-1} (F_3P_2) produced the highest grain yield (7039 kg ha^{-1}) and paid the highest gross (₹ 87970 ha^{-1}) and net returns (₹ 59695 ha^{-1}). Higher growth attributes and greater yield components of hybrid rice at F_3P_2 combination led to high grain productivity (7039 kg ha^{-1}). The study advocates growing of hybrid rice at a plant density of 33 hills m^{-2} (20×15 cm^2 spacing) with 125 kg N, 62.5 kg P_2O_5 and 62.5 kg K_2O ha^{-1} (F_3P_2) for its high productivity and profitability.

1. Introduction

Rice (*Oryza sativa* L.) is the staple food providing about two-thirds of the calories for more than two billion people in humid and sub-humid Asia and one-third of the calorie intake of nearly one billion people in Africa and Latin America. It is cultivated in about 154.3 mha which produce about 634.6 mt of rice grain (FAO, 2009). Since the mid-sixties, when semi-dwarf varieties triggered the green revolution, rice production has increased at 2.4% per year, faster than the rate of population growth (Nguyen, 2010). Achieving self-sufficiency in rice production and maintaining price stability are important political objectives in low-income countries because of the importance of this crop in providing national food security and generating employment and income for low-income people (Ghosh et al., 2009). Most Asian countries have done remarkably well in meeting the food needs of the growing population in the last quarter century. However, the future poses even more challenging and ambitious tasks. The yield ceilings of rice varieties of the green revolution era must be lifted yet again because by 2020 global rice demand would be about 753 mt of paddy in 2030 and about 781 mt of paddy in 2050 (Xie et al., 2007). The gaps between global rice production in 2006 and the projected rice demand in 2030 and in 2050 are considerably large. Producing more rice to fill these gaps will be essential for ensuring food security and poverty reduction in the 21st century (Nguyen, 2010). This production increase must comes from less land, less labour, less water and less pesticides and it must be sustainable. The productivity of rice in India and China are 2.69 and 5.73 t ha^{-1} respectively. High rice productivity of China is mainly due to cultivation of hybrid rice. The yield of hybrid rice was about 8.0 to 10.0 t ha^{-1} with a yield advantage of 30% over conventional varieties (Peng et al., 2010). Hybrid rice cultivation is a technology which was fully utilized in China where its exploitation has paid rich dividend to alleviate hunger and poverty (Qing, 2010). China has extended the cultivation of hybrid rice to more than half of its total rice land by 1990 to emerge as the world's largest rice producer. Most studies on optimizing hybrid rice management were conducted with temperate hybrid rice in China. These strategies cannot be adopted directly for tropical hybrid rice.

With the rapid progress in developing tropical hybrid rice, physiology-based management strategies need to be developed for maximizing the grain yield of tropical hybrid rice (Zhu et al., 2010). Using hybrid rice may be an appropriate strategy to meet the challenge of food security. The response of recent rice hybrids to various levels of fertility and plant density needs to be studied thoroughly to get in insight into the physiological basis of yield variation in hybrid rice. The present study was, therefore, undertaken to investigate how crop nutrition and plant density influence the growth and productivity of hybrid rice.

2. Materials and Methods

A field experiment was conducted during the *kharif* season of 2010 and 2011 to study the effect of plant density and fertility level on growth and productivity of hybrid rice at the farm of the Institute of Agriculture (Palli Siksha Bhavana), Visva-Bharati, Sriniketan, West Bengal. The place is situated at $23^0 39'$ N latitude, $87^0 42'$ E longitude and an elevation of 58.9 m above mean sea level. Normally the area receives about 1000 mm rainfall during the *kharif* season (July to October). But there was low rainfall during the crop season of both the years (672 mm in 2010 and 720 mm in 2011). The deficiency in rainfall was 32.2% in 2010 and 27.4% in 2011. The soil of the experimental plot was sandy loam in texture (60.0% sand, 23.2% silt and 16.8% clay), neutral in reaction (pH 6.7) medium in organic carbon (0.63%) and low in available N (193.4 kg ha^{-1}), medium in available P (12.4 kg ha^{-1}) and K (171.0 kg ha^{-1}) status.

The experiment was laid out in Randomized Block Design with three replications in 5×2 m^2 plots with three plant densities (25, 33 and 50 plants m^{-2}) and four fertility levels (F_1=75-37.5-37.5, F_2=100-50-50, F_3=125-62.5-62.5 and F_4=150-75-75 kg ha^{-1} NPK respectively). The hybrid rice PHB 71 and 25P25 were transplanted on July 30, 2010 and July 28, 2011, respectively taking single seedling $hill^{-1}$ at three plant densities (hill spacings of 20×20 cm^2, 20×15 cm^2 and 20×10 cm^2). Both the hybrids mature in 130-135 days during *kharif* season and are suitable for cultivation in both *kharif* and dry seasons under alluvial and lateritic belts of West Bengal. All plots received full dose of P and K and $1/4^{th}$ N fertilizer at basal and remaining N fertilizer in three equal splits-at mid-tillering, panicle initiation and flowering as per treatments. The field was irrigated as and when required. Insects were controlled by chemicals to avoid biomass and yield loss. No fungicide was applied under the study. The weeds were removed manually at 20 and 40 days after transplanting (DAT). Harvesting was done on November 11, 2010 and November 7, 2011.

The observation on plant height was recorded from 10 hills randomly selected in each plot at different stages and their average was worked out. Tiller number from the same hills was also recorded at 45 DAT. Samples for biomass has been collected from 5 hills from ear-marked area in each plot and fresh weights were recorded. The plant samples then separated into stem (leaf sheath+stem), green leaves (lamina) and panicles and kept in separate paper packets which in turn placed in an oven for drying at 65-70^0C 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 (1952). DMA at different stages was used for determining crop growth rate (CGR). Observation on yield parameters like panicle length, number of panicles m^{-2}, number of spikelets and filled grains $panicle^{-1}$, test weight along with grain yield, straw yield and harvest index were recorded at maturity. The economics of hybrid rice was worked out considering the prevailing market price of the inputs and outputs. The data were statistically analyzed applying the techniques of analysis of variance and the significance of different sources of variations were tested by error mean square of Fisher Snedecor's 'F' test at probability level 0.05 (Cochran and Cox, 1977).

3. Results and Discussion

3.1. Growth attributes

Plant height at all the growth stages and tillering increased steadily due to increasing level of fertilizer application during both the years of the study. The tallest plants and highest number of tillers m^{-2} were recorded in both the hybrids receiving 150 kg N, 75 kg P_2O_5 and 75 kg K_2O ha^{-1} (F_4), but was comparable to those of its immediate lower (F_3) level (125 kg N, 62.5 kg P_2O_5 and 62.5 kg K_2O ha^{-1}). Under these treatments significantly taller plants and greater number of tillers m^{-2} were recorded compared to that at low fertility level (F_1). Both the hybrids at low fertility (F_1) level (75 kg N, 37.5 kg P_2O_5 and 37.5 kg K_2O ha^{-1}) produced dwarf plants at all the growth stages and lowest number of tillers m^{-2} among all other fertility treatments in both the years (Table 1). Tiller production did not vary much between the two hybrids, but 25P25 hybrid produced somewhat taller plants than that of PHB 71. It appeared that hybrid rice required high rate of fertilizer application for better growth of the crop as reflected by its tillering and plant height. The results are in conformity with the findings of Peng et al. (2006). Plant density showed significant positive effect on plant height and tiller production in both rice hybrids. Increasing plant density steadily increased plant height at all the growth stages and number of tillers m^{-2} (Table 1). The tallest plants and highest number of tillers (506 tillers m^{-2} in PHB 71 and 468 tillers m^{-2} in 25P25) were produced at high plant density (50 plants m^{-2}) and were significantly greater than that obtained at lower plant densities in both the years. Dwarf plants at different stages and lowest number of tillers (306 tillers m^{-2} in PHB 71 and 304 tillers m^{-2} in 25P25) were recorded in crop at low plant density (25 plants m^{-2}). The tropical hybrids are moderate in tillering and required close spacing to attain optimum number of tillers m^{-2} as compared to the inbred varieties (Siddiq et al., 1996). Fertility level exerted significant effect on LAI, DMA and CGR in both the hybrids at all the growth stages in the respective years of the study. Maximum LAI, DMA and CGR were recorded in crop at high fertility level (F_4); but were comparable to those obtained at its immediate low fertility level (F_3). Both the above fertility levels produced significantly higher values of LAI, DMA and CGR than those recorded at lower fertility levels (F_1 and F_2) in most of the stages during both the years (Tables 2 and 3). Rice hybrids at low fertility (F_1) produced the lowest values of LAI, DMA and CGR as compared to those at all other fertility levels in most of the growth stages. Higher fertility levels (F_4 and F_3) increased DMA by 20 to 52% over low fertility level (F_1) at different stages due to increased CGR. Two hybrids did not respond differently to fertility level in producing LAI, DMA and CGR under the study. Wang et al. (2001) noticed that moderate LAI (5.0) functioning for longer duration was more important than maximum LAI functioning for short period on influencing the crop productivity. In our study, the crop at higher fertility levels (F_4 and F_3) produced LAI around 5.0 at panicle initiation (45 DAT) and maintained it up to flowering (65 DAT). High LAI at higher fertility levels functioning during tillering to flowering resulted in high CGR that caused further increase in DMA during the reproductive period leading high crop productivity (Peng et al., 2002; Huang et al., 2008). The two hybrids responded significantly to plant density on recording LAI, DMA and CGR. The highest values of LAI and DMA was recorded in both the hybrids at the highest plant density (50 plants m^{-2}) and was significantly greater than what obtained at lower plant densities (25 and 33 hills m^{-2}) at all the growth stages during both the years. The highest CGR values in PHB 71 in 2010 was recorded at the highest plant density (50 plants m^{-2}), but were comparable to that of the medium plant density (33 plants m^{-2}) in all the cases. The lowest values of LAI, DMA and CGR of both hybrids were produced by the crop at the low plant density (25 hills m^{-2}) at all the growth stages (Tables 2 and 3). However, 25P25 recorded high CGR at high plant density during 25-45 DAT and at medium plant density during 45-65 DAT in 2011. The CGR of 25P25 during 65-85 DAT did not vary among the plant densities in 2011. The results indicated that tropical rice hybrids required close spacing for higher LAI development that was responsible for greater CGR and DMA than those of wide spacing. The results corroborate the findings of Lin et al. (2009).

3.2. Yield components

Both the rice hybrids responded well to fertility level in improving the yield components. All the yield components like number of panicles m^{-2}, panicle length, number of spikelets and filled grains panicle^{-1} and test weight of both the hybrids increased steadily up to the application F_3 and were comparable to F_4 (Table 4). Both F_3 and F_4 recorded significantly higher number of panicles m^{-2}, longer panicle length, higher number of spikelets and filled grains panicle^{-1}, higher test weight than what obtained at lower fertility levels (F_1 and F_2). The crop at low fertility level (F_1) produced the lowest values of all the yield components, but was comparable to those obtained at F_2 in most of the cases during both the years. The tropical rice hybrids are panicle size (large panicles) and require adequate nutrition for producing higher number of large size panicles (Buresh et al., 2005). Application of lower dose of fertilizer (F_1 and F_2) did not mitigate the nutrient need of the crop

Table 1: Effect of fertility level and plant density on plant height and tillering of hybrid rice

Treatments	Plant height (cm)								Tillers m^{-2}	
Fertility level	2010 (PHB 71)				2011 (25P25)				2010	2011
(NPK kg ha^{-1})	25 DAT	45 DAT	65 DAT	85 DAT	25 DAT	45 DAT	65 DAT	85 DAT		
F_1^*	57.1	79.3	97.4	117.2	64.1	82.1	104.2	122.5	329	318
F_2	61.6	83.4	102.2	122.7	67.5	85.0	108.7	126.4	387	350
F_3	65.8	86.8	105.9	123.2	68.0	86.6	110.3	128.1	431	403
F_4	66.5	88.1	107.0	125.8	69.6	88.1	112.8	131.8	436	430
SEm±	0.9	1.3	1.4	1.6	0.8	1.0	1.4	1.3	12	10
CD (p=0.05)	2.7	3.8	4.1	4.6	2.3	2.9	4.1	3.7	34	30
Plant density (plants m^{-2})										
P_1 (25)	60.1	81.6	100.2	119.1	65.1	83.2	105.4	124.2	306	304
P_2 (33)	63.1	84.9	104.1	123.2	67.5	85.9	109.2	127.8	375	354
P_3 (50)	65.1	86.6	105.1	124.2	69.4	87.3	111.9	129.5	506	468
SEm±	0.8	1.1	1.1	1.4	0.7	0.9	1.2	1.1	10	9
CD (p=0.05)	2.3	3.3	3.5	4.0	2.1	2.6	3.5	3.3	29	26

*F_1=75-16.7-31.3; F_2=100-22.2-41.7; F_3=125-27.8-52.1; F_4=150-33.3-62.5 kg NPK ha^{-1} respectively; P_1=25 plants m^{-2} at 20×20 cm^2; P_2=33 plants m^{-2} at 20×15 cm^2; P_3=50 plants m^{-2} at 20×10 cm^2

Table 2: Effect of fertility level and plant density on leaf area index and dry matter accumulation of hybrid rice

Treatments[$]	Leaf area index (LAI)								Dry matter accumulation (m^{-2})							
	2010 (PHB 71)				2011 (25P25)				2010 (PHB 71)				2011 (25P25)			
	25 DAT	45 DAT	65 DAT	85 DAT	25 DAT	45 DAT	65 DAT	85 DAT	25 DAT	45 DAT	65 DAT	85 DAT	25 DAT	45 DAT	65 DAT	85 DAT
F_1^*	1.61	3.81	3.92	1.11	1.67	3.87	3.85	1.47	128	356	661	847	130	356	587	776
F_2	1.76	4.48	5.08	1.40	1.79	4.78	4.50	1.63	143	402	771	1074	142	395	743	952
F_3	1.96	5.04	5.80	1.52	1.97	5.65	5.19	1.76	157	447	839	1278	153	452	850	1098
F_4	1.98	5.35	6.01	1.59	2.03	6.02	5.45	1.81	158	476	862	1295	160	482	895	1146
SEm±	0.04	0.18	0.20	0.03	0.04	0.16	0.17	0.03	4.4	15.0	21.1	20.0	2.9	12.0	17.8	17.6
CD**	0.10	0.53	0.56	0.10	0.11	0.47	0.50	0.10	12.9	44.1	61.4	59.4	8.7	35.3	52.3	51.7
Plant density (plants m^{-2})																
P_1 (25)	1.11	4.14	4.70	1.29	1.61	4.58	4.35	1.52	112	362	708	1026	120	370	707	929
P_2 (33)	1.83	4.66	5.23	1.41	1.91	5.06	4.88	1.64	140	419	775	1122	137	412	780	993
P_3 (50)	2.54	5.21	5.67	1.52	2.04	5.60	5.39	1.85	188	481	866	1223	183	482	820	1057
SEm±	0.04	0.16	0.13	0.03	0.03	0.15	0.16	0.03	3.8	13.0	18.5	20.5	2.6	10.4	15.5	15.3
CD**	0.12	0.46	0.37	0.10	0.09	0.44	0.46	0.09	11.2	38.2	54.1	60.1	7.5	30.5	45.3	44.8

CD**: CD (p=0.05); $: Fertility level (NPK kg ha^{-1})

Table 3: Effect of fertility level and plant density on crop growth rate (CGR) of hybrid rice

Treatments	Crop Growth Rate (CGR in g m^{-2} day^{-1})					
Fertility level (NPK in kg ha^{-1})	2010 (PHB 71)			2011 (25P25)		
	25-45 DAT	45-65 DAT	65-85 DAT	25-45 DAT	45-65 DAT	65-85 DAT
F_1^*	11.4	15.3	9.3	11.3	11.6	9.5
F_2	13.0	18.5	15.2	12.7	17.4	10.5
F_3	14.5	19.6	22.0	15.0	19.9	12.4
F_4	15.9	19.3	21.7	16.1	20.7	12.6
SEm±	0.49	0.47	0.50	0.55	0.5	0.46
CD (p=0.05)	1.4	1.3	1.4	1.6	1.5	1.37
Plant density (plants m^{-2})						
P_1 (25)	12.5	17.3	15.9	12.5	16.8	11.1
P_2 (33)	14.0	17.8	17.4	13.8	18.4	10.7
P_3 (50)	14.7	19.3	17.9	15.0	16.9	11.9
SEm±	0.45	0.43	0.44	0.51	0.4	0.41
CD (p=0.05)	1.3	1.2	1.3	1.4	1.1	NS

particularly during its reproductive period resulting in lower number of spikelets and filled grains $panicle^{-1}$ with low test weight due to its adverse affect on grain filling of hybrid rice (Hu et al., 2007).

Plant density showed significant effect on all the yield components of hybrid rice during both the years. Only panicle production positively influenced by high plant density (P_3) and it recorded the highest number of panicles m^{-2} (329 in PHB 71 and 389 in 25P25) which was significantly greater than that of other plant densities (P_1 and P_2). The lowest number of panicles m^{-2} (213 in PHB 71 and 208 in 25P25) was obtained with P_1 during both the years. Panicle length, number of spikelets $panicle^{-1}$, number of filled grains $panicle^{-1}$ and test weight decreased markedly by increasing plant density (Table 4). Accordingly the highest values of the above yield parameters were obtained at low plant density (P_1), but were comparable to those of medium plant density (P_2). The shortest panicle length, lowest number of spikelets and filled grains $panicle^{-1}$ and lowest test weight of grain were obtained at high plant density (P_3). However, filled grain percent did not vary much among the different plant densities during both the years. The crop having wide space at low plant density (P_1) developed healthy, strong and long panicles that in turn produced higher number of spikelets and filled grains $panicle^{-1}$ with high test weight (Huang et al., 2008) and (Pramanik et al., 2013).

3.3. *Crop productivity*

The fertility level exerted significant effect on grain yield, straw yield and harvest index (HI) of hybrid rice during both the years. The highest grain yield (6809 kg ha^{-1} of PHB 71 in 2010 and 6850 kg ha^{-1} of 25P25 in 2011) was produced in crop receiving F_3 fertility level (125 kg N, 62.5 kg P_2O^5 and 62.5 kg K_2O ha^{-1}); whereas, the highest straw yield (7561 kg ha^{-1} of PHB 71 in 2010 and 7367 kg ha^{-1} of 25P25 in 2011) was obtained from the crop at high fertility level of 150 kg N, 75 kg P_2O^5 and 75 kg K_2O ha^{-1} (F_4). PHB 71 in 2010 accorded high HI (49.8%) at F_2; but 25P25 in 2011 recorded high HI (49.7%) at F_3. The grain and straw yield did not vary between the above two fertility levels (F_3 and F_4); but both of them

Table 4: Effect of fertility level and plant density on yield components and productivity of hybrid rice

Treatments[$]	No. of panicles m^{-2}		Panicle length (cm)		No. of spikelets $panicle^{-1}$		No. of filled grains $panicle^{-1}$		Test weight (g)		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Harvest index (%)	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
F_1*	249	237	24.9	27.6	111	129	91	111	21.2	23.3	4578	4650	5232	5672	46.7	45.0
F_2	262	272	28.2	28.4	131	144	112	122	22.4	24.3	6057	6008	6103	6337	49.8	48.7
F_3	284	303	30.5	29.9	152	181	139	152	22.5	24.4	6809	6850	7222	6945	48.5	49.7
F_4	282	325	29.6	29.9	148	171	135	146	22.2	24.0	6707	6497	7560	7367	47.0	46.9
SEm±	6.5	9.3	0.46	0.38	1.8	4.0	1.8	4.0	0.24	0.2	130	138	209	183	0.86	0.58
CD**	19.2	27.4	1.4	1.11	5.3	11.9	5.4	11.6	0.7	0.6	379	404	612	538	2.51	1.71
Plant density (plants m^{-2})																
P_1 (25)	213	208	29.8	29.4	146	165	133	143	22.5	24.4	5676	5637	5747	6313	49.7	47.2
P_2 (33)	265	257	28.3	29.2	136	157	121	133	22.1	24.0	6171	6085	6450	6445	48.9	48.6
P_3 (50)	329	389	26.8	28.2	125	147	104	122	21.6	23.6	6267	6281	7393	6983	45.9	47.4
SEm±	5.9	8.1	0.4	0.33	1.5	3.5	1.6	3.4	0.21	0.18	112	119	181	159	0.74	0.5
CD**	17.1	23.7	1.2	0.97	4.6	10.3	4.7	10.1	0.6	0.5	328	349	530	466	2.17	NS

CD**: CD (p=0.05); $: Fertility level (NPK kg ha^{-1}); A: PHB71 (2010); B: 25P25 (2011)

recorded significantly higher grain and straw yield than those obtained at the lower fertility levels (F_1 and F_2). Similarly HI did not differ significantly between F_2 and F_3; but both of them had higher HI than high (F_4) and low (F_1) fertility levels. High crop productivity at F_3 and F_4 was mainly responsible for better growth of the crop at greater LAI functioning over critical periods of spikelet formation and grain filling at adequate fertility level (Peng et al., 2006; Huang et al., 2008). The crop at low fertility level (F_1) produced the lowest grain (4578 kg ha^{-1} of PHB 71 in 2010 and 4650 kg ha^{-1} of 25P25 in 2011) and straw yields (5232 kg ha^{-1} of PHB 71 in 2010 and 5672 kg ha^{-1} of 25P25 in 2011) which were significantly lower than those obtained at other fertility levels (Table 4). The grain yield increased by 30.8% and 48.0% due to application of F_2 and F_3 over F_1 and straw yield increased by 5.4, 20.1 and 37.2% by increasing fertility level of F_2, F_3 and F_4 over F_1. Both high (F_4) and low fertility (F_1) levels accorded low HI during both the years because the crop at F_1 showed poor growth and yield and at F_4 produced grain and straw yield in a similar trend, thus nullified its effect on HI. Over all hybrid rice took longer period (40 days or more) for grain filling and thus produced 25-30% higher grain yield than any high yielding variety. The results are in conformity with the findings of Krishnakumar et al. (2005), Pattanayak et al. (2008) and Lin et al. (2009). Plant density played an important role in regulating the grain and straw yield of hybrid rice. The highest grain yield (6267 kg ha^{-1} of PHB 71 in 2010 and 6281 kg ha^{-1} of 25P25 in 2011) was recorded in crop grown at high density (P_3) and was closely followed by the crop raised at medium (P_2) density (6171 kg ha^{-1} of PHB 71 in 2010 and 6085 kg ha^{-1} of 25P25 in 2011) Both high and medium density crop produced significantly higher grain yield than that obtained (5676 and 5637 kg ha^{-1} in respective years at low density (P_1). The straw yield increased steadily and significantly up to the highest plant density (7393 and 6983 kg ha^{-1} in 2010 and 2011 respectively) which was significantly superior to that obtained at other plant densities (P_1 and P_2). The lowest grain and straw yields were obtained from the crop at P_1. It decreased grain yield by 9.8 and 7.7% and straw yield by 15.9 and 6.5% when compared with those of P_3 and P_2 respectively (Table 4). The results suggested that tropical hybrid rice be planted relatively at closer spacing (P_2) to have adequate number of panicles m^{-2} necessary for obtaining high grain yield. The results corroborate the findings of Jayawardena and Abeysekera (2005). But, Lin et al. (2009) noticed that wide spacing was favourable for increasing growth and productivity of temperate rice in China because of long vegetative growth period of temperate hybrids as compared to the tropical hybrids. HI showed significant response to plant density in 2010; but in 2011, it did not vary significantly among the plant densities. The highest value of HI (49.7%) was obtained from PHB 71 in 2010 at P_1 which was closely followed by P_2 (48.9%). Both P_1 and P_2 accorded significantly higher HI than what obtained at P_3 (45.9%). The results indicate that rice hybrids at high density become less efficient in partitioning photosynthate in to the reproductive organs.

3.4. Economics

Fertility levels exerted significant effect on economics of hybrid rice production. The gross return, net return and return $rupee^{-1}$ invested increased steadily up to F_3 fertility level and maximum gross return (₹ 75527 ha^{-1} in 2010 and ₹ 73709 ha^{-1} in 2011), net return (₹ 47598 ha^{-1} in 2010 and ₹ 44398 ha^{-1} in

2011) and return rupee^{-1} invested (2.70 and 2.51) were obtained at this fertility level (F_3) during both the years and were closely followed by the crop at high fertility level (F_4) in 2010 when, both F_3 and F_4 fertility levels paid significantly higher gross return, net return and return rupee^{-1} invested than those recorded at F_1 and F_2 fertility levels (Table 5). But in 2011, the economic parameters of F_2 were comparable to those of F_4. The crop at low fertility (F_1) paid the lowest gross return (₹ 47877 ha^{-1} in 2010 and ₹ 53254 in 2011), net return (₹ 23598 ha^{-1} in 2010 and ₹ 25745 in 2011) and return rupee^{-1} invested (1.97 and 1.94 in 2010 and 2011 respectively). The study indicated the need of adequate nutrition of hybrid rice for greater productivity and higher profit (Jin et al., 2002; Krishnakumar et al*.,* 2005).

The hybrid rice responded well to plant density in respect of its economics. High plant density (P_3) paid the highest gross (₹ 69458 ha^{-1} in 2010 and ₹ 68049 ha^{-1} in 2011) and net return (₹ 41961 ha^{-1} in 2010 and ₹ 38605 ha^{-1} in 2011) from hybrid rice (Table 5) and were closely followed by the crop at medium plant density (P_2). Both P_2 and P_3 recorded significantly greater gross and net returns than those at low plant density (P_1). The low plant density registered the lowest gross (₹ 61025 ha^{-1} in 2010 and ₹ 61110 ha^{-1} in 2011) and net returns (₹ 35168 ha^{-1} in 2010 and ₹ 32816 ha^{-1} in 2011). Return rupee^{-1} invested, however, did not vary much among the plant densities during both the years. The results suggest the need of planting hybrid rice at a relatively higher plant density (Wang et al., 2001).

3.5. Interaction effect

Plant density and fertility exerted significant interaction effect on different growth attributes, yield components, yield and economics of hybrid rice. As both the varieties responded more or less similarly to fertility and plant density, the interaction effects were estimated on average value of the two varieties grown in different years. Tillering, LAI at 65 and 85 DAT, DMA at 65 and 85 DAT and CGR during the period of 65-85 DAT of hybrid rice were markedly influenced due to interaction of plant density and fertility (Table 6). The high tillering, LAI values at 65 and 85 DAT, DMA at 65 and 85 DAT and CGR between 65-85 DAT were recorded in crop at high plant density receiving high fertility level (P_3F_4); but were comparable to those of the crop at P_2F_3, P_2F_4 and P_3F_3 combinations in most of the cases. These plant density and fertility combinations recorded much higher values of the above growth variables than what obtained with other combinations. The crop at low plant density with low fertility level (P_1F_1) produced the lowest values of all the above growth attributes which were significantly lower than those obtained at higher plant densities and fertility levels. Higher levels plant density and fertility were conducive for exploiting early vegetative growth by triggering tillering and LAI that helped in improving the growth of hybrid rice at later stages (Peng et al., 2006).

Panicle production, grain filling, yield and economics of hybrid rice were responded well to the interaction between plant density and fertility level. Except filled grains panicle^{-1}, all other parameters were increased by increasing the level of plant density and fertility. The highest number of filled grains panicle^{-1} was recorded in crop grown at low plant density (P_1) receiving F_3 fertility and were closely followed by of the crop at P_1F_4, P_2F_3 and P_2F_4 combinations. The Crop at higher level of plant density and fertility showed significant reduction in number of filled grains panicle^{-1}. This might be due to wide spacing at low plant density provided better scope of healthy panicles for greater grain filling (Bera and Pramanik, 2013). The number of panicles m^{-2}, grain yield, straw yield and gross and net returns from hybrid rice were increased greatly due to increasing levels of fertility and plant density combinations. Low plant density at with low fertility level (F_1P_1) produced the lowest number of panicles m^{-2}.

Fertility level and plant density recorded significant interaction effect on grain and straw yield. The highest grain yield (7039 kg ha^{-1}) was recorded in crop having 125 kg N, 62.5 kg P_2O_5 and 62.5 kg K_2O ha^{-1} at medium plant density (F_3P_2) and was closely followed by the crop at the same or higher fertility level with other plant densities. But the highest straw yield (8740 kg ha^{-1}) was recorded in crop receiving 150 kg N, 75 kg P_2O_5 and 75 kg K_2O ha^{-1} at high plant density (F_4P_3) and was closely followed by of the crop having 125 kg N, 62.5 kg P_2O_5 and 62.5 kg K_2O ha^{-1} at high plant density (F_3P_3). The lowest grain (4111 kg ha^{-1}) and straw (4656 kg ha^{-1}) yields were obtained from the crop grown with low fertility level at low plant density. The results advocate to plant hybrid rice at medium plant density (33 hills m^{-2}) with 125 kg N, 62.5 kg P_2O_5 and 62.5 kg K_2O ha^{-1} (F_3P_2) for producing high grain yield during *kharif* season under lateritic belt of West Bengal. The results corroborate the findings of Bera and Pramanik (2013).

The fertility and plant density had significant interaction effect on gross and net returns from hybrid rice cultivation. The highest gross (₹ 87970 ha^{-1}) and net returns (₹ 59695 ha^{-1}) were paid by the crop at medium plant density (33 hills m^{-2}) receiving 125 kg N, 62.5 kg P_2O_5 and 62.5 kg K_2O ha^{-1} (F_3P_2) and was followed by the crop at the high plant density (50 hills m^{-2}) with same fertility level and/or by the crop at medium or high plant densities with high fertility level (150 kg N, 75 kg P_2O_5 and 75 kg K_2O ha^{-1}); but was significantly superior to all other combinations of fertility and plant densities. The lowest gross (₹ 51934 ha^{-1}) and net returns (₹ 28705 ha^{-1}) were paid by the crop with low fertility level (75 kg N, 37.5 kg P_2O_5 and 37.5 kg K_2O ha^{-1}) at low plant density (F_1P_1) and was markedly lower than those recorded at all other fertility and plant density combinations. The combination of medium fertility level and plant density (F_3P_2) was found suitable for increasing productivity and profitability of hybrid rice under West Bengal situation.

Table 5: Effect of fertility level and plant density on economics of hybrid rice production

Fertility level (NPK kg ha^{-1})	2010 (PHB 71) Cultivation cost (₹ ha^{-1})	Gross* return (₹ ha^{-1})	Net return (₹ ha^{-1})	Return ₹$^{-1}$ invested	2011 (25P25) Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	Return ₹$^{-1}$ invested
F_1	24279	47877	23598	1.97	27509	53254	25745	1.94
F_2	26466	65764	39298	2.48	28410	64911	36501	2.28
F_3	27929	75527	47598	2.70	29311	73709	44398	2.51
F_4	28535	74696	46161	2.62	30211	67923	37712	2.25
SEm±		924	862	0.061		1191	801	0.060
CD (p=0.05)		2709	2527	0.19		3493	2350	0.18
Plant density (plants m^{-2})								
P_1 (25)	25857	61025	35168	2.36	28294	61110	32816	2.16
P_2 (33)	27052	67414	40362	2.49	28844	65688	36844	2.28
P_3 (50)	27498	69458	41960	2.53	29444	68049	38605	2.31
SEm±		800	746	0.06		1031	694	0.052
CD (p=0.05)		2346	2189	NS		3025	2035	NS

*Based on cost of inputs N: ₹ 16 kg^{-1}; P: ₹ 37 kg^{-1}; K: ₹ 10 kg^{-1}; FYM: ₹ 1000 t^{-1}; Seed: ₹ 200 kg^{-1}; Labour: ₹ 100 manday^{-1}; Puddling: ₹ 600 ha^{-1}; Irrigation: ₹ 800 ha^{-1}; Plant protection: ₹ 500 ha^{-1}; Price of grain: ₹ 11500 t^{-1}; Price of straw: ₹ 1000 t^{-1}

Table 6: Interaction effect of fertility level and plant density on tillering, LAI, DMA, CGR, panicle production, grain filling, crop productivity, and economics of hybrid rice (average data of 2 years)

Treatments	Tillers m^{-2}			LAI at 65 DAT			LAI at 85 DAT		
	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
F_1*	252	305	414	3.41	3.76	4.51	1.20	1.29	1.39
F_2	290	337	480	4.22	4.89	5.27	1.46	1.54	1.57
F_3	329	401	521	4.91	5.45	6.15	1.62	1.57	1.75
F_4	350	416	532	5.34	5.88	5.96	1.34	1.72	2.07
CD (p=0.05)		54			0.65			0.18	
	DMA (g m^{-2}) at 65 DAT			DMA (g m^{-2}) at 85 DAT			CGR (g m^{-2} day^{-1}) at 65-85 DAT		
F_1	573	622	677	752	826	857	8.1	10.2	9.9
F_2	664	786	821	921	1021	1097	12.7	12.0	13.8
F_3	785	823	925	1110	1174	1281	16.1	17.6	17.9
F_4	807	880	949	1127	1210	1326	16.6	17.0	17.9
CD (p=0.05)		118.0			150.0			4.5	
	Panicles m^{-2}			Grains panicle^{-1}			Grain yield (kg ha^{-1})		
F_1	178.8	214.7	336.9	114	102	87	4297	4650	4894
F_2	197.1	260.6	345.6	133	117	100	5611	6074	6414
F_3	229.9	275.2	375.8	157	149	128	6397	6986	7105
F_4	236.3	294.0	378.5	148	140	134	6322	6803	6682
CD (p=0.05)		30			15.0			657	
	Straw yield (kg ha^{-1})			Gross return (₹ ha^{-1})			Net return (₹ ha^{-1})		
F_1	5134	5567	5656	48512	50155	53030	21256	25620	27138
F_2	5829	6135	6698	60555	66223	69235	34500	38905	40293
F_3	6409	6857	7986	69564	76236	78054	42245	46933	48815
F_4	6749	7232	8413	65641	73591	74696	37968	42955	44886
CD (p=0.05)		1060			5370			4224	

4. Conclusion

The results of this investigation indicates that hybrid rice needs to be planted at moderate plant density with relatively higher fertility level for better growth (higher number of tillers m^{-2}, high LAI acted over the period of grain filling and greater DMA) that are responsible for producing high crop yield with greater profit. The results advocate that hybrid rice be planted at medium plant density with medium fertility ($P_2 \times F_3$) for higher yield with greater profit during *kharif* season.

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