PRODUCTION POTENTIAL OF HYBRID RICE (*Oryza sativa* L.) IN LOWLAND ECOSYSTEM

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by

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KERALA, INDIA

2012

DECLARATION

I hereby declare that this thesis entitled **"Production potential of hybrid rice (*Oryza sativa* L.) in lowland ecosystem"** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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Dedicated to my beloved parents, my sister and to my dearest teacher

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

%	-	per cent
@	-	at the rate of
^{0}C	-	Degree celsius
B : C	-	Benefit cost ratio
CD	-	Critical difference
cm	-	centimetre
DAT	-	Days after transplanting
DMP	-	Dry matter production
et al.	-	and co-workers
FYM	-	Farmyard manure
g $hill^{-1}$	-	gram per hill
g	-	gram
ha^{-1}	-	per hectare
i.e.	-	that is
K	-	Potassium
kg	-	kilogram

kg ha^{-1}	-	kilogram per hectare
KAU	-	Kerala Agricultural University
LAI	-	Leaf area index
m	-	metre
MOP	-	Muriate of potash
MT	-	Maximum tillering
N	-	Nitrogen
nos.	-	Numbers
NS	-	Not significant
P	-	Phosphorus
PI	-	Panicle initiation
POP	-	Package of practices
RBD	-	Randomized block design
Rs.	-	Rupees
t ha^{-1}	-	tonnes per hectare
viz.	-	namely

Introduction

1. INTRODUCTION

Rice (*Oryza sativa* L.), the first ever commodity to acquire a year designated as "International" in its honour, is the most important cereal crop of the developing world. Over the last half century, rice has been the source for approximately 18 to 20 per cent of the world's human caloric consumption. More specifically, it is considered as the main food, staple for more than 50 per cent of the world's population (Childs, 2004). Because of the importance of rice for supplying food, there is a demand for higher grain yield per hectare. It has been suggested that by 2025, global rice production must increase by more than 50 per cent from mid – 1990 levels to meet the demand (Subbaiah, 2010). Further, considering the natural resource constraints, much of this increase has to come from increased yields (Smith *et al.*, 2007).

India has the largest area under rice cultivation, as it is one of the principal food crops and consequently one of the leading producers of this crop. In 2011-'12, the total rice production in India was 104.32 million tonnes (FAO, 2011). Further, the projection of India's rice production target for 2025 A.D. is 140 million tonnes, which can be achieved only by increasing the productivity to at least 3.2 t ha-1 from the present level of 3.0 t ha-1. However, it appears that we have exhausted the potential of the 'green revolution' strategies, as we witness declining rice productivity. In the next three decades, farmers need new approaches and technologies to produce fifty to sixty per cent more rice, on existing or less land and water with limiting and /or expensive inputs.

In Kerala, despite considerable investment and special attention given to rice, the fact remains that the area and production of the crop continues to decline. According to FIB (2012) the rice area of the State has drastically declined from 4.71 lakh ha (1995 -'96) to 2.34 lakh ha (2009 -'10) with the production declining from 9.53 lakh tonnes to 5.98 lakh tonnes.

Since the yield of high yielding varieties of rice is plateauing, it is rather difficult to achieve this target with the present day inbred varieties. Therefore to sustain self sufficiency in rice, additional production of 1.5 million tonnes is needed every year. Among the limited options, hybrid rice is the only proven technology currently available for stepping up the rice production significantly. Further, hybrid rice technology has been identified as one of the alternative means to meet the challenge of food security for the increasing population (Islam *et al.*, 2009).

Chinese rice scientists were the first to develop and use commercial rice hybrids, which increased the rice yield by about 20 per cent over the popular semi - dwarf varieties (Yuan *et al.*, 1994). The first rice hybrid was released in 1976. Hybrid rice can give 10-15 per cent yield advantage over modern inbred varieties through vigorous growth, extensive root system, efficient and greater sink size, higher carbohydrate translocation from vegetative parts to spikelets and larger leaf area index during the grain filling stage (Peng *et al.*, 1998). However, the physiological basis for heterosis remains unknown.

The first generation progeny (F_1) obtained by crossing two genetically different varieties (parents) is called 'hybrid'. The cytoplasmic male sterile (CMS) line used as the female parent is called the 'A' line. The fertility restoring line which is called 'pollinator' is the male parent. It is generally referred to as 'R' line. The hybrid combines the desirable characters from CMS line and R line. The harvested grains from hybrid crop should not be used for planting the next crop. This makes the hybrid rice seed very costly.

As a result of concerted, goal-oriented, time bound and co-ordinated efforts of the rice scientists of India, 43 rice hybrids have been released, including 15 private sector hybrids. Among the 28 public sector hybrids, Karnataka Rice Hybrid - 2 (KRH-2) was developed by University of Agricultural Sciences, Bengaluru, and released for Karnataka during 1996 and for the country during 2002. It has been reported to be one of the best rice hybrids of the country, suitable for majority of rice growing states of the country. This hybrid variety has been claimed to yield on an average 10t ha-1 (Siddiq, 1993).

It is about two decades now since hybrids were developed and released for commercial cultivation in India in 1994. During the first decade, adoption of hybrid rice has been much slower than expected, mainly because of lower grain quality and consequently lower market price for the produce. It has picked up since 2004, mainly because of increasing popularity and profitability of hybrid rice among the rice farmers. During 2008, hybrids were grown in an area of around 1.4 million hectares (3 per cent of total rice area). It is expected that by 2015, hybrids may be cultivated in India in an approximate area of 4.0 million hectares.

The success of hybrid rice cultivation depends on the exploitation of the full heterotic potential of the hybrids with improved package of practices such as suitable genotype, optimum plant population and optimum nutrition. The cost of hybrid rice seeds is very high and need to be replaced every season. Thus it is very essential to reduce the cost on seeds by optimizing the seed rate through appropriate adjustment in seedling density and planting geometry. This would definitely help a long way in popularizing the cultivation of hybrid rice in India and Kerala.

Keeping in view the above facts, the present investigation was undertaken to evaluate the production potential of hybrid rice (*Oryza sativa* L.) in lowland ecosystem. The main objectives of the study were as follows:

- To assess the production potential of hybrid rice in lowland ecosystem.
- To quantify its nutritional requirement in relation to plant spacing and seedling density.
- To work out the economics of hybrid rice production as against a conventional inbred.

Review of Literature

2. REVIEW OF LITERATURE

Hybrid technology is one of the feasible approaches to break the yield plateau in rice. Yield increase in hybrid rice varieties developed so far, has been primarily due to an increase in their physiological efficiency. The hybrid rice approach facilitates to combine the improved plant type with increased physiological efficiency to increase productivity. However, the hybrid rice production technology needs to be streamlined with reference to genotype, spacing, seedling density, nutritional requirements and quality. Keeping this in view an experiment was undertaken to assess the production potential of hybrid rice in the lowland in comparison with a popular inbred. The research work done on these aspects is reviewed in this chapter. Wherever, the available literature is limited with special reference to hybrid rice, relevant literature on inbreds were also reviewed.

2.1 EFFECT OF SPACING ON RICE

Spacing is one of the important factors in planting pattern design. Proper plant spacing helps in getting maximum benefit cost ratio from the rice field.

2.1.1 Effect of Spacing on Growth Characters

Research conducted by Raju *et al.* (1984) on the effect of spacing on dry matter production, revealed that dry matter production per plant decreased at closer spacing. Studies conducted by Reddy and Reddy (1986) showed that plant height was more under closer spacing of 10cm x 10cm than under wider spacing. Budhar *et al.* (1989) observed that the leaf area index increased with plant density. While the leaf area index at a plant density of 500 plants per square metre was 7.4 at flowering stage, it was only 3.6 at 200 plants per square metre. Higher plant population per unit area resulted in higher dry matter production (Kabayashi *et al.*, 1989).

The studies conducted in rice cv. Bhavani, by Srinivasan (1990) showed that the dry matter accumulation per clump was significantly higher at a closer spacing of 15cm x 10cm than at a wider spacing of 20cm x 10cm and 25cm x 10cm. The production of more number of leaves per unit area was highlighted as the reason for higher leaf area index under closer spacing by Balasubramaniyan and Palaniappan (1991). Cai *et al.* (1991) concluded that closer spacing resulted in higher leaf area index at booting stage than wider spacing. Results of experiments conducted at the Directorate of Rice Research, Hyderabad revealed that rice planted at a closer spacing of 15cm x 15cm produced more number of tillers per square metre and leaf area index than the crop planted at wider spacing (DRR, 1991). Miller (1991) also observed that the number of tillers per square metre increased with increasing the plant population in rice. Rice cv. K39 was observed to attain maximum height and tiller count when planted at closer spacing of 10cm x 10cm and minimum plant height at 20cm x 20cm (Shah *et al.*, 1991). Kanungo and Roul (1994) also reported similar effects for spacing in rice. Dry matter production was maximum at a closer spacing of 10cm x 10cm as against wider spacing of 20cm x 10cm and 20cm x 20cm (Dhal and Mishra, 1994). An experiment conducted by Om *et al.* (1998) showed that rice cv. Basmati 370 planted at closer spacing of 15cm x 15cm recorded maximum plant height than that at wider spacing of 22.5cm x 15cm and 30cm x 15cm. In a study conducted by Padmaja and Reddy (1998) with hybrid rice, APHR-2, it was seen that the crop transplanted at a closer spacing of 15cm x 15cm produced significantly higher dry matter than that planted at a comparatively wider spacing of 20cm x 15cm, at all the growth stages.

Hybrid rice has higher seedling dry matter content thicker leaves, larger leaf area and longer root system (BRRI, 2000). Geethadevi *et al.* (2000) observed that hybrid rice attained maximum plant height in crop planted at a spacing of 20cm x 10cm than that at 15cm x 10cm. Sultan and Kaleem (2006) observed an increase in plant height and dry matter production of hybrid rice at wider spacings of 20cm x

15cm and 20cm x 20cm. The results of the field study conducted by Jayawardena and Abeysekera (2002) concluded that spacing wider than that recommended for inbreds, increased the dry matter accumulation in hybrid rice. Obulamma and Reddeppa (2002) observed that rice hybrids, DRRH-1 and APHR-2 showed higher dry matter production and leaf area index at a spacing of 15cm x 10cm than those at 20cm x 10cm, 15cm x 15cm and 20cm x 15cm. The field trial conducted at Bhubaneshwar on hybrid rice, PA 6201 revealed that wider spacing of 20cm x 15cm recorded the maximum plant height, tiller count and dry matter accumulation per clump that those at closer spacing of 20cm x 10cm and 15cm x 15cm (Nayak *et al.*, 2003). Shivay and Singh (2003) and Zhang *et al.* (2004) could not observe any significant effect for planting geometry on plant height at the harvesting stage. Lin *et al.* (2009) observed that the leaf area index of hybrid rice at flowering stage increased significantly when planted at a wider spacing. Zhu *et al.* (2010) reported that with wider spacing, most of the roots of hybrid rice got distributed in the top layer and the roots became shallower.

Plant height, number of tillers per hill, number of leaves per hill and dry matter accumulation was found to be higher at closer spacing as suggested by different workers, while leaf area index was observed to be higher at wider spacing during the panicle initiation stage. Plant height and dry matter production was more at wider spacing in hybrid rice than that of inbreds as suggested by Jayawardena and Abeysekera (2002) and Sultan and Kaleem (2006).

2.1.2 Effect of Spacing on Yield attributes and Yield

Hybrid rice IR 54752 A gave the highest yield (stubble crop 6.9 t ha^{-1}), mainly due to more total and filled spikelets plus more panicles per unit land area (Mahadevappa *et al.*, 1989). Studies conducted by Srinivasan (1990) revealed that raising rice cv. Bhavani at a closer spacing of 15cm x 10cm resulted in higher number of productive tillers per square metre, than wider spacing of 20cm x 10cm and 25cm x 10cm. Srivastav and Tripathi (1998) carried out a trial with the hybrid rice variety PA 6201 and observed that the number of fertile grains per panicle was higher at closer spacing of 15cm x 10cm than that at 20cm x 15cm. Samdhia (1996) in an experiment with rice hybrid PA 6201 observed significantly higher harvest index (0.42) at wider spacing of 20cm x 15cm. Hybrid DRRH-1 planted at 15cm x 10cm spacing recorded the highest spikelet sterility percentage (28.8 per cent) and the least was observed in APHR-2 at 20cm x 15 cm spacing (20.6 per cent) as reported by Obulamma *et al.* (2004). Padmaja and Reddy (1998) observed significantly more number of panicles per square metre in hybrid rice APHR-2 planted at 15cm x 15cm spacing than the crop at 20cm x 15cm. Higher number of filled grains per panicle, test weight, lower spikelet sterility percentage were obtained at a wider spacing of 20cm x 15cm (Padmavathi *et al.*, 1998; Obulamma *et al.*, 2004).

System of Rice Intensification (SRI) recommend wider spacing 25cm x 25cm to 30cm x 30cm for higher yields (Batuwitage, 2000). Experiments conducted at Odisha showed significantly more number of productive tillers per hill (8.95) in hybrid rice planted with 20cm x 10cm spacing than the crop at 15cm x 10cm (7.41) and 10cm x 10cm (6.15) spacing (Patra and Nayak, 2001). The number of filled grains per panicle increased significantly with the increase in spacing up to 25cm x 25cm (Jayawardena and Abeysekera, 2002). Sultan and Kaleem (2006) reported that spacing had no effect on number of filled grains per panicle. Obulamma and Reddeppa (2002) recorded more number of productive tillers per square metre at 15cm x 10cm spacing for the rice hybrids, DRRH-1 and APHR-2 as compared to the other spacings (20cm x 10cm, 15cm x 15cm, 20cm x 15cm) tried. Verma *et al.* (2002) and Nayak *et al.* (2003) who studied the effect of spacing on rice hybrid PA 6201, found that the crop planted at 20cm x 20cm and 20cm x 15cm produced significantly more number of productive tillers per square metre, than that at 20cm x 10cm. Shinde *et al.* (2005) studied the response of hybrid rice Sahyadri at different spacings and concluded that wider spacing of 30cm produced significantly higher number of panicle per square metre (292), length of panicle (25.78 cm) and thousand grain weight (26.94g) than those at a closer spacing of 25cm. Panicle length, number of grains per panicle and harvest index were significantly higher at wider spacing of 20cm x 20cm than those at a closer spacing 0f 15cm x 15cm (Bozorgi *et al.*, 2011). Similar results were observed by Awan *et al.* (2011) at a spacing of 22.5cm x 22.5cm.

Significantly higher grain yield was recorded with a spacing of 20cm x 10cm over 15cm x 15cm and 20cm x 15cm which was on a par with 15cm x 10cm (Reddy and Reddy, 1994). Pandey and Tripathi (1995) reported that a closer spacing of 15cm x 10cm resulted in more grain yield than wider spacing of 20cm x 10cm. Padmaja and Reddy (1998) conducted a field trial on hybrid rice APHR-2 and recorded significantly higher grain yield at 20cm x 15cm.

Geethadevi *et al.* (2000) observed maximum grain yield for hybrid rice at 20cm x 10cm than at 15cm x 10cm. Powar and Deshpande (2001) found that the rice hybrid, Sahyadri recorded significantly more grain (6.3 t ha^{-1}) and straw yield (16.2 t ha^{-1}) at closer spacing of 20cm x 10cm than wider spacing of 20cm x 16cm and 20cm x 20cm. Jayawardena and Abeysekera (2002) suggested the possibility of adopting wider spacing in hybrid rice, through their experiment in which higher grain yields were obtained at wider spacing of 20cm x 15cm and 20cm x 20cm. Rajesh and Thanunathan (2003) reported that hybrid rice planted with wider spacing of 20cm x 15cm recorded significantly higher grain yield as compared to a crop planted with closer spacing of 20cm x 10cm and 15cm x 15cm. Higher grain yield and straw yield of rice was recorded by Obulamma *et al.* (2004) at 20cm x 10cm as compared to 15cm x 10cm in rice. Shinde *et al.* (2005) studied the response of hybrid rice Sahyadri at different spacings and concluded that wider spacing of 30cm produced significantly higher grain yield (9.53 t ha^{-1}) and straw yield (12.79 t ha^{-1}). In a study conducted by Awan *et al.* (2011) grain yield of rice was maximum at 22.5cm x 22.5cm.

In general the number of fertile grains per panicle was higher at closest spacing than at wider spacing, while the number of filled grains per panicle, panicle length, test weight, harvest index, grain yield and straw yield were found to be higher at wider spacing as suggested by different scientists.

2.2 EFFECT OF SEEDLING DENSITY ON RICE

The number of seedlings per hill plays an important role in boosting the yield of rice crop. The number of seedlings per hill assumes paramount importance for successful rice production, because it affects tiller formation, solar radiation interception, nutrient uptake, rate of photosynthesis and ultimately the growth and development of the rice plant. The optimum density of plant population per unit area helps in obtaining maximum yields. Optimum plant density also helps in reducing the cost of hybrid seed.

2.2.1 Effect of Seedling Density on Growth Characters

According to Cai *et al.* (1991), tiller number increased with increasing seedling density from one to three per hill. Chaudhury (1991) conducted a field trial at Bhubaneswar and found significantly maximum leaf area index (9.95) with six seedlings per hill followed by four seedlings per hill at 80 days after transplanting. However, six seedlings per hill recorded significantly more dry matter accumulation over two and four seedlings per hill at 20 DAT, 60 DAT and harvesting stages.

Mishra (1992) reported maximum leaf area index (7.37) at flowering stage with one seedling per hill. Gupta (1996) found that transplanting one seedling per hill significantly increased plant height, than higher number of seedlings per hill.

Srinivasulu (1999) conducted a field experiment with two hybrids APHR-1 and APHR-2 and one cv. Chaitanya at Bapatla and concluded that the crop transplanted with two seedlings per hill produced significantly higher tillers per square metre than the crop transplanted with one seedling per hill. A field experiment was conducted by Srivastav and Tripathi (1998) at Raipur with rice hybrid PA 6201 and cv. R 320-300 and revealed that crop transplanted with two seedlings per hill recorded significantly more effective tillers per square metre (316) as compared to that with one (308) and three seedlings per hill (309). Jati (1999) worked on rice hybrids PA 6201and NPH 4507 and observed that number of seedlings per hill significantly influenced leaf area index at all growth stages. Two seedlings per hill recorded significantly higher leaf area index than one seedling per hill. The results of field trial conducted at Bapatla with rice hybrids APHR-1, APHR-2 and cv. Chaitanya and revealed that leaf area index was not affected significantly by seedling density (Srinivasulu,1999).

Shrirame *et al.* (2000) observed that plant height and leaf area index were not affected significantly by seedling density. Dongarwar *et al.* (2002) studied the response of seedling density on hybrid rice Sahyadri and observed that transplanting one seedling per hill was at par with transplanting of two seedlings per hill with respect to plant height and tillers per square metre. Obulamma and Reddeppa (2002) concluded that planting of three seedlings per hill gave more dry mater production and leaf area index in hybrid rice APRH-2 than the planting of one and two seedlings per hill. Verma *et al.* (2002) observed that in hybrid rice PA 6201 plant height was significantly more when planted with one seedling per hill than two seedlings per hill. Pariyani and Naik (2004) did not observe significant difference in the plant height of rice hybrids PA 6201 and PAC 801, between planting at one seedling per hill and two seedlings per hill.

The review of seedling density from experiments conducted by different scientists revealed that while plant height was more at one seedling per hill than two seedlings per hill, the other growth attributes like leaf area index and number of tillers were higher at two seedlings per hill. Dry matter accumulation, in general, increased with the number of seedlings per hill.

2.2.2 Effect of Seedling Density on Yield attributes and Yield

Zhang and Hung (1990) reported significant decrease in number of panicles per plant, length of panicle, fertile spikelets per panicle and thousand grain weight in rice when the seedling density per hill was increased from two to five. Chaudhury (1991) recorded significantly higher panicle length (28.98 cm) and number of fertile grains (90.77) with planting of two seedlings per hill as compared to planting of four and six seedlings per hill, in cv. Rambha. Gupta (1996) noticed that rice crop planted with four seedlings per hill recorded significantly higher length of panicle, grains per panicle, thousand grain weight and grain yield over two and six seedlings per hill. The results of field trials conducted at Faizabad, Varanasi and Kaul during *Kharif* 1995, revealed that there was no appreciable difference in grain yield between seedling densities of one and two seedlings per hill (DRR, 1995). Three seedlings per hill recorded significantly higher spikelet sterility percentage than two and one seedling per hill (Reddy and Bharathi, 1997). Srinivasulu (1999) observed equal number of filled grains per panicle (116) in rice hybrids APHR-1, APHR-2 and cv. Chaitanya, raised with one and two seedlings per hill. However, a seedling density of one seedling per hill resulted in higher test weight (21.39 g). Experiment conducted at CRRI, Cuttack with hybrid rice VRH 2 revealed that there was no significant difference in grain yield due to transplanting of one to three seedlings per hill (CRRI, 1997). Number of filled grains per panicle was significantly higher with one seedling per hill (114) than two (110) and three (105) seedlings per hill as reported by Rudrapadhya *et al.* (1998). Jati (1999) reported that number of seedlings per hill had no significant effect on panicle length and harvest index in rice hybrids, PA 6201 and NPH 4507. However, one seedling per hill recorded more panicle length (32.2 cm) and harvest index (0.44) than two seedlings per hill.

Rajarathinam and Balasubramaniyan (1999) worked on hybrid rice CORH 2 at Madurai, Tamil Nadu and found that one or two seedlings per hill did not affect grain yield significantly. Shrirame *et al.* (2000) reported that two seedlings per hill gave significantly higher grain and straw yield than one and three seedlings per hill. However, one seedling per hill gave significantly higher harvest index than two and three seedlings per hill. Molla (2001) conducted an experiment at West Bengal and observed that two seedlings per hill produced significantly more number of panicles per square metre and grain yield as compared to one seedling per hill with rice hybrids PA 6201 and CNRH-3. The field trial conducted by Obulamma and Reddeppa (2002) on rice hybrids DRRH-1 and APHR-2 in Andhra Pradesh, revealed that the crop planted with one seedling per hill recorded significantly more grain yield than that planted with two and three seedlings per hill. Dongarwar *et al.* (2002) carried out a field investigation at Agricultural Research Station, Bhandara on rice hybrid Sahyadri and noticed that panicle length, thousand grain weight, grain and straw yields did not differ significantly between one and two seedlings per hill. However, planting at one seedling per hill recorded numerically higher values for these yield attributes and yield. Rao and Moorthy (2003) reported from Cuttack, that planting of one seedling per hill was advantageous as compared to two seedlings per hill in terms of grain yield. A field trial was conducted by Pariyani and Naik (2004) at Jabalpur on rice hybrids PA 6201, PHB 71 and PAC 801 and they reported that planting of one or two seedlings per hill did not show significant variation in yield attributes and yield.

Lin *et al.* (2009) and Bozorgi *et al.* (2011) observed the highest number of grains per panicle, harvest index and grain yield in rice, when planted at two seedlings per hill than one seedling per hill. On the contrary, studies conducted by Roshan *et al.* (2011) revealed that increasing the seedling density from one to seven significantly reduced the number of productive tillers per square metre and percentage of filled grains per panicle. However, grain yield did not vary significantly among the different seedling densities tried.

2.3 EFFECT OF NPK ON RICE

Nitrogen, phosphorus and potassium are the major nutrients essential for the growth and development of rice plants. Among the three, nitrogen plays an important role in the vegetative growth required to support the productivity of the crop. While phosphorus plays a vital role in the root development, potassium affects water balance and crop health. The current soaring prices of fertilizers and their inadequate availability warrant the most judicious and efficient use of fertilizers. .

2.3.1 Effect of NPK on Growth Characters

Increasing the levels of nutrition was observed to increase the dry matter accumulation in rice hybrids over check varieties (IRRI, 1994). Plant height and dry matter production increased significantly with each successive addition of N dose from 0 to 150 kg ha^{-1} as reported by Om (1995). Kandasamy (1996) and Babu (1998) reported that a NPK dose of 120: 38: 38 kg ha^{-1} recorded significantly maximum plant height, leaf area index and tiller number per hill compared to the other nutrient levels. Pradeep (1999) observed that application of 100 per cent recommended dose of NPK increased the growth characters like leaf area index, number of tillers per square metre and dry matter production of rice cv. PY 5. Siddique *et al.* (1999) revealed that application of 120: 60: 60 kg NPK ha^{-1} significantly increased the leaf area.

Plant height, leaf area index and dry matter production of rice were found to increase with increasing levels of NPK application by Geethadevi *et al.* (2000).

Kumar (2001) observed significant increase in plant height, number of tillers per square metre, leaf area index and dry matter production of rice with 25 per cent extra dose of nitrogen application. Studies conducted by Somasundaram *et al.* (2002) revealed significant increase in plant height, leaf area index and dry matter accumulation with each successive increase in N level from 0 to 150 kg ha^{-1}. Ramarao (2004) observed higher dry matter production in TNRH-6 under higher fertilizer doses and attributed this to the higher leaf area index, leaf area duration and better growth rates. Hybrid rice has been reported to be highly fertilizer responsive on account of its profuse vegetative growth (Islam *et al.*, 2009).

The review can be concluded that application of 100 per cent recommended dose of NPK helped in increasing the growth characters like leaf area index, number of tillers per square metre and dry matter production. Application of 25 percent extra dose of NPK helped in increasing the plant height. Plant height, and dry matter production of hybrid rice increased significantly with each successive addition of NPK.

2.3.2 Effect of NPK on Yield Attributing Characters and Yield

The yield response of rice to incremental doses of NPK, especially phosphorus was more in soils with moderate to high content of clay, probably because of the fixation of P in the colloidal complex at lower doses (Raju *et al.*, 1992). Om (1995) recorded significant increase in panicle weight of hybrid rice upto 150 kg N ha^{-1} with the heaviest panicles at 200 kg N ha^{-1}. Om *et al.* (1998) reported that the productive tiller count and panicle weight of hybrid rice increased significantly up to 150 kg N ha^{-1}.

NPK fertilizers @180: 90: 90 kg ha^{-1} produced maximum number of panicles per square metre as reported by Bhowmick and Nayak (2000). They also reported an increase in panicles per square metre, filled grains and test weight by increasing the levels of nutrition. The number of panicles per square metre, panicle weight and test weight of the crop responded positively to NPK treatments and registered significantly higher values for hybrid rice variety KRH-2 (Bali *et al.*, 2006).

The magnitude of increase in grain yield was 55.4, 98.9, 120.7 and 135.5 per cent and 42.3, 66.5, 77.5 and 80.4 per cent respectively with the application of 50,100, 150 and 200 kg N ha^{-1} over the control (Om *et al.*, 1998). They also reported an increase in straw yield upto the highest dose of nitrogen (150 kg ha^{-1}). Grain yield and nutrient uptake of rice hybrid CORH-2 was found to be maximum at a NPK dose of 150: 75: 75 kg ha^{-1} (Krishnakumar *et al.*, 2005). Hybrid rice KRH-2 significantly out yielded the inbred checks with an average yield increase of 32.84 per cent in the sandy loam soils of Jammu (Bali *et al* ., 2006). It was also observed that application of 150 kg N + 80 kg P_20_5 + 60 kg K_2O ha^{-1} recorded maximum mean grain yield of 6.26 t ha^{-1}. A study conducted on the effect of different nutrient levels on hybrid rice by Singh and Bharadwaj (2007) showed that the grain yield and straw yield of hybrid rice increased with nutrient levels and the maximum grain yield (5.5 t ha^{-1}) and straw yield(6.6 t ha^{-1}) was recorded with a NPK dose of 200: 34.4: 66.6 kg ha^{-1}. Verma *et al.* (2009) stated that among N, P and K the yield and yield attributes of rice increased significantly with levels of N. Application of recommended dose of fertilizers produced the maximum grain yield and harvest index (Singh *et al.*, 2010).

Increased level of nutrients helped in increasing the growth of the rice crop especially hybrid rice. Application of nutrients at a higher dose helped in increasing the panicle number, productive tillers, panicle weight and grain yield.

2.3.3 Effect of NPK on Nutrient Uptake by Rice

Kandasamy (1996) reported that application of NPK at the rate of 120: 38: 38 kg ha^{-1} resulted in the highest nutrient uptake in rice. Singh and Verma

(1999) observed that the uptake of K by rice grain and straw increased significantly with successive increase in the levels of K. Application of graded levels of NPK fertilizers significantly affected the nutrient uptake of rice (Srinivasan and Angayarkanni, 2008). Lin *et al.* (2009) reported that increasing the N application rate from 120 to 180 kg ha^{-1} increased the nitrogen uptake from 140.2 to 156.7 kg ha^{-1}. Kundu and Sarkar (2009) observed that nutrient uptake of rice increased with nutrient levels and was influenced greatly by the grain and straw yields of the crop. The total uptake of nutrients was found to be significantly higher with application of chemical fertilizers in rice (Upadhyay *et al.* 2011)

2.4 EFFECT OF SPACING, SEEDLING DENSITY AND NUTRITION ON GRAIN QUALITY

Grain quality is a complex character which is directly or indirectly related with other characters. Amylose content of the grain is an important factor affecting cooking and eating quality. The appearance, size and shape of rice grain is another important quality character which decides the consumer preference.

Nandisha and Mahadevappa (1984) reported that spacing of 20cm x 10 cm recorded higher seed protein percentage compared to seeds harvested from 15cm x 10 cm closer spacing in Madhu and Intan mutant varieties.

Environmental factors are known to affect the composition of the rice grain (Juliano, 1985). Protein content tends to increase with wider spacing or in borders and in response to high N fertilizer application, especially at flowering. Short growth duration and cloudy weather during grain development, as in the wet season, may increase protein content. Stresses such as drought, salinity, alkalinity, high or low temperature, diseases or pests may increase the protein content of the rice grain. An increase in protein content is essentially at the expense of a reduction in starch content. Starch is the major constituent of milled rice at about 90 percent of the dry matter. Starch consists of an essentially linear fraction, amylose, and a branched fraction, amylopectin (Hizukuri *et al.*, 1989).

Mineral nutrition affects the protein content of the rice grain: soil organic matter, total nitrogen, exchangeable calcium, available copper and molybdenum and total chlorine all tend to increase the grain protein content (Huang, 1990).

Nitrogen application at higher dosage increased the amylose content in long slender varieties (Rao *et al.*, 1993). Suwanarit *et al.* (1996) reported that application of nitrogenous fertilizers adversely affected cooking and eating qualities of rice *viz.* aroma, softness, whiteness, stickiness and glossiness.

Reddy and Reddy (2003) observed that the quality parameters of rice kernel (protein and amylose content) varied significantly due to different N management practices, whereas the cooking quality parameters like elongation ratio did not show any statistically noticeable variation due to different N management practices. Shivay and Singh (2003) reported that planting spacing had no significant effect on N recovery and protein content in grain. However, 20cm x 15 cm spacing recorded higher N recovery (27.8 per cent) than the other planting geometries.

A field investigation carried out by Chauhan (2005) at Kanpur revealed that crop transplanted with three seedlings per hill gave 0.83 and 0.31 per cent more rice recovery than that with 1 and two seedlings per hill, respectively. However, three seedlings per hill also gave significantly higher protein content in grain than 1 and two seedlings per hill. Volume expansion ratio and amylose content of rice was not affected significantly by the different dose of nutrients (Chaudhary *et al.*, 2011).

2.5 EFFECT OF SPACING, SEEDLING DENSITY AND NUTRITION ON ECONOMICS

The research work conducted on rice hybrids VRH 704 and HRI 129 at Kanpur by Dayal (1999) revealed that planting at two seedlings per hill fetched the maximum net income (Rs.15035.70 ha^{-1}) as compared to one seedling per hill (Rs.13492.47 ha^{-1}). Planting hybrids at a spacing of 20cm x 10 cm was more economical than other spacings (20cm x 15cm and 15cm x 15 cm) with higher net returns and benefit cost ratio (Obulamma *et al*., 2004). Bhowmick and Nayak (2000) reported maximum net profit in hybrid rice with an NPK dose of 180: 90: 90 kg ha^{-1} and the highest benefit cost ratio was obtained at 150: 75: 75 kg ha^{-1}. Powar and Deshpande (2001) who worked on hybrid rice Sahyadri found that wider plant spacing of 20cm x 20cm resulted in highest net monetary return (Rs.23895 ha^{-1}) as compared to closer spacing of 20cm x 10cm and 20cm x 15cm. In an investigation conducted at Jabalpur with rice hybrid PA 6201, Kewat *et al*. (2002) found that a spacing of 20cm x10cm resulted in maximum net monetary return and benefit: cost ratio (2.8) than 15cm x 15 cm and 20cm x 15cm spacing. Hybrid rice variety, KRH -2 recorded a B: C ratio 1.44 as reported by Bali *et al*. (2006).

Materials and Methods

3. MATERIALS AND METHODS

The research project entitled "Production potential of hybrid rice (*Oryza sativa* L.) in lowland ecosystem" was carried out at the Cropping Systems Research Centre, Karamana, Thiruvananthapuram, during the second crop season of 2011. The main objective of the experiment was to assess the production potential of hybrid rice in lowland ecosystem, to quantify its nutritional requirement in relation to plant spacing and seedling density and to work out the economics of cultivating hybrid rice as compared against a conventional inbred. The details regarding the materials used and methods employed for the study are presented in this chapter.

3.1 EXPERIMENTAL SITE

The farm at the Cropping Systems Research Centre is geographically located at 8.5o N latitude and 76.9o E longitude at an altitude of 29m above mean sea level. The experimental field had fairly levelled topography and good drainage.

3.1.1 Soil

Prior to the experiment, composite soil samples were drawn from a depth of 0 to 15 cm layer and analyzed for its mechanical composition and chemical properties. The data on the mechanical composition and chemical nature of the soil of the experimental site are presented in Tables 1a and 1b respectively.

The soil of the experimental site was sandy clay loam, belonging to the taxonomical order Oxisol. It was acidic in reaction, medium in organic carbon content, low in available nitrogen, medium in available phosphorus and high in available potassium.

Table1a. Mechanical composition of the soil of the experimental site

Sl.No.	Fractions	Content in soil (%)	Method adopted
1	Coarse sand	72.0	Bouyoucos Hydrometer Method (Bouyoucos ,1962)
2	Silt	7.10	
3	Clay	20.0	

Textural class: Sandy clay loam.

Table1b. Chemical properties of the soil of the experimental site

Sl.No	Fractions	Content	Method adopted
1	Available nitrogen (kg ha-1)	196.00 (Low)	Alkaline Permanganate Method (Subbiah and Asija, 1956)
2	Available phosphorus (kg ha-1)	12.32 (Medium)	Bray Colorimetric Method (Jackson,1973)
3	Available potassium (kg ha-1)	282.40 (High)	Ammonium Acetate Method (Jackson,1973)
4	Organic carbon (%)	0.72 (Medium)	Walkley and Black Rapid Titration Method (Jackson,1973)
5	Soil reaction (pH)	5.3 (Acidic)	1:2.5 Soil solution ratio using pH meter with glass electrode (Jackson,1973)

3.1.2 Cropping History of the Field

The area was under a bulk crop of rice before the experiment.

3.1.3 Season

The experiment was conducted during the second crop season from July to November, 2011.

3.1.4 Weather Conditions

A warm humid tropical climate prevailed over the experimental site. Data on weather parameters like temperature, rainfall, relative humidity and evaporation were obtained from the Class B Agromet Observatory at the College of Agriculture, Vellayani. The average values of weather parameters recorded during the cropping period are given in Appendix-I and graphically presented in Fig.1. The mean maximum and minimum temperature ranged between 25.7ºC to 30.8ºC and 23.5ºC to 26.6ºC respectively. The mean maximum and minimum relative humidity ranged from 81.2 per cent to 90.9 per cent and 79.4 per cent to 86.9 per cent. A total rainfall of 783.4 mm was recorded during the cropping period. The mean evaporation during the cropping period was 3.24 mm day-1.

3.2 MATERIALS

3.2.1 Crop Variety

The rice varieties selected for the experiments were hybrid rice (KRH-2) and inbred rice (Jaya). Karnataka Rice Hybrid - 2 (KRH-2) is a rice hybrid developed by University of Agricultural Sciences, Bengaluru, by crossing IR 58025A, an IRRI CMS line with KMR – 3R, a locally developed line. It is a medium duration (125 – 130 days), semi-tall, non-lodging and non-shattering variety with tolerance to pest and diseases and an average yield of 7.5 to 8.5 t ha-1. Jaya, the hybrid derivative of the cross between TN-1 and T-141, released in 1968 by the Directorate of Rice Research, Hyderabad, is a medium duration rice variety (120 – 125 days).

3.2.2 Source of Seed Material

The seeds of KRH-2 and Jaya were obtained from the Zonal Agricultural Research Station, V.C.Farm, Mandya and the National Seeds Corporation, Karamana, Thiruvananthapuram, respectively.

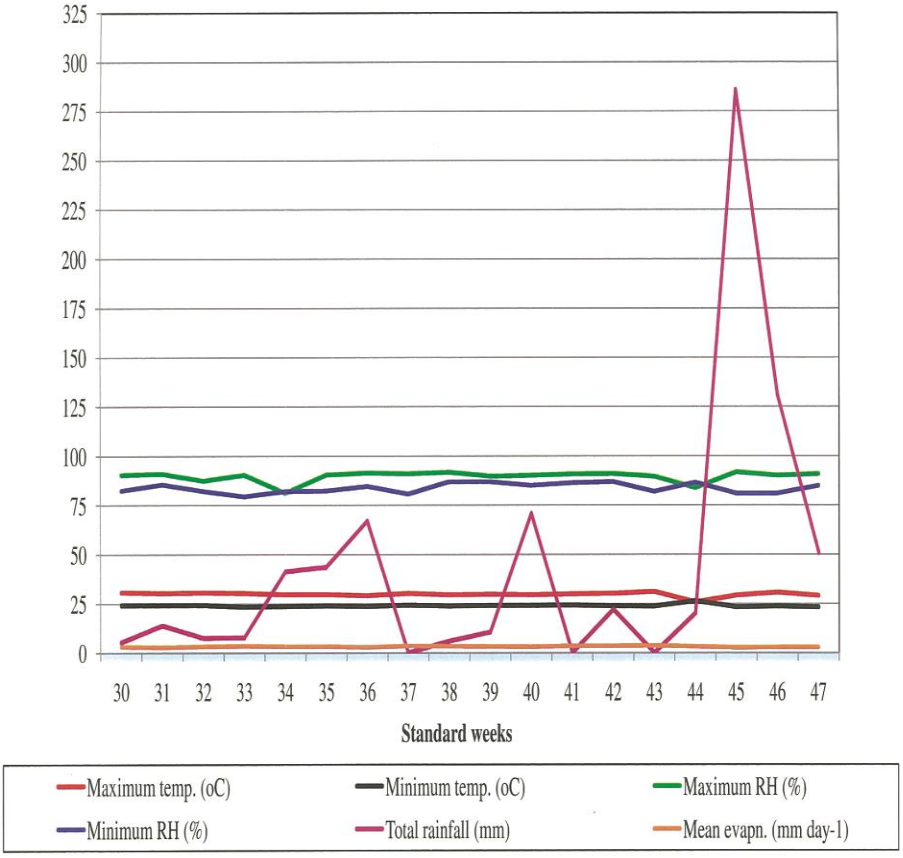

Fig. 1. Standard week wise mean weather parameters during the cropping period

3.2.3 Manures and Fertilizers

FYM (0.50 per cent N, 0.31 per cent P_2O_5, and 0.22 per cent K_2O), urea (46 per cent N), rock phosphate (20 per cent P_2O_5) and muriate of potash (60 per cent K_2O) were used to supply the major nutrients required for the crop.

3.3 METHODS

3.3.1 Design and Layout

The field experiment was laid out in randomized block design with (12+1) treatment combinations, replicated thrice. The lay out plan of the experiment is given in Fig.2.

The details of the layout of the experiment are given below.

Design	:	Randomized Block Design (RBD)
Treatments	:	(2 x 2 x 3) + 1
Replications	:	3
Gross plot size	:	4m x 3m
Net plot size	:	3.6m x 2.8m (for 20cm x 10cm spacing)
		3.6m x 2.7m (for 20cm x15cm spacing)

3.3.2 Treatments

The treatments comprised hybrid rice (KRH-2) raised at two spacings, two seedling densities and three nutrient levels, compared against inbred (Jaya) raised as per the KAU POP.

A. Spacing (S)

S_1 : 20cm x 10cm

S_2 : 20cm x 15cm

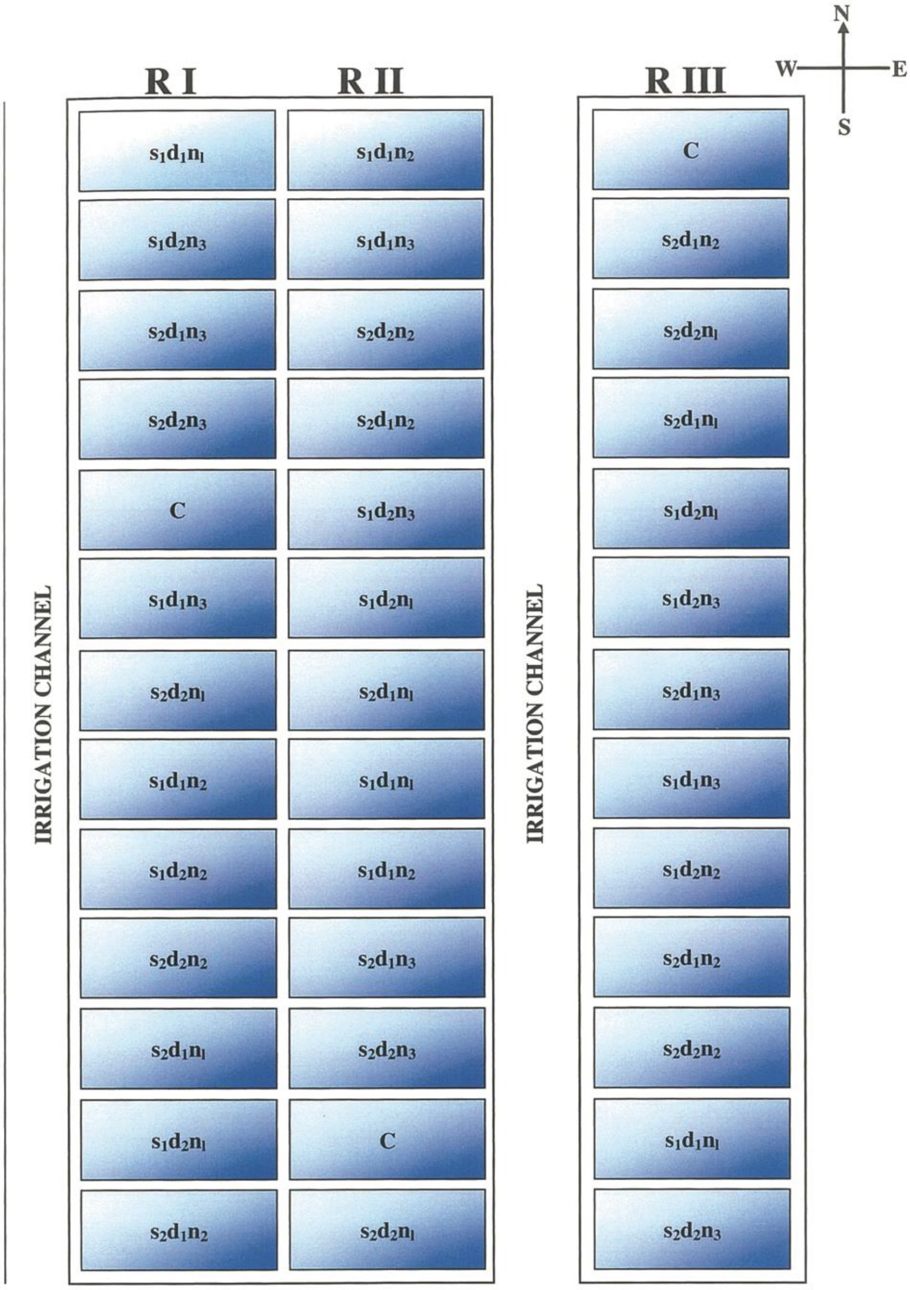

Fig. 2. Layout plan of field experiment

B Seedling density (D)

D_1 : 1 seedling per hill

D_2 : 2 seedlings per hill

C. Nutrient level (N)

N_1 : 90: 45: 45 kg NPK per ha

N_2 : 120: 60: 60 kg NPK per ha

N_3 : 150: 75: 75 kg NPK per ha

Control

C : Variety Jaya raised as per KAU POP

3.3.3 Treatment Combinations (12 + 1)

$s_1d_1n_1$: 20cm x 10cm + 1 seedling per hill + 90: 45: 45 kg NPK per ha

$s_1d_1n_2$: 20cm x 10cm + 1 seedling per hill + 120: 60: 60 kg NPK per ha

$s_1d_1n_3$: 20cm x 10cm + 1 seedling per hill + 150: 75: 75 kg NPK per ha

$s_1d_2n_1$: 20cm x 10cm + 2 seedlings per hill + 90: 45: 45 kg NPK per ha

$s_1d_2n_2$: 20cm x 10cm + 2 seedlings per hill + 120: 60: 60 kg NPK per ha

$s_1d_2n_3$: 20cm x 10cm + 2 seedlings per hill + 150: 75: 75 kg NPK per ha

$s_2d_1n_1$: 20cm x 15cm + 1 seedling per hill + 90: 45: 45 kg NPK per ha

$s_2d_1n_2$: 20cm x 15cm + 1 seedling per hill + 120: 60: 60 kg NPK per ha

$s_2d_1n_3$: 20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK per ha

$s_2d_2n_1$: 20cm x 15cm + 2 seedlings per hill + 90: 45: 45 kg NPK per ha

$s_2d_2n_2$: 20cm x 15cm + 2 seedlings per hill + 120: 60: 60 kg NPK per ha

$s_2d_2n_3$: 20cm x 15cm + 2 seedlings per hill + 150: 75: 75 kg NPK per ha

Control: Variety Jaya raised as per KAU POP

(20cm x 10cm + 2 seedlings per hill + 90: 45: 45 kg NPK per ha)

Plate 1. Layout of field experiment

3.4 CROP HUSBANDRY

3.4.1 Nursery

3.4.1.1 Land Preparation

The nursery area was ploughed, levelled and weeds were removed from the nursery bed. Two separate nursery beds were prepared for KRH – 2 and Jaya.

3.4.1.2 ***Seeds and Sowing***

Pre germinated seeds for KRH-2 and Jaya @ 60kgha-1 were broadcasted in two separate nursery beds during the last week of July 2011. Twenty five day old healthy seedlings were pulled out from the nursery beds and transplanted in the main field.

3.4.2 Main Field

3.4.2.1 ***Land Preparation***

The experimental area was ploughed twice, puddled, levelled and weeds were removed from the field. The experimental plots were laid out into three blocks with 13 plots each. The plots and the blocks were separated with bunds of 30cm width. Irrigation channels of 30cm width were provided between the blocks.

3.4.2.2 ***Manures and Fertilizers***

FYM @ 5 t ha-1 was applied to all the plots at the time of land preparation. Urea, Rajphos and MOP were applied as per the treatments after leveling the fields prior to transplanting. One-third dose of nitrogen, entire phosphorus and half the dose of potassium were applied basally, one-third nitrogen at maximum tillering and the remaining nitrogen and potassium were applied one week prior to panicle initiation.

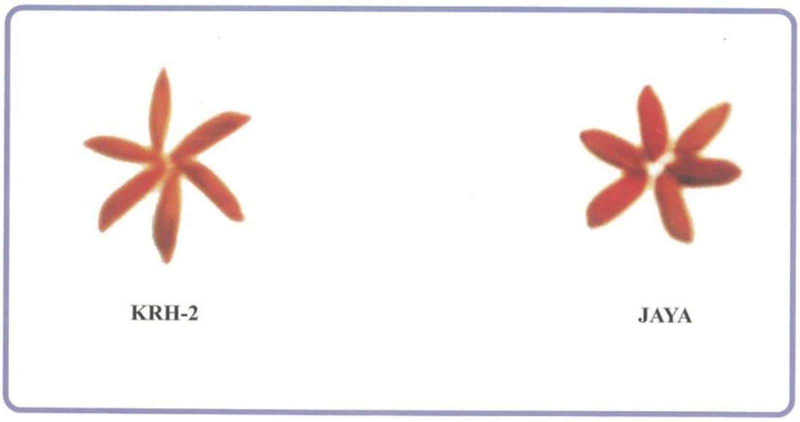

Plate 2. Seeds of KRH-2 and JAYA

3.4.2.3 *Transplanting*

Twenty five days old seedlings were gently pulled out from the nursery beds and transplanted into the main field maintaining the spacing and seedling density as per the treatments.

3.4.2.4 *Weed Management*

The field was maintained weed free up to 45 DAT with two hand weedings, at 20 DAT and 40 DAT.

3.4.2.5 *Water Management*

Water level was maintained at 5 ± 2cm throughout the cropping period with occasional drainage before fertilizer application. The field was drained 10 days prior to harvest.

3.4.2.6 *Plant Protection*

None of the pests or diseases were observed above the economic threshold levels warranting control measures.

3.4.2.7 *Harvest*

The crop was harvested when the straw just turned yellow. The net plots were harvested separately, threshed, winnowed and the weight of straw and grain were recorded separately from the individual plots.

3.5 OBSERVATIONS

3.5.1 Plant Sampling

Six plants were selected randomly from the net plot area of each plot and tagged as observation plants. Two rows from all sides of the plot were left as border rows.

KRH-2 JAYA

Plate 3. Seedlings at transplanting stage

3.5.2 Crop Growth Characters

3.5.2.1 *Plant Height*

Plant height was recorded at maximum tillering, panicle initiation, and harvest stages using the method described by Gomez (1972). The height was measured from the base of the plant to the tip of the longest leaf or tip of the longest ear head, which ever was longer and the average was recorded in centimetres.

3.5.2.2 *Tillers per Hill*

Tiller count was taken from the tagged observation hills at maximum tillering panicle initiation and harvest stages and the mean value was recorded as number of tillers per hill.

3.5.2.3 *Leaves per Hill*

The leaves borne by the tagged observation hills at maximum tillering, panicle initiation and harvest stages were counted and the mean recorded as the number of leaves per hill.

3.5.2.4 *Leaf Area Index (LAI)*

Leaf area index was calculated at maximum tillering, panicle initiation and harvest stages using the method suggested by Yoshida *et al.* (1976). The maximum length 'l' and width 'w' of all the leaves of the middle tiller of the six sample hills were recorded from all the plots and leaf area index was calculated.

Leaf area of a single leaf = l x w x k

k - adjustment factor (0.75 at maximum tillering, panicle initiation and flowering and 0.67 at harvest stage).

$$\text{LAI} = \frac{\text{Sum of leaf area /hill of 6 sample hills (cm2)}}{\text{Area of land covered by the 6 sample hills (cm}^2\text{)}}$$

3.5.2.5 *Dry Matter Production*

Dry matter production (DMP) was recorded at maximum tillering, panicle initiation and harvest stages. The sample hills were uprooted separated into roots, culms, leaves and panicles, dried under shade and later in an oven at 65-70oC. The dry weight of each plant was recorded separately as shoot, root and total DMP using an electronic weighing balance.

3.5.2.*6 Rooting Depth*

The depth of rooting was recorded from the hills uprooted for assessing the DMP and expressed in centimetres.

3.5.3 YIELD ATTRIBUTES AND YIELD

3.5.3.1 *Productive Tillers per Hill*

The number of productive tillers were counted at the harvest stage and expressed as the number of productive tillers per hill.

3.5.3.2 Panicle Length

Twelve panicles were collected randomly from each net plot at harvest and the lengths were measured and the mean expressed in centimetres.

3.5.3.3 Panicle Weight

Twelve panicles collected at random from each net plot at harvest were weighed and the mean weight per panicle expressed in grams.

3.5.3.3 Spikelets per Panicle

The spikelets present on the twelve randomly selected panicles were counted and the mean expressed as the number of spikelets per panicle.

Plate 4. General view of the experiment

3.5.3.4 Filled Grains per Panicle

The filled grains obtained from the twelve randomly selected panicles were counted and the mean expressed as the number of filled grains per panicle.

3.5.3.5 Sterility Percentage

Sterility percentage was worked out using the following relationship.

$$\text{Sterility percentage} = \frac{\text{Number of unfilled grains per panicle} \times 100}{\text{Total number of grains per panicle}}$$

3.5.3.6 Thousand Grain Weight

One thousand grains were counted from the cleaned and dried produce from each plot and the weight recorded in grams.

3.5.3.7 Grain Yield

The net plot area was harvested individually, threshed, winnowed, dried and the dry weight was recorded in kg $ha^{-1.}$

3.5.3.8 Straw Yield

The straw harvested from each individual net plot was dried and the weight was recorded and expressed in kg ha^{-1}.

3.5.3.9 Harvest Index

The harvest index was calculated from the grain yield and straw yield using the equation suggested by Donald and Hamblin (1976).

$$\text{Harvest Index} = \frac{\text{Economic yield}}{\text{Biological yield}}$$

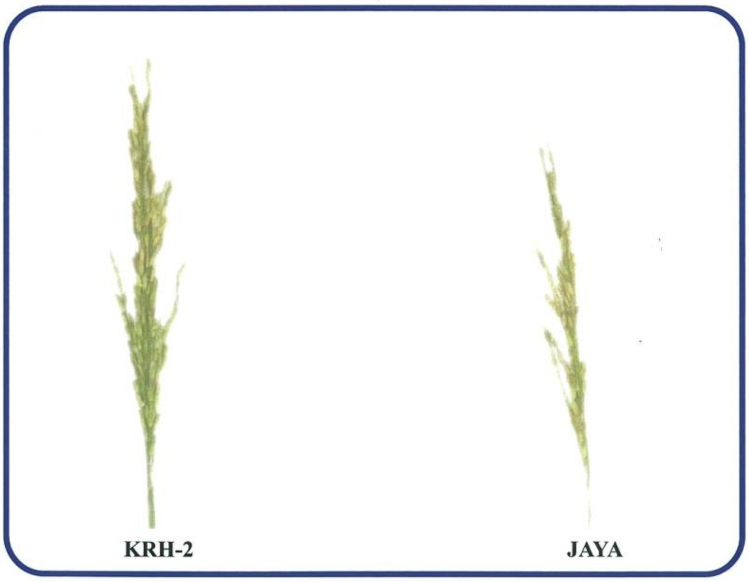

Plate 5. Panicles at harvest

3.5.4 Pest and Disease Scoring

No major pests and diseases were found to infest the crop beyond the economic threshold level demanding control measures. Since the insect and disease attack were below the economic threshold level, scoring was not done.

3.5.5 QUALITY ATTRIBUTES

3.5.5.1 Cooking properties

3.5.5.1.1 *Optimum Cooking Time*

Grain samples from the harvested lot of each plot were analyzed and optimum cooking time was determined by the method suggested by Hirrannaiah *et al.*(2001). Milled rice was screened visually and whole sound grains were collected. Samples of 10 g of rice were taken in a 250 ml vessel containing 150 ml slow boiling water over an electric stove (1.5kw). The cooking time was determined using glass plate opaque – core method by drawing few grains periodically and pressing between two glass slides till no opaque portion or white core remained.

3.5.5.1.2 *Volume Expansion Ratio*

Volume expansion ratio or kernel expansion ratio was determined from the ratio between the cooked volumes of rice to that of uncooked rice as per the method suggested by Pillaiyar and Mohandoss (1981).

3.5.5.1.3 *Grain Elongation Ratio*

Grain elongation ratio of grain samples was evaluated by the method suggested by Juliano and Perez (1984). Elongation ratio of grains was expressed as the ratio of the length of cooked kernels to that of the raw kernels. The length of ten cooked kernels and ten raw kernels was measured and mean length of cooked kernels was divided by mean length of raw kernels.

3.5.5.2 CHEMICAL PROPERTIES

3.5.5.2.1 Crude Protein Content

Crude protein content was computed by multiplying the nitrogen content of the grains with the factor 6.25 (Simpson *et al.*, 1965).

3.5.5.2.2 Total Starch Content

Starch was estimated by the Ferric cyanide method suggested by Aminoff *et al.* (1970).

3.5.5.2.3 Amylose Content

Amylose content was estimated using the method suggested by Mc Cready and Hassid (1943) and expressed as the percentage of starch.

3.5.5.2.4 Amylopectin Content

Amylopectin content was determined as the difference between the total starch content and amylose content and expressed as the percentage of starch.

3.5.5.2.5 Organoleptic Test

The overall acceptability of hybrid rice, KRH-2 and Jaya was evaluated. The organoleptic qualities were tested by ten panel members, selected through the triangle test (Jellink, 1964) .The test was conducted as per the standard procedure prescribed by Swaminathan (1974). The major quality attributes *viz.* colour, appearance, flavour, texture and taste were scored by the panel members using a score card.

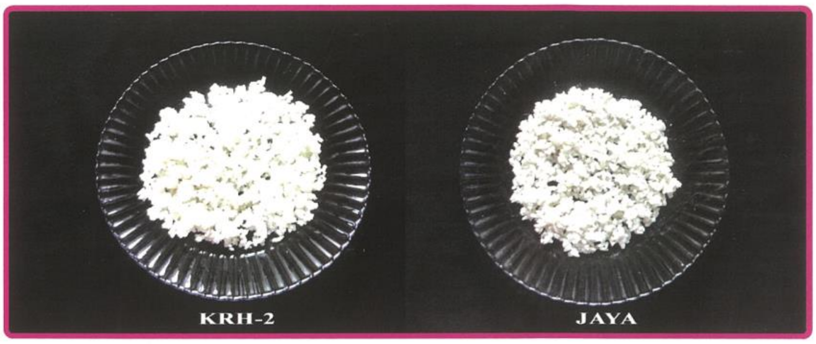

Plate 6. Cooked grains of rice

3.5.6 CHEMICAL ANALYSIS

3.5.6.1 Plant Analysis

The whole plants and grains were analyzed separately for their nitrogen, phosphorus and potassium contents. The samples collected from each plot at the time of harvest were dried in a hot air oven at 70oC and the samples were ground and sieved using a 0.5 mm sieve. The required quantities of samples were weighed out in an electronic balance and subjected to acid digestion and the nutrient contents were determined.

3.5.6.1.1 Total Nitrogen Content and Uptake

The total nitrogen content was estimated using the Modified Microkjeldhal Method (Jackson, 1973) and the uptake of nitrogen was calculated by multiplying the nitrogen content of plant sample with the total dry weight of plants.

3.5.6.1.2 Total Phosphorus Content and Uptake

The total phosphorus content was estimated using Vanado Molybdo Phosphate Yellow Colour Method. The intensity of colour developed was read in spectrophotometer at a wavelength of 470nm (Jackson, 1973) and the uptake was calculated by multiplying the phosphorus content of the plant sample with the total dry weight of plants.

3.5.6.1.3 Total Potassium Content and Uptake

The total potassium content was determined using the Flame photometer method (Jackson, 1973) and the uptake was calculated by multiplying the potassium content of plant sample with the total dry weight of plants.

3.5.7.2 SOIL ANALYSIS

Composite soil samples were collected from the whole plot before starting the experiment and analyzed to determine the nitrogen, phosphorus and potassium content. After the harvest, soil samples were collected from each plot separately and analyzed to determine the organic carbon, nitrogen, phosphorus and potassium contents.

3.5.7.2.1 Organic Carbon

Organic carbon content was determined using the Walkley and Black rapid titration method (Jackson, 1973) and expressed in percentage.

3.5.7.2.2 Available Nitrogen

Available nitrogen content was determined using the alkaline permanganate method suggested by Subbiah and Asija (1956) and expressed in kg N ha^{-1}.

3.5.7.2.3 Available Phosphorus

Available phosphorus content of the soil was determined by Dickman and Bray's molybdenum blue method using a spectrophotometer and expressed as kg P ha^{-1}.

3.5.7.2.4 Available Potassium

Available potassium content was determined in neutral normal ammonium acetate extract, estimated in a flame photometer (Jackson, 1973) and expressed as kg K ha^{-1}.

3.5.8 ECONOMICS OF CULTIVATION

Economics of cultivation was calculated based on the total income and total expenditure.

3.5.8.1 Net Income

Net income was computed using the formula

Net income (Rs ha^{-1}) = Gross income - Total expenditure

3.5.8.2 Benefit Cost Ratio

Benefit cost ratio was calculated using the formula

$$BCR = \frac{\text{Gross income}}{\text{Total expenditure}}$$

3.5.9 Statistical Analysis

Data recorded were statistically analyzed using the analysis of variance technique as applied to Randomized Block Design (Panse and Sukhatme, 1985) and the significance was tested using F test (Snedecor and Cochran, 1967). Wherever the F values were found significant, critical difference was worked out at five per cent and one per cent probability levels. The significance of the control treatments with the other treatment combinations was also tested. The scores obtained in the organoleptic test, being non-parametric in nature, were subjected to chi-square test and the mean scores were worked out.

Results

4. RESULTS

The experiment entitled "Production potential of hybrid rice (*Oryza sativa* L.) in lowland ecosystem" was undertaken at the Cropping Systems Research Centre, Karamana, Thiruvananthapuram, during July to November, 2011. The main objectives of the study were to assess the production potential of hybrid rice in lowland ecosystem, to quantify its nutritional requirement in relation to spacing and seedling density and to work out the economics of hybrid rice production as against a conventional inbred. The results of the experiment are presented in this chapter.

4.1 CROP GROWTH CHARACTERS

4.1.1 Plant Height

The results on plant height at different stages of crop growth *viz.* maximum tillering, panicle initiation and harvest are presented in Table 2a and 2b.

The perusal of data showed that the spacing and seedling density did not have any significant effect on plant height at all stages of growth. Among the different nutrients levels, N_3 (150: 75: 75 kg NPK ha^{-1}) recorded significantly greater plant height at panicle initiation stage (128.19cm) and harvest stage (125.64cm).

The first order (spacing x seedling density, spacing x nutrient level, seedling density x nutrient level) and the second order interactions (spacing x seedling density x nutrient level) had no significant impact on plant height. Comparing treatments with control, hybrid rice, KRH-2 was significantly taller than the control, Jaya at the panicle initiation (123.44cm, 114.25cm) and harvest stages (120.99cm, 111.48cm).

The comparison made between the treatment combinations including control, revealed significant difference in plant height at the panicle initiation and harvest stages, with the treatment combination, $s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) recording the maximum plant height at panicle initiation (129.41cm) and harvest stages (127.05cm).

Table 2a. Effect of spacing, seedling density and nutrient level on plant height, cm

Treatment	Plant height		
	Maximum tillering	Panicle initiation	Harvest
Spacing			
S_1	66.12	122.48	119.95
S_2	68.71	124.39	120.03
Seedling density			
D_1	66.16	122.83	120.41
D_2	68.67	124.04	121.57
Nutrient level			
N_1	62.08	118.69	116.31
N_2	68.77	123.44	121.01
N_3	71.39	128.19	125.64
SEm S	2.84	1.01	0.96
D	2.84	1.01	0.96
N	3.48	1.23	1.17
CD (0.05) S	-	-	-
D	-	-	-
N	-	3.616	3.433

Table 2b. Interaction effect of spacing, seedling density and nutrient level on plant height, cm

Treatment	Plant height					
	Maximum tillering		Panicle initiation		Harvest	
S x D	S_1	S_2	S_1	S_2	S_1	S_2
D_1	62.82	69.43	121.38	123.58	118.65	121.24
D_2	69.50	67.92	124.28	124.50	122.16	121.89
SEm	4.01		1.43		1.35	
CD (0.05)	-		-		-	
S x N	S_1	S_2	S_1	S_2	S_1	S_2
N_1	61.25	62.92	117.20	120.18	114.86	117.77
N_2	68.46	69.08	122.29	124.58	119.79	122.22
N_3	68.67	74.13	127.96	128.42	125.19	126.09
SEm	4.92		1.75		1.66	
CD (0.05)	-		-		-	
D x N	D_1	D_2	D_1	D_2	D_1	D_2
N_1	63.88	60.29	118.21	119.17	115.86	116.77
N_2	70.58	66.96	122.83	124.04	120.37	121.64
N_3	64.02	78.77	127.46	128.91	125.00	126.29
SEm	4.92		1.75		1.66	
CD (0.05)	-		-		-	
S x D x N						
$s_1d_1n_1$	64.25		115.57		113.15	
$s_1d_1n_2$	70.92		122.08		119.47	
$s_1d_1n_3$	53.29		126.50		123.34	
$s_1d_2n_1$	63.50		120.85		118.56	
$s_1d_2n_2$	70.25		123.58		121.26	
$s_1d_2n_3$	74.75		128.42		126.66	
$s_2d_1n_1$	58.25		118.83		116.57	
$s_2d_1n_2$	66.00		122.50		120.11	
$s_2d_1n_3$	84.04		129.41		127.05	
$s_2d_2n_1$	62.33		119.50		116.97	
$s_2d_2n_2$	67.92		122.58		123.18	
$s_2d_2n_3$	73.50		128.42		125.53	
Treatment mean	67.42		123.44		120.99	
Control mean	68.66		114.25		111.48	
SEm	6.96		2.47		2.35	
CD (0.05)	-		-		-	
Treatment Vs. Control	NS		S		S	
Between treatmentss (including control)	NS		S		S	

4.1.2 Number of Tillers per Hill

The number of tillers per hill recorded at maximum tillering, panicle initiation, and harvest stages are presented in Table 3a. The first order and second order interactions are presented in Table 3b.

While spacing and seedling density had no significant effect on the number of tillers per hill, nutrient levels resulted in significant variation in the tiller count at all the three stages. The nutrient level, N_3 recorded the maximum number of tillers per hill at the maximum tillering (15.47), panicle initiation (13.48) and harvest (11.33) stages.

Among the three first order interactions, the interaction between spacing and seedling density had significant impact on the tiller count at the harvest stage with s_2d_2 (20cm x 15cm + 2 seedlings per hill) recording the highest number of tillers per hill (9.89) and it was on a par with s_1d_1 and s_2d_1. The interaction between spacing and nutrient levels proved significant at the panicle initiation stage. The treatment interaction, s_1n_3 (20cm x 10cm + 150: 75: 75 kg NPK ha^{-1}) produced the maximum number of tillers per hill (14.65). The interaction among spacing, seedling density and nutrient levels was not significant.

The tiller number per hill did not vary significantly between KRH-2 (12.42, 11.10, and 9.32) and Jaya (12.50, 11.21, and 9.45) at the maximum tillering, panicle initiation and harvest stages. The comparison made between treatments including control revealed significant difference at all the three stages, with $s_2d_1n_3$ recording the maximum tiller count at the maximum tillering (15.92), panicle initiation (14.75) and harvest (12.37) stages.

Table 3a. Effect of spacing, seedling density and nutrient level on number of tillers per hill, nos.

Treatment	Tillers per hill		
	Maximum tillering	Panicle initiation	Harvest
Spacing			
S_1	12.56	11.23	9.34
S_2	12.27	10.97	9.31
Seedling density			
D_1	12.26	11.06	9.18
D_2	12.58	11.14	9.47
Nutrient level			
N_1	9.87	8.77	7.16
N_2	12.67	11.05	9.49
N_3	15.47	13.48	11.33
SEm S	0.32	0.31	0.26
D	0.32	0.31	0.26
N	0.39	0.38	0.32
CD (0.05) S	-	-	-
D	-	-	-
N	1.159	1.119	0.937

Table 3b. Interaction effect of spacing, seedling density and nutrient level on number of tillers per hill, nos.

Treatment	Tillers per hill					
	Maximum tillering		Panicle initiation		Harvest	
S x D	S_1	S_2	S_1	S_2	S_1	S_2
D_1	12.75	12.38	11.39	11.07	9.62	9.05
D_2	11.76	12.79	10.73	11.21	8.74	9.89
SEm	0.45		0.44		0.37	
CD (0.05)	-		-		1.082	
S x N	S_1	S_2	S_1	S_2	S_1	S_2
N_1	9.46	10.29	8.21	9.34	6.97	7.36
N_2	12.54	12.53	10.83	11.25	9.09	9.89
N_3	15.69	14.01	14.65	12.30	11.95	10.70
SEm	0.56		0.54		0.45	
CD (0.05)	-		1.583		-	
D x N	D_1	D_2	D_1	D_2	D_1	D_2
N_1	10.08	9.66	9.07	8.48	7.38	6.94
N_2	12.14	12.92	10.87	11.23	9.15	9.83
N_3	14.54	15.17	13.24	13.71	11.02	11.64
SEm	0.56		0.54		0.45	
CD (0.05)	-		-		-	
S x D x N						
$s_1d_1n_1$	9.92		8.86		7.48	
$s_1d_1n_2$	12.42		10.56		8.99	
$s_1d_1n_3$	15.47		14.55		11.53	
$s_1d_2n_1$	10.25		9.28		7.28	
$s_1d_2n_2$	11.87		11.18		9.30	
$s_1d_2n_3$	13.16		11.74		9.66	
$s_2d_1n_1$	9.00		7.55		6.45	
$s_2d_1n_2$	12.67		11.10		9.18	
$s_2d_1n_3$	15.92		14.75		12.37	
$s_2d_2n_1$	10.32		9.40		7.44	
$s_2d_2n_2$	13.18		11.36		10.47	
$s_2d_2n_3$	14.87		12.86		11.75	
SEm	0.79		0.76		0.64	
CD (0.05)	-		-		-	
Treatment mean	12.42		11.10		9.32	
Control mean	12.50		11.21		9.45	
Treatment Vs. Control	NS		NS		NS	
Between treatments (including control)	S		S		S	

4.1.3 Number of Leaves per Hill

The data on the number of leaves per hill presented in Table 4a, showed that the effect of seedling density and nutrient levels was significant at all the three stages. Between the seedling densities tested, the higher density, D_2 produced significantly more number of leaves per hill at maximum tillering (56.87), panicle initiation (51.95) and harvest (37.23) stages. The highest nutrient level, N_3 resulted in significantly more number of leaves at maximum tillering (66.49), panicle initiation (60.83) and harvest (46.00) stages.

The first order and second order interactions presented in Table 4b, revealed that the first order interactions between the three treatments were not significant. The S x D x N interaction was significant only at the harvest stage, with the treatment combination $s_2d_2n_3$ recording the highest number of leaves per hill (49.22). It was at par with $s_1d_2n_3$, $s_2d_2n_2$, $s_1d_2n_2$ and $s_1d_2n_1$.

Hybrid rice, KRH-2 with 53.30, 48.28 and 38.37 leaves per hill at the maximum tillering, panicle initiation and harvest stages respectively, did not vary significantly from the control, Jaya with 54.16, 50.10 and 35.86 leaves per hill at the same stages. The comparison made between treatments including control proved to be significant with the maximum number of leaves at $s_2d_2n_3$ during all the three stages.

Table 4a. Effect of spacing, seedling density and nutrient level on number of leaves per hill, nos.

Treatment	Leaves per hill		
	Maximum tillering	Panicle initiation	Harvest
Spacing			
S_1	51.91	47.03	37.54
S_2	54.71	49.54	38.45
Seedling density			
D_1	49.75	44.61	32.38
D_2	56.87	51.95	37.23
Nutrient level			
N_1	40.58	36.51	32.29
N_2	52.85	47.50	36.84
N_3	66.49	60.83	46.00
SEm S	1.79	1.51	0.95
D	1.79	1.51	0.95
N	2.19	1.85	1.16
CD (0.05) S	-	-	-
D	5.231	4.429	2.777
N	6.406	5.425	3.402

Table 4b. Interaction effect of spacing, seedling density and nutrient level on number of leaves per hill, nos.

Treatment	Leaves per hill					
	Maximum tillering		Panicle initiation		Harvest	
S x D	S_1	S_2	S_1	S_2	S_1	S_2
D_1	48.92	54.90	44.02	50.04	29.32	35.43
D_2	50.58	58.83	45.21	53.87	45.75	42.98
SEm	2.53		2.14		1.34	
CD (0.05)	-		-		-	
S x N	S_1	S_2	S_1	S_2	S_1	S_2
N_1	38.63	42.54	35.16	37.86	33.6	30.97
N_2	49.38	56.32	44.97	50.04	35.69	37.99
N_3	67.73	65.26	60.95	60.72	43.33	48.67
SEm	3.10		2.62		1.64	
CD (0.05)	-		-		-	
D x N	D_1	D_2	D_1	D_2	D_1	D_2
N_1	38.92	42.25	34.16	38.86	25.00	39.57
N_2	47.79	57.91	43.19	51.82	28.26	45.41
N_3	62.54	70.44	56.49	65.18	43.87	48.13
SEm	3.10		2.62		1.64	
CD (0.05)	-		-		-	
S x D x N						
$s_1d_1n_1$	37.92		33.51		22.26	
$s_1d_1n_2$	44.75		41.60		26.08	
$s_1d_1n_3$	64.08		56.94		39.62	
$s_1d_2n_1$	39.92		34.80		44.94	
$s_1d_2n_2$	50.83		44.79		45.29	
$s_1d_2n_3$	61.00		56.04		47.03	
$s_2d_1n_1$	39.33		36.81		27.74	
$s_2d_1n_2$	54.00		48.35		30.44	
$s_2d_1n_3$	71.37		64.95		48.11	
$s_2d_2n_1$	45.17		40.92		34.20	
$s_2d_2n_2$	61.81		55.28		45.53	
$s_2d_2n_3$	69.51		65.41		49.22	
SEm	4.38		3.71		2.33	
CD (0.05)	-		-		6.804	
Treatment mean	53.30		48.28		38.37	
Control mean	54.16		50.10		35.86	
Treatment Vs. Control	NS		NS		NS	
Between treatmentss (including control)	S		S		S	

4.1.4 Leaf Area Index

The perusal of the data on leaf area index presented in Table 5a, showed that spacing had significant effect on leaf area index at the maximum tillering and harvest stages. While seedling density had no significant effect, nutrient levels proved significant at all stages including harvest. S_2 (20cm x 15cm) recorded significantly higher leaf area index at the maximum tillering (5.24) and harvest (4.39) stages. Significantly higher leaf area index was recorded at N_3 during the maximum tillering (5.82), panicle initiation (5.31) and harvest (4.87) stages.

The first order interactions and second order interactions are presented in Table 5b. Among the interactions, while S x D and S x N were significant at all the three stages, D x N proved to be significant only at the panicle initiation stage. The treatment combination, s_2d_2 (20cm x 15cm + 2 seedlings per hill) resulted in significantly higher leaf area index at the maximum tillering stage (5.43) and panicle initiation stage (4.94) and it was on a par with s_1d_1 during both the stages. Significantly higher leaf area index of 4.48 recorded by s_2d_2 at the harvest stage was at par with s_1d_1 and s_1d_2. The treatment combination, s_1n_3 resulted in significantly higher leaf area index at maximum tillering stage (6.04) and panicle initiation stage (5.50). Significantly higher leaf area index of 4.88 was recorded by the treatment s_2n_3 (20cm x 15cm + 150: 75: 75 kg NPK ha^{-1}) at harvest stage and it was on a par with s_1n_3.

The leaf area index of hybrid rice, KRH-2 (5.12, 4.72 and 4.29) was significantly more than the control Jaya (4.20, 3.94 and 3.70) during all the three growth stages. Between treatment combinations including control, $s_2d_2n_3$ and $s_2d_1n_3$ recorded higher leaf area indices of 4.94 and 4.80 respectively.

Table 5a. Effect of spacing, seedling density and nutrient level on leaf area index

Treatment	Leaf area index		
	Maximum tillering	Panicle initiation	Harvest
Spacing			
S_1	5.06	4.68	4.19
S_2	5.24	4.77	4.39
Seedling density			
D_1	5.16	4.72	4.30
D_2	5.14	4.73	4.29
Nutrient level			
N_1	4.50	4.15	3.73
N_2	5.14	4.71	4.28
N_3	5.82	5.31	4.87
SEm S	0.06	0.06	0.05
D	0.06	0.06	0.05
N	0.07	0.08	0.07
CD (0.05) S	0.176	-	0.168
D	-	-	-
N	0.216	0.247	0.205

Table 5b. Interaction effect of spacing, seedling density and nutrient levels on leaf area index.

Treatment	Leaf area index					
	Maximum tillering		Panicle initiation		Harvest	
S x D	S_1	S_2	S_1	S_2	S_1	S_2
D_1	5.27	4.86	4.84	4.51	4.30	4.09
D_2	5.06	5.43	4.60	4.94	4.30	4.48
SEm	0.08		0.09		0.08	
CD (0.05)	0.249		0.285		0.291	
S x N	S_1	S_2	S_1	S_2	S_1	S_2
N_1	4.20	4.80	3.88	4.42	3.47	3.98
N_2	4.96	5.32	4.65	4.77	4.24	4.31
N_3	6.04	5.61	5.50	5.12	4.86	4.88
SEm	0.10		0.11		0.09	
CD (0.05)	0.306		0.349		0.291	
D x N	D_1	D_2	D_1	D_2	D_1	D_2
N_1	4.38	4.61	3.96	4.34	3.63	3.83
N_2	5.28	5.00	4.84	4.58	4.40	4.16
N_3	5.82	5.82	5. 36	5.26	4.87	4.87
SEm	0.10		0.11		0.09	
CD (0.05)	-		0.349		-	
S x D x N						
$s_1d_1n_1$	4.18		3.81		3.46	
$s_1d_1n_2$	5.32		4.96		4.50	
$s_1d_1n_3$	6.31		5.75		4.92	
$s_1d_2n_1$	4.59		4.10		3.79	
$s_1d_2n_2$	5.24		4.72		4.29	
$s_1d_2n_3$	5.34		4.98		4.82	
$s_2d_1n_1$	4.21		3.94		3.49	
$s_2d_1n_2$	4.59		4.33		3.98	
$s_2d_1n_3$	5.77		5.26		4.80	
$s_2d_2n_1$	5.00		4.74		4.17	
$s_2d_2n_2$	5.41		4.82		4.33	
$s_2d_2n_3$	5.88		5.26		4.94	
SEm	0.14		0.16		0.14	
CD (0.05)	-		-		-	
Treatment mean	5.12		4.72		4.29	
Control mean	4.20		3.94		3.70	
Treatment Vs. Control	S		S		S	
Between treatments (including control)	S		S		S	

4.1.5 Rooting Depth

The results on the effect of spacing, seedling density and nutrient levels on the rooting depth of hybrid rice and its comparison with the control Jaya are presented in Table 6a.

On perusal of the data, it was observed that seedling density (D) and nutrient levels (N) significantly influenced the rooting depth of hybrid rice, in the maximum tillering, panicle initiation and harvest stages. The higher seedling density, D_2 and the lowest nutrient level, N_1 recorded higher rooting depths of 24.58cm and 25.63cm at the maximum tillering stage, 26.46cm and 27.39cm at the panicle initiation stage and 23.01cm and 23.63cm at the harvest stage respectively. Spacing was found to affect the rooting depth significantly at the panicle initiation stage only, with the wider spacing S_2 recording the maximum rooting depth (26.04cm).

The first order and second order interactions presented in Table 6b showed that S x D and S x N were significant at the harvest stage. While the treatment combination s_2d_2 revealed significantly higher rooting depth (23.48cm) at the harvest stage, s_1n_1 recorded the same (23.92cm) at this stage. The treatment combination, d_2n_1 resulted in significantly deeper roots during the maximum tillering (26.75cm), panicle initiation (28.52cm) and harvest (24.87cm) stages. At the maximum tillering stage d_2n_1 was at par with d_2n_2. The treatment *versus* control comparison did not show any significant difference between KRH-2 and Jaya. The between treatments including control comparison revealed significant difference.

Table 6a. Effect of spacing, seedling density and nutrient level on rooting depth, cm

Treatment	Rooting depth		
	Maximum tillering	Panicle initiation	Harvest
Spacing			
S_1	23.46	25.34	21.89
S_2	24.11	26.04	22.34
Seedling density			
D_1	22.98	24.92	21.23
D_2	24.58	26.46	23.01
Nutrient level			
N_1	25.63	27.39	23.63
N_2	24.30	26.23	22.51
N_3	21.41	23.44	20.22
SEm S	0.25	0.22	0.21
D	0.25	0.22	0.21
N	0.31	0.27	0.26
CD (0.05) S	-	0.65	-
D	0.740	0.65	0.63
N	0.906	0.805	0.77

Table 6b. Interaction effect of spacing, seedling density and nutrient level on rooting depth, cm

Treatment	Rooting depth					
	Maximum tillering		Panicle initiation		Harvest	
S x D	S_1	S_2	S_1	S_2	S_1	S_2
D_1	22.67	23.30	24.64	25.19	21.26	21.20
D_2	24.24	24.91	26.03	26.89	22.53	23.48
SEm	0.35		0.31		0.30	
CD (0.05)	-		-		0.89	
S x N	S_1	S_2	S_1	S_2	S_1	S_2
N_1	25.82	25.45	27.48	27.30	23.92	23.33
N_2	23.85	24.75	25.70	26.77	22.05	22.97
N_3	20.70	22.12	22.83	24.05	19.72	20.72
SEm	0.43		0.39		0.374	
CD (0.05)	-		-		1.093	
D x N	D_1	D_2	D_1	D_2	D_1	D_2
N_1	24.52	26.75	26.27	28.52	22.38	24.87
N_2	23.12	25.48	25.18	27.28	21.40	23.62
N_3	21.32	21.50	23.30	23.58	19.90	20.53
SEm	0.43		0.39		0.374	
CD (0.05)	1.282		1.138		1.093	
S x D x N						
$s_1d_1n_1$	24.70		26.53		22.97	
$s_1d_1n_2$	23.10		25.20		21.63	
$s_1d_1n_3$	20.20		22.20		19.17	
$s_1d_2n_1$	26.93		28.43		24.87	
$s_1d_2n_2$	24.60		26.20		22.47	
$s_1d_2n_3$	21.20		23.47		20.27	
$s_2d_1n_1$	24.33		26.00		21.80	
$s_2d_1n_2$	23.13		25.17		21.17	
$s_2d_1n_3$	22.43		24.40		20.63	
$s_2d_2n_1$	26.57		28.60		24.87	
$s_2d_2n_2$	26.37		28.37		24.77	
$s_2d_2n_3$	21.80		23.70		20.80	
SEm	0.62		0.55		0.52	
CD (0.05)	-		1.610		-	
Treatment mean	23.78		25.68		22.11	
Control mean	24.96		26.8		23.1	
Treatment Vs. Control	NS		NS		NS	
Between treatments (including control)	S		S		S	

4.1.6 Dry Matter Production

The results on dry matter production (shoot, root and total) at maximum tillering, panicle initiation and harvest stages are presented in Table 7a, 7b and 7c.

4.1.6.1 *Dry Matter Production (Shoot)*

The shoot dry matter production (g $hill^{-1}$) varied significantly between the two spacings at maximum tillering, panicle initiation and harvest stages. While S_2 recorded higher shoot dry matter production at the maximum tillering (4.71g $hill^{-1}$) and harvest (67.98g $hill^{-1}$) stages, S_1 produced more shoot dry matter (34.57g $hill^{-1}$) during the panicle initiation stage.

The effect of seedling density on shoot dry matter production was significant at the panicle initiation and harvest stages. Between the two seedling densities tested, higher seedling density, D_2 recorded more shoot dry matter (34.78g $hill^{-1}$) at the panicle initiation stage, D_1 recorded the same (69.44g $hill^{-1}$) during harvest.

The shoot dry matter at all the three growth stages was significantly influenced by the nutrient levels. Among the three nutrient levels, N_3 proved to be superior at maximum tillering (5.29g $hill^{-1}$), panicle initiation (37.98g $hill^{-1}$) and harvest (82.97g $hill^{-1}$) stages.

The results on three first order interactions presented in Table 7b and second order interactions in 7c, when compared, showed that spacing x seedling density (S x D) and seedling density x nutrient level (D x N) were significant with respect to shoot dry matter at the panicle initiation and harvest stages and spacing x nutrient level (S x N) was significant at the harvest stage. The shoot dry matter during the panicle initiation stage was highest at s_1d_2 (35.44g $hill^{-1}$) and it was at par with s_2d_2 (34.11g $hill^{-1}$). At the harvest stage, s_1d_1 recorded the highest shoot dry matter (70.83g $hill^{-1}$). The significance of the S x N interaction at the harvest stage was due to s_2n_3 which yielded 96.38g $hill^{-1}$ of shoot dry matter. Among the 12 second order interactions, $s_2d_1n_3$ produced significantly higher shoot dry matter (101.90g hill^{-1}).

The shoot dry matter production of KRH-2 was significantly more than Jaya at the maximum tillering (4.40g hill^{-1}, 2.02g hill^{-1}) and panicle initiation (32.74g hill^{-1}, 24.56g hill^{-1}) stages. However, at harvest, Jaya exhibited a slightly higher shoot dry matter (68.94g hill^{-1}) than KRH-2 (62.67g hill^{-1}). The comparison made between the treatment combinations including control also revealed significance with the treatment combination $s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) producing more dry matter during the maximum tillering (5.90g hill^{-1}) and harvest (101.90g hill^{-1}) stages and $s_1d_1n_3$ at panicle initiation stage (40.77g hill^{-1}).

4.1.6.2 *Dry Matter Production (Root)*

Spacing had significant effect on the root dry matter production at the maximum tillering stage with S_2 (20cm x 15 cm) recording the maximum (15.37g hill^{-1}). The root dry matter production at maximum tillering, panicle initiation and harvest stages varied significantly with seedling density and nutrient levels. D_1 (1 seedling per hill) and N_1 (90: 45: 45: kg NPK per ha) contributed highest to the root dry matter at all the three stages of growth. While D_1 resulted in 15.23g hill^{-1}, 19.57g hill^{-1} and 17.62g hill^{-1} root dry weight at maximum tillering, panicle initiation and harvest stages, N_1 recorded 17.62g hill^{-1}, 21.36g hill^{-1} and 19.52g hill^{-1} respectively at the above growth stages.

Among the first order interactions, S x D and D x N had significant effect at the maximum tillering and panicle initiation and harvest stages respectively, S x N showed significance only at the maximum tillering stage. The treatment combination, s_2d_1 produced significantly more root dry matter at the maximum tillering (16.95g hill^{-1}) and panicle initiation (20.86g hill^{-1}) and harvest (18.81g hill^{-1}) stages. Among the S x N interactions, the treatment combination, s_2n_1 produced significantly higher root dry matter (17.67g hill^{-1}) at the maximum tillering stage and it was on a par with s_1n_1. The interaction d_1n_1 recorded significantly higher root dry matter per plant *i.e.* 19. 05g hill^{-1} and 22.92g hill^{-1}, 21.01g hill^{-1} at the maximum tillering, panicle initiation and harvest stages respectively.

The interaction, S x D x N was observed to be significant at the maximum tillering and panicle initiation stages. The treatment combination $s_2d_1n_1$ produced significantly more root dry matter at maximum tillering (19.52g hill^{-1}) and panicle initiation (23.27g hill^{-1}) stages. At the panicle initiation stage, the best treatment $s_2d_1n_1$ was at par with $s_1d_1n_1$ (22.57g hill^{-1}).

Hybrid rice produced significantly more root dry matter at all the three growth stages (14.78g hill^{-1}, 18.83g hill^{-1}, 16.89g hill^{-1}) as compared to the control Jaya (8.95g hill^{-1}, 12.86g hill^{-1}, 11.12g hill^{-1}). Between the treatments including control, the treatment combination, $s_2d_1n_1$ (20cm x15cm + 1 seedling per hill + 90: 45: 45 kg NPK ha^{-1}) produced the highest root dry matter followed by $s_1d_1n_1$.

4.1.6.3 *Total Dry Matter Production*

The results on the effect of spacing, seedling density and nutrient level on the total dry matter production per hill are presented in Table 7a and the first order and second order interactions in Tables 7b and 7c respectively. The results are graphically presented in Fig. 3a and 3b.

Spacing, seedling density and nutrient levels had significant effect on the total dry matter production per plant. Wider spacing, S_2 (20cm x 15cm) recorded the maximum dry matter at maximum tillering (20.08g hill^{-1}), panicle initiation (49.95g hill^{-1}) and harvest (84.98g hill^{-1}) stages. While D_1 (1 seedling per hill) resulted in significantly higher dry matter production at maximum tillering (19.83g hill^{-1}) and harvest (87.06g hill^{-1}) stages, D_2 was significantly superior (52.88g hill^{-1}) at the panicle initiation stage. Among the three nutrient levels, N_1 (90: 45: 45 kg NPK ha^{-1}) was significantly superior in terms of the total dry matter production at the maximum tillering stage (21.22g hill^{-1}) and N_3

(150: 75: 75 kg NPK ha^{-1}) at panicle initiation (54.73g $hill^{-1}$) and harvest (97.70g $hill^{-1}$) stages.

The first order interactions, S x D, S x N and D x N significantly affected the total dry matter production at the maximum tillering and harvest stages. While interaction, s_2d_1 produced significantly higher dry matter (21.90g $hill^{-1}$) at the maximum tillering stage, s_1d_1 proved superior (87.27g $hill^{-1}$) at the harvest stage. However, at the harvest stage s_1d_1 was on a par with s_2d_1. The treatment combination, s_2n_1 recorded significantly more dry matter per plant at the maximum tillering (19.29g $hill^{-1}$) and s_2n_3 proved superior at harvest (111.9g $hill^{-1}$) stages. Among the D x N interactions, while d_1n_1 was significantly superior (22.95g $hill^{-1}$) at the maximum tillering stage, d_1n_3 proved superior (111.49g $hill^{-1}$) at the harvest stage.

The second order interaction, S x D x N had significant effect on the total dry matter production per plant only at the maximum tillering stage, with the treatment combination $s_2d_1n_1$ recording the highest total dry matter (23.81g $hill^{-1}$).

Hybrid rice, KRH-2 when compared with Jaya, showed significantly higher total dry matter production per hill at the maximum tillering (19.19g $hill^{-1}$ as against 10.98g $hill^{-1}$) stage and (51.58g $hill^{-1}$ as against 37.43g $hill^{-1}$) at panicle initiation stage. The comparison made between treatments including control revealed significance and the treatment combination $s_2d_1n_1$ recorded the highest total dry matter per plant (23.81g $hill^{-1}$) at maximum tilllering stage and the treatment combination $s_1d_2n_3$ at panicle initiation (56.37g $hill^{-1}$) stage.

Table 7a . Effect of spacing, seedling density and nutrient level on dry matter production (shoot. root, total), g $hill^{-1}$

Treatment	Shoot dry matter production			Root dry matter production			Total dry matter production		
	MT	PI	Harvest	MT	PI	Harvest	MT	PI	Harvest
Spacing									
S_1	4.10	34.57	57.36	14.21	18.64	16.79	18.31	53.21	74.15
S_2	4.71	30.93	67.98	15.37	19.02	16.99	20.08	49.95	84.98
Seedling density									
D_1	4.60	30.72	69.44	15.23	19.57	17.62	19.83	50.28	87.06
D_2	4.21	34.78	55.90	14.34	18.10	16.16	18.55	52.88	72.06
Nutrient level									
N_1	3.61	27.77	43.24	17.62	21.36	19.52	21.22	49.13	62.76
N_2	4.32	32.50	61.81	14.05	18.39	16.42	18.36	50.89	78.23
N_3	5.29	37.98	82.97	12.70	16.75	14.73	17.99	54.73	97.70
SEm S	0.13	0.39	0.65	0.12	0.27	0.28	0.12	0.44	0.78
D	0.13	0.39	0.65	0.12	0.27	0.28	0.12	0.44	0.78
N	0.16	0.48	0.79	0.15	0.33	0.34	0.15	0.54	0.96
CD (0.05) S	0.397	1.153	1.898	0.359	-	-	0.366	1.292	2.298
D	-	1.153	1.898	0.359	0.791	0.817	0.366	1.292	2.298
N	0.486	1.412	2.326	0.440	0.969	1.001	0.449	1.583	2.815

Table 7b. Interaction effect of spacing x seedling density, spacing x nutrient level and seedling density x nutrient level on dry matter production, g hill^{-1}

Treatment	Shoot dry matter production						Root dry matter production						Total dry matter production					
	MT		PI		Harvest		MT		PI		Harvest		MT		PI		Harvest	
S x D	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
D_1	4.26	4.94	33.69	27.74	70.83	68.05	13.50	16.95	18.28	20.86	16.43	18.81	17.76	21.90	51.97	48.60	87.27	86.86
D_2	3.94	4.48	35.44	34.11	43.89	67.91	14.91	13.78	19.01	17.19	17.14	15.18	18.85	18.26	54.46	51.30	61.03	83.09
SEm	0.19		0.55		0.92		0.17		0.38		0.39		0.17		0.62		1.11	
CD (0.05)	-		1.631		2.686		0.508		1.119		1.156		0.518		-		3.25	
S x N	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
N_1	3.15	4.06	30.22	25.32	44.81	41.67	17.56	17.67	21.42	21.30	19.61	19.43	20.71	21.73	51.63	46.62	64.42	61.10
N_2	4.09	4.55	33.75	31.25	57.73	65.88	13.43	14.66	18.25	18.53	16.50	16.34	17.52	19.21	52.00	49.78	74.23	82.23
N_3	5.06	5.53	39.73	36.22	69.55	96.38	11.63	13.76	16.27	17.23	14.26	15.21	16.69	19.29	56.00	53.45	83.81	111.59
SEm	0.235		0.68		1.12		0.21		0.46		0.48		0.21		0.76		1.36	
CD (0.05)	-		-		3.290		0.622		-		-		0.635		-		3.981	
D x N	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2
N_1	3.90	3.31	24.50	31.03	43.58	42.90	19.05	16.18	22.92	19.80	21.01	18.03	22.95	19.49	47.42	50.83	64.59	60.93
N_2	4.49	4.15	30.10	34.90	68.28	55.34	13.87	14.22	18.77	18.02	16.82	16.02	18.36	18.37	48.87	52.92	85.10	71.35
N_3	5.42	5.16	37.55	38.40	96.47	69.46	12.76	12.63	17.02	16.48	15.03	14.44	18.18	17.80	54.57	54.88	111.49	83.91
SEm	0.235		0.68		1.12		0.21		0.46		0.48		0.21		0.76		1.36	
CD (0.05)	-		1.997		3.290		0.622		1.371		1.416		0.635		-		3.981	

Table 7c. Interaction effect of spacing x seedling density x nutrient level on dry matter production, g $hill^{-1}$

Treatment	Shoot dry matter production			Root dry matter production			Total dry matter production		
	MT	PI	Harvest	MT	PI	Harvest	MT	PI	Harvest
S x D x N									
$s_1d_1n_1$	3.50	27.73	49.80	18.59	22.57	20.68	22.09	50.30	70.48
$s_1d_1n_2$	4.35	32.57	71.67	11.80	17.40	15.65	16.15	49.97	87.32
$s_1d_1n_3$	4.94	40.77	91.03	10.11	14.87	12.97	15.05	55.63	104.00
$s_1d_2n_1$	2.79	32.70	39.82	16.54	20.27	18.53	19.33	52.97	58.35
$s_1d_2n_2$	3.84	34.93	43.79	15.05	19.10	17.34	18.89	54.03	61.13
$s_1d_2n_3$	5.18	38.70	48.06	13.15	17.67	15.55	18.33	56.37	63.61
$s_2d_1n_1$	4.29	21.27	37.36	19.52	23.27	21.34	23.81	44.53	58.70
$s_2d_1n_2$	4.63	27.63	64.88	15.93	20.13	18.00	20.57	47.77	82.88
$s_2d_1n_3$	5.90	34.33	101.90	15.41	19.17	17.08	21.31	53.50	118.99
$s_2d_2n_1$	3.84	29.37	45.99	15.82	19.33	17.52	19.66	48.70	63.51
$s_2d_2n_2$	4.46	34.87	66.89	13.39	16.93	14.69	17.85	51.80	81.58
$s_2d_2n_3$	5.15	38.10	90.87	12.12	15.30	13.33	17.27	53.40	104.20
SEm	0.33	0.96	1.59	0.30	0.66	0.68	0.30	1.08	1.92
CD (0.05)	-	-	4.653	0.622	1.939	-	0.898	-	-
Treatment mean	4.40	32.74	62.67	14.78	18.83	16.89	19.19	51.58	79.56
Control mean	2.02	24.56	68.94	8.95	12.86	11.12	10.98	37.43	80.07
Treatment Vs. Control	S	S	S	S	S	S	S	S	NS
Between treatments (including control)	S	S	S	S	S	S	S	S	S

4.2 YIELD ATTRIBUTES AND YIELD

4.2.1 Productive Tillers per Hill

The data on the effect of spacing, seedling density and nutrient levels on the number of productive tillers per hill at the harvest stage are presented in Table 8a and graphically represented in Fig. 4a. The first order and second order interactions are presented in Table 8b and 4b.

The results revealed that among the three factors, nutrient levels alone had significant effect on the number of productive tillers at harvest. The highest nutrient level tested, N_3 (150: 75: 75 kg NPK per ha) produced significantly more number of productive tillers (7.91). The interactions, S x D and S x N were significant. The treatment combination, s_1d_1 recorded significantly more number of productive tillers per hill (7.06) and was on a par with s_2d_2 (6.44) and s_2d_1 (6.38). The treatment combination s_1n_3 produced significantly more number of productive tillers per hill (8.64). The S x D x N interactions were insignificant.

Hybrid rice, KRH-2 did not show significant difference when compared with control, Jaya with respect to the number of productive tillers per hill. However, the comparison made between treatments including control was significant, with the combination $s_1d_1n_3$ recording the highest productive tiller count per hill (8.86), followed by $s_2d_1n_3$ (8.42).

4.2.2 Spikelets per Panicle

The perusal of the data presented in Table 8a and Fig. 5a, revealed that spacing, seedling density and nutrient levels had significant effect on the number of spikelets per panicle.

The number of spikelets per panicle was significantly higher at closer spacing, S_1 (144.14), higher seedling density, D_2 (145.77) and at the highest nutrient level, N_3 (150.08).

The first order and second order interactions are presented in Table 8b and Fig. 5b. Among the two factor interactions, spacing x seedling density alone proved significant, with s_2d_1 recording significantly higher number of spikelets per panicle (149.51). The other first order interactions were not significant. The interaction among spacing, seedling density and nutrient level was significant. The treatment combination, $s_2d_1n_3$ produced significantly higher number of spikelets per panicle (157.30).

Hybrid rice, KRH-2 which produced 143.05 spikelets per panicle was significantly superior to the control, Jaya which could produce only 132.03 spikelets per panicle. The comparison made between treatments including control was also significant, with the treatment combination $s_2d_1n_3$ recording the highest number of spikelets per panicle.

Table 8a. Effect of spacing, seedling density and nutrient level on productive tillers per hill and spikelets per panicle at harvest, nos.

Treatment	Productive tillers per hill	Spikelets per panicle
Spacing		
S_1	6.72	144.14
S_2	6.19	141.97
Seedling density		
D_1	6.50	140.33
D_2	6.41	145.77
Nutrient level		
N_1	4.70	137.57
N_2	6.75	141.51
N_3	7.91	150.08
SEm S	0.18	0.56
D	0.18	0.56
N	0.23	0.69
CD (0.05) S	-	1.653
D	-	1.653
N	0.673	2.025

Table 8b. Interaction effect of spacing, seedling density and nutrient level on productive tillers per hill and spikelets per panicle at harvest, nos.

Treatment	Productive tillers per hill		Spikelets per panicle	
S x D	S_1	S_2	S_1	S_2
D_1	7.06	6.38	138.77	149.51
D_2	5.94	6.44	141.90	142.03
SEm	0.26		0.80	
CD (0.05)	0.777		2.338	
S x N	S_1	S_2	S_1	S_2
N_1	4.28	5.13	138.63	136.52
N_2	7.23	6.26	141.43	141.58
N_3	8.64	7.18	152.35	147.80
SEm	0.32		0.98	
CD (0.05)	0.952		-	
D x N	D_1	D_2	D_1	D_2
N_1	3.63	3.83	135.07	140.08
N_2	4.40	4.16	138.48	144.53
N_3	4.87	4.87	147.45	142.70
SEm	0.09		0.98	
CD (0.05)	-		-	
S x D x N				
$s_1d_1n_1$	4.90		135.03	
$s_1d_1n_2$	7.41		133.87	
$s_1d_1n_3$	8.86		147.40	
$s_1d_2n_1$	4.52		135.10	
$s_1d_2n_2$	6.10		143.10	
$s_1d_2n_3$	7.19		147.50	
$s_2d_1n_1$	3.66		142.22	
$s_2d_1n_2$	7.06		149.00	
$s_2d_1n_3$	8.42		157.30	
$s_2d_2n_1$	5.74		137.93	
$s_2d_2n_2$	6.42		140.07	
$s_2d_2n_3$	7.16		148.10	
SEm	0.46		1.38	
CD (0.05)	-		4.051	
Treatment mean	6.45		143.05	
Control mean	6.29		132.03	
Treatment Vs. Control	NS		S	
Between treatments (including control)	S		S	

4.2.3 Panicle Weight

The results pertaining to panicle weight are presented in Table 9a. It revealed that nutrient levels alone had significant impact on panicle weight. Panicles produced at the highest nutrient level N_3 were the heaviest (3.16g). Spacing and seedling density failed to reveal significant effect on panicle weight.

The first order and second order interactions presented in Table 9b, failed to reveal any significance.

Hybrid rice, KRH-2 recorded significantly higher panicle weight (3.08g) than the inbred Jaya (2.47g). The comparison between treatments including control proved to be significant with the treatment combination $s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) recording the highest panicle weight (3.08g) and the least value (2.89) was observed for the treatment $s_2d_2n_1$.

4.2.4 Panicle Length

The data on the effect of spacing, seedling density and nutrient levels on panicle length are presented in Table 9a and their interaction effects are presented in Table 9b. Panicles produced at a closer spacing S_1 were significantly longer (30.29cm) than at the wider spacing S_2 (29.68cm). While seedling density had no significant effect on panicle length, nutrient levels significantly affected the same. N_3 produced longer panicles (30.28cm) and was on a par with N_2 (30.08cm).

The interaction between spacing and seedling density was significant with the treatment combination, s_2d_1 recording more panicle length (30.61cm).

The panicles produced by KRH-2 were significantly longer (29.98cm) than those of the control, Jaya (26.46cm). The between treatments including control comparison was significant and the treatment combination, $s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) produced the longest panicles (31.12cm).

Table 9a. Effect of spacing, seedling density and nutrient level on panicle weight and panicle length

Treatment	Panicle weight (g)	Panicle length (cm)
Spacing		
S_1	3.06	30.29
S_2	3.08	29.68
Seedling density		
D_1	3.25	29.91
D_2	3.17	30.07
Nutrient level		
N_1	3.03	29.61
N_2	3.06	30.08
N_3	3.16	30.28
SEm S	0.02	0.09
D	0.02	0.09
N	0.04	0.11
CD (0.05) S	-	0.275
D	-	-
N	0.062	0.337

Table 9b. Interaction effect of spacing, seedling density and nutrient level on panicle weight and panicle length

Treatment	Panicle weight (g)		Panicle length (cm)	
S x D	S_1	S_2	S_1	S_2
D_1	3.21	3.29	29.98	30.61
D_2	2.91	2.93	29.84	29.52
SEm	0.02		0.13	
CD (0.05)	-		0.389	
S x N	S_1	S_2	S_1	S_2
N_1	3.04	3.02	29.73	29.48
N_2	3.05	3.08	30.49	29.67
N_3	3.09	3.23	30.66	29.90
SEm	0.05		0.16	
CD (0.05)	-		-	
D x N	D_1	D_2	D_1	D_2
N_1	3.16	2.91	25.59	29.62
N_2	3.22	2.91	30.04	30.12
N_3	3.37	2.94	30.10	30.47
SEm	0.15		0.16	
CD (0.05)	0.130		-	
S x D x N				
$s_1d_1n_1$	3.16		29.63	
$s_1d_1n_2$	3.19		30.09	
$s_1d_1n_3$	3.27		30.21	
$s_1d_2n_1$	2.92		29.55	
$s_1d_2n_2$	2.91		29.99	
$s_1d_2n_3$	2.90		29.98	
$s_2d_1n_1$	3.15		29.83	
$s_2d_1n_2$	3.24		30.89	
$s_2d_1n_3$	3.48		31.12	
$s_2d_2n_1$	2.89		29.41	
$s_2d_2n_2$	2.91		29.34	
$s_2d_2n_3$	2.98		29.82	
SEm	0.05		0.23	
CD (0.05)	-		-	
Treatment mean	3.08		29.98	
Control mean	2.47		26.46	
Treatment Vs. Control	S		S	
Between treatmentss (including control)	S		S	

4.2.5 Filled Grains per Panicle

The results on the number of filled grains per panicle as influenced by spacing, seedling density and nutrient levels are presented in Table 10a, and the effect of their interactions in Table 10b.

Seedling density and nutrient levels were found to exert significant influence on the number of filled grains per panicle. The number of filled grains per panicle was significantly higher in D_2 (111.73) and N_3 (115.00).

All the three first order interactions, *viz.*, S x D, S x N and D x N had significant effect on the number of filled grains per panicle. The interaction, s_2d_1 recorded significantly higher number of filled grains per panicle (116.03). Among the S x N interactions, s_1n_3 produced significantly more number of filled grains per panicle (115.63), but was on a par with s_2n_3 (114.37). The D x N interactions showed d_2n_2 to be produced significantly superior with more number of filled grains per panicle (110.73) which was at par with d_2n_3 (110.72) and d_1n_3 (110.28). The S x D x N interaction was not significant.

Hybrid rice, KRH-2 (106.42) and the control, Jaya (104.63) had no significant difference with respect to the number of filled grains per panicle. However, the comparison made between treatments including control revealed significance, with the hybrid rice at $s_2d_1n_3$ recording the highest number of filled grains per panicle (124.37).

4.2.6 Sterility Percentage

The perusal of data presented in Table 10a and 10b and Fig. 6a and 6b, showed significant effect for spacing, seedling density, nutrient levels and their interaction on the sterility percentage. Sterility percentage was significantly lower in S_2 (24.63 per cent), D_2 (23.43 per cent) and N_3 (23.41 per cent).

Among the S x D, S x N and D x N interactions, sterility percentage was significantly lower at s_2d_1 (22.44 per cent), s_2n_3 (22.62 per cent) and d_2n_3 (21.62 per cent). The treatment combination, $s_2d_1n_3$ revealed significantly lower percentage of sterile grains (20.93 per cent).

Significant difference was observed in the sterility percentage between hybrid rice and the control, Jaya. Sterility percentage was significantly higher in hybrid rice (25.76 per cent) than Jaya (20.76 per cent). Significance was observed in the comparison made between the treatments including control. While the treatment combination, $s_1d_1n_1$ recorded the highest sterility percentage (38.77 per cent), $s_2d_1n_3$ recorded the least value (20.93 per cent) for percentage sterility.

4.2.7 Thousand Grain Weight

The data on thousand grain weight as influenced by spacing, seedling density and nutrient levels and their interactions are presented in Table 10a and 10b .respectively.

The perusal of the data revealed that the effect of spacing and seedling density was non-significant with respect to the thousand grain weight. However, nutrient levels had significant effect with N_3 recording significantly higher thousand grain weight (22.63g). The first order and second order interactions could not affect thousand grain weight significantly.

The treatment mean when compared against control proved significant. The thousand grain weight of the control, Jaya (25.58g) was significantly higher than that of the hybrid rice, KRH-2 (21.96g). The significance observed in the comparison made between treatments including control also showed the control to be superior, followed by the treatment combinations, $s_2d_2n_3$ (22.74g), $s_2d_1n_3$ (22.64g), $s_1d_2n_3$ (22.64g) and $s_1d_1n_3$ (22.51g)

Table 10a. Effect of spacing, seedling density and nutrient level on filled grains per panicle, sterility percentage and thousand grain weight

Treatment	Filled grains per panicle (nos.)	Sterility percentage (%)	Thousand grain weight (g)
Spacing			
S_1	105.76	26.89	21.92
S_2	107.09	24.63	22.01
Seedling density			
D_1	101.12	28.09	21.93
D_2	111.73	23.43	21.99
Nutrient level			
N_1	97.68	29.12	21.37
N_2	106.59	24.76	21.89
N_3	115.00	23.41	22.63
SEm S	0.58	0.30	0.56
D	0.58	0.30	0.56
N	0.71	0.36	0.06
CD (0.05) S	-	0.877	-
D	1.702	0.877	-
N	2.085	1.074	0.203

Table 10b. Interaction effect of spacing, seedling density and nutrient level on filled grains per panicle, sterility percentage and thousand grain weight

Treatment	Filled grains per panicle (nos.)		Sterility percentage (%)		Thousand grain weight (g)	
S x D	S_1	S_2	S_1	S_2	S_1	S_2
D_1	95.49	116.03	31.34	22.44	21.87	21.96
D_2	106.76	107.42	24.83	24.42	21.99	22.03
SEm	0.82		0.42		0.08	
CD (0.05)	2.408		1.240		-	
S x N	S_1	S_2	S_1	S_2	S_1	S_2
N_1	95.23	100.13	31.57	26.67	21.23	21.50
N_2	106.42	106.77	24.92	24.60	21.94	21.84
N_3	115.63	114.37	24.20	22.62	22.57	22.69
SEm	1.01		0.52		0.09	
CD (0.05)	2.942		1.519		-	
D x N	D_1	D_2	D_1	D_2	D_1	D_2
N_1	90.63	104.73	32.98	25.25	21.34	21.39
N_2	102.45	110.73	26.08	23.43	21.89	21.89
N_3	110.28	110.72	25.20	21.62	22.58	22.69
SEm	1.01		0.52		0.09	
CD (0.05)	2.942		1.519		-	
S x D x N						
$s_1d_1n_1$	82.90		38.77		21.13	
$s_1d_1n_2$	96.67		27.80		21.98	
$s_1d_1n_3$	106.90		27.47		22.51	
$s_1d_2n_1$	98.37		27.20		21.54	
$s_1d_2n_2$	108.23		24.37		21.79	
$s_1d_2n_3$	113.67		22.93		22.64	
$s_2d_1n_1$	107.57		24.37		21.13	
$s_2d_1n_2$	116.17		22.03		21.90	
$s_2d_1n_3$	124.37		20.93		22.64	
$s_2d_2n_1$	101.90		26.13		21.46	
$s_2d_2n_2$	105.30		24.83		21.89	
$s_2d_2n_3$	115.07		22.30		22.74	
SEm	1.42		0.73		0.13	
CD (0.05)	-		2.148		-	
Treatment mean	106.42		25.76		21.96	
Control mean	104.63		20.76		25.58	
Treatment Vs. Control	NS		S		S	
Between treatments (including control)	S		S		S	

4.2.8 Grain Yield

The perusal of the results on grain yield presented in Table 11a and Fig. 7a, showed that spacing had no significant impact on grain yield. But grain yield varied significantly with seedling density and nutrient levels.

The treatment D_2 (two seedlings per hill) resulted in the higher grain yield (4607.44 kg ha^{-1}). Among the three nutrient levels, N_3 (150: 75: 75 kg NPK ha^{-1}) produced significantly higher grain yield (4887.30 kg ha^{-1}).

The first order and second order interactions are presented in Table 11b and Fig. 7b. The interactive effect between spacing and seedling density (S x D) and spacing and nutrient levels (S x N) were observed to be significant. Among the S x D interactions, s_2d_1 was significantly higher (4985.40 kg ha^{-1}) in terms of grain yield. The S x N combination revealed significantly higher grain yields at s_1n_3 (5068.47 kg ha^{-1}). The S x D x N interaction was not significant.

The treatment (KRH-2) when compared against control (Jaya) showed that Jaya produced significantly higher grain yield (4578.33 kg ha^{-1}) than KRH-2 (4194.67 kg ha^{-1}). However, the comparison made between treatments including control was significant. By this comparison it was observed that the treatment combination, $s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) recorded the maximum grain yield (5803.30 kg ha^{-1}).

4.2.9 Straw Yield

The results presented in Table 11a and Fig. 7a indicated that while spacing had no significant effect on straw yield, it varied significantly with seedling density and nutrient levels. Higher straw yield was recorded at D_2 (6214.90 kg ha^{-1}) and N_3 (6328.75 kg ha^{-1}).

The results on interaction effects are presented in Table 11b and Fig. 7b. The effect of spacing x seedling density was significant and the treatment combination, s_2d_1 recorded significantly higher straw yield (6598.09 kg ha^{-1}).

The interaction among spacing, seedling density and nutrient levels was also significant. The treatment combination, $s_2d_1n_3$ recorded the maximum straw yield (6904.03 kg ha^{-1}) and it was observed to be at par with $s_2d_2n_3$ (6612.80 kg ha^{-1}), $s_2d_1n_2$ (6529.80 kg ha^{-1}) and $s_2d_1n_1$ (6360.43 kg ha^{-1}).

The control, Jaya produced significantly more straw yield (6674.43 kg ha^{-1}) than hybrid rice, KRH-2 (5715.17 kg ha^{-1}). The comparison made between treatments including control revealed significance. As in the case of grain yield, the treatment combination $s_2d_1n_3$ was significantly superior in terms of straw yield also.

4.2.10 Harvest Index

Data summarized in Table 11a showed that among the three treatments, nutrient levels alone had significant effect on harvest index. Spacing and seedling density had no significant effect on this yield attribute. Nutrient level, N_3 alone revealed significant effect on harvest index (0.44).

The data on interaction effects are presented in Table 11b. The S x D and S x N interactions were significant. While the treatment combination s_2d_1 had significantly higher harvest index (0.43), s_1n_3 revealed the same (0.44) at par with s_1n_2 and s_2n_3.

Hybrid rice (KRH-2) recorded significantly higher harvest index (0.42) than the control, Jaya (0.40). The between treatments including control comparison revealed the treatment combination, $s_2d_1n_3$ to be the best in terms of harvest index.

Table 11a. Effect of spacing, seedling density and nutrient level on grain yield, straw yield and harvest index

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index
Spacing			
S_1	4229.07	5733.07	0.42
S_2	4160.27	5697.28	0.42
Seedling density			
D_1	3781.89	5215.44	0.42
D_2	4607.44	6214.90	0.42
Nutrient level			
N_1	3571.50	5179.03	0.41
N_2	4125.20	5637.74	0.42
N_3	4887.30	6328.75	0.44
SEm S	53.97	86.52	0.002
D	53.97	86.52	0.002
N	66.10	105.96	0.002
CD (0.05) S	-	-	-
D	157.538	252.555	-
N	192. 944	309.315	0.0071

Table 11b. Interaction effect of spacing, seedling density and nutrient level on grain yield, straw yield and harvest index

Treatment	Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Harvest index	
S x D	S_1	S_2	S_1	S_2	S_1	S_2
D_1	3472.73	4985.40	4868.04	6598.09	0.42	0.43
D_2	4091.04	4229.49	5562.84	5831.71	0.42	0.42
SEm	76.32		122.36		0.0028	
CD (0.05)	222.793		357.166		0.0082	
S x N	S_1	S_2	S_1	S_2	S_1	S_2
N_1	3496.60	3646.40	5181.70	5176.35	0.40	0.41
N_2	4122.13	4128.27	5571.73	5703.75	0.43	0.42
N_3	5068.47	4706.13	6445.77	6211.73	0.44	0.43
SEm	93.48		149.86		0.0034	
CD (0.05)	272.864		-		0.0100	
D x N	D_1	D_2	D_1	D_2	D_1	D_2
N_1	3129.38	4013.62	4528.45	5829.60	0.41	0.41
N_2	3771.10	4479.30	5218.80	6056.68	0.42	0.43
N_3	4445.18	5329.42	5899.08	6758.42	0.43	0.44
SEm	93.48		149.86		0.0034	
CD (0.05)	-		-		-	
S x D x N						
$s_1d_1n_1$	2700.23		4002.97		0.40	
$s_1d_1n_2$	3384.33		4613.67		0.42	
$s_1d_1n_3$	4333.03		5987.50		0.42	
$s_1d_2n_1$	3558.53		5053.93		0.41	
$s_1d_2n_2$	4157.87		5823.93		0.42	
$s_1d_2n_3$	4556.73		5810.67		0.44	
$s_2d_1n_1$	4292.97		6360.43		0.40	
$s_2d_1n_2$	4859.93		6529.80		0.43	
$s_2d_1n_3$	5803.30		6904.03		0.46	
$s_2d_2n_1$	3734.27		5298.77		0.41	
$s_2d_2n_2$	4098.67		5583.57		0.42	
$s_2d_2n_3$	4855.53		6612.80		0.42	
SEm	132.20		211.93		0.004	
CD (0.05)	-		618.631		0.0141	
Treatment mean	4194.67		5715.17		0.42	
Control mean	4578.33		6674.43		0.40	
Treatment Vs. Control	S		S		S	
Between treatments (including control)	S		S		S	

4.3 QUALITY ATTRIBUTES

4.3.1 Cooking Properties

Cooking properties of hybrid rice (KRH-2) and Jaya were evaluated by determining the optimum cooking time, volume expansion ratio and grain elongation ratio.

4.3.1.1 *Optimum Cooking Time*

The results on the optimum cooking time as influenced by spacing, seedling density and nutrient levels are presented in Table12a and their interaction effects are presented in Table 12b.

The optimum cooking time did not vary significantly between the two spacings, two seedling densities and three nutrient levels. The interaction effects were also non–significant.

The control, Jaya took significantly more time to get cooked (29.00 minutes) compared to hybrid rice, KRH-2 (24.19 minutes). The comparison made between treatments including control was significant, with maximum cooking time for Jaya and the minimum for the treatment combination, $s_2d_2n_1$ (23.33 minutes) for hybrid rice.

4.3.1.2 *Volume Expansion Ratio*

The results on volume expansion ratio are summarized in Table12a and 12b. It was observed that spacing, seedling density, nutrient levels and their interactions had no significant effect on the volume expansion ratio.

The volume expansion ratio of Jaya (3.35) was significantly more than that for KRH-2 (3.25). When the treatment combinations were compared including the control, $s_2d_1n_2$ showed the maximum volume expansion ratio (3.45) and $s_1d_1n_1$ the least (3.17).

4.3.1.2 *Grain Elongation Ratio*

The perusal of the data presented in Tables 12a and 12b, revealed that the grain elongation ratio did not vary significantly between the spacings, seedling densities and nutrient levels. Hybrid rice, KRH-2 (1.34) and the control, Jaya (1.35) did not vary significantly. The comparison made between treatments including control was observed to be significant. The treatment combinations $s_1d_1n_3$ and $s_2d_1n_2$ which recorded a grain elongation ratio of 1.37 each was the highest.

Table 12a. Effect on spacing, seedling density and nutrient level on optimum cooking time, volume expansion ratio and grain elongation ratio

Treatment	Optimum cooking time (min.)	Volume expansion ratio	Grain elongation ratio
Spacing			
S_1	24.28	3.23	1.35
S_2	24.11	3.29	1.34
Seedling density			
D_1	24.11	3.25	1.34
D_2	24.28	3.27	1.35
Nutrient level			
N_1	24.17	3.22	1.34
N_2	24.25	3.32	1.35
N_3	24.17	3.24	1.34
SEm S	0.14	0.02	0.01
D	0.14	0.02	0.01
N	0.17	0.03	0.01
CD (0.05) S	-	-	-
D	-	-	-
N	-	-	-

Table12b. Interaction effect on spacing, seedling density and nutrient level on optimum cooking time, volume expansion ratio and grain elongation ratio

Treatment	Optimum cooking time (min.)		Volume expansion ratio		Grain elongation ratio	
S x D	S_1	S_2	S_1	S_2	S_1	S_2
D_1	24.22	24.00	3.20	3.30	1.34	1.33
D_2	24.33	24.22	3.26	3.28	1.36	1.34
SEm	0.20		0.03		0.01	
CD (0.05)	-		-		-	
S x N	S_1	S_2	S_1	S_2	S_1	S_2
N_1	24.50	23.83	3.25	3.20	1.35	1.34
N_2	24.33	24.17	3.28	3.36	1.34	1.35
N_3	24.00	24.33	3.17	3.30	1.36	1.32
SEm	0.24		0.04		0.01	
CD (0.05)	-		-		-	
D x N	D_1	D_2	D_1	D_2	D_1	D_2
N_1	24.50	23.83	3.15	3.30	1.34	1.34
N_2	23.83	24.67	3.38	3.25	1.35	1.34
N_3	24.00	24.33	3.23	3.25	1.32	1.35
SEm	0.24		0.04		0.01	
CD (0.05)	-		-		-	
S x D x N						
$s_1d_1n_1$	24.67		3.17		1.34	
$s_1d_1n_2$	24.00		3.31		1.33	
$s_1d_1n_3$	24.00		3.13		1.37	
$s_1d_2n_1$	24.33		3.32		1.36	
$s_1d_2n_2$	24.67		3.24		1.35	
$s_1d_2n_3$	24.00		3.21		1.36	
$s_2d_1n_1$	24.33		3.13		1.35	
$s_2d_1n_2$	23.67		3.45		1.37	
$s_2d_1n_3$	24.00		3.32		1.28	
$s_2d_2n_1$	23.33		3.27		1.33	
$s_2d_2n_2$	24.67		3.26		1.33	
$s_2d_2n_3$	24.67		3.29		1.35	
SEm	0.35		0.05		0.02	
CD (0.05)	-		-		-	
Treatment mean	24.19		3.25		1.34	
Control mean	29.00		3.35		1.35	
Treatment Vs. Control	S		S		NS	
Between treatments (including control)	S		S		S	

4. 3. 2 Chemical Properties

The chemical properties, which govern the nutritional quality of the grains, were assessed in terms of the crude protein, total starch, amylose and amylopectin contents.

4. 3. 2.1 *Crude Protein Content*

The results on the crude protein content are presented in Table 13a and Fig. 8a. The perusal of the data revealed that while spacing and seedling density, had no significant effect, nutrient levels significantly influenced the crude protein content of the grain. Crude protein content of hybrid rice was significantly higher at N_3 (8.49 per cent).

The first order and second order interactions are presented in Table 13b and Fig. 8b. Among the three first order interactions, the effect of seedling density (D) x nutrient level (N) was significant. The treatment combinations, d_1n_3 (8.75 per cent) and d_2n_2 (8.38 per cent) were significantly superior and were on a par. The S x D x N interaction showed significance with the treatment combination, $s_2d_1n_3$ recording the highest crude protein content (9.33 per cent) in hybrid rice.

Jaya (8.93 per cent) registered significantly higher crude protein than KRH-2 (7.26 per cent). The comparison made between treatments including control also showed significance. The treatment combination, $s_2d_1n_3$ had significantly higher crude protein content.

4.3.2.2 *Total Starch Content*

The data on the effect of spacing, seedling density and nutrient levels and their interactions are presented in Table 13a and 13b respectively. Starch content failed to respond significantly to the treatments. Hybrid rice (KRH-2) which recorded 71.22 per cent starch, did not vary significantly from the control (Jaya) with 70.30 per cent starch. However, the comparison made between the treatments including control proved significant. Among the different treatment combinations, $s_2d_1n_3$ recorded the highest starch content (72.33 per cent) and the control Jaya, the least (70.30 per cent).

4. 3.2.3 *Amylose Content*

The results on the amylose content presented in Table 13a and their interaction effects presented in Table 13b revealed that neither the spacing, seedling density and nutrient levels nor their interaction had any significant effect on the amylose content of the grain.

However, the treatment versus control comparison showed that the control Jaya was significantly superior in terms of the amylose content of the grains (22.66 per cent of starch) than the hybrid rice, KRH-2 (18.60 per cent of starch). The comparison made between the treatments including control proved to be significant. Jaya recorded the highest amylose content among all the treatment combinations.

4.3.2.4 *Amylopectin Content*

The perusal of the data presented in Table 13a and Table 13b indicated a non-significant effect for spacing, seedling density, nutrient levels and their interaction on the amylopectin content of the rice. However, Jaya recorded significantly lower amylopectin content (77.34 per cent of starch) as compared to KRH-2 (81.51 per cent of starch). Between treatments including control, $s_1d_1n_1$ and $s_1d_2n_3$ recorded the higest amylose contents of 81.87 per cent of starch, each.

Table 13a. Effect of spacing, seedling density and nutrient level on chemical properties of grain

Treatment	Crude protein (%)	Total starch (%)	Amylose (% of starch)	Amylopectin (% of starch)
Spacing				
S_1	8.08	71.10	18.62	81.88
S_2	7.96	71.17	18.66	81.13
Seedling density				
D_1	7.64	71.16	18.68	81.37
D_2	8.06	71.33	18.87	81.64
Nutrient level				
N_1	7.43	70.88	18.55	81.45
N_2	7.88	71.37	18.72	81.53
N_3	8.49	71.40	18.54	81.53
SEm S	0.09	0.18	0.22	0.30
D	0.09	0.18	0.22	0.30
N	0.12	0.22	0.27	0.37
CD (0.05) S	-	-	-	-
D	-	-	-	-
N	0.317	-		-

Table 13b. Interaction effect of spacing, seeding density and nutrient level on chemical properties of grain

Treatment	Crude protein (%)		Total starch (%)		Amylose (% of starch)		Amylopectin (% of starch)	
S x D	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
D_1	7.66	7.62	70.83	71.49	18.77	18.60	81.23	81.40
D_2	8.51	7.94	71.36	71.19	18.46	18.58	81.54	81.42
SEm	0.125		0.26		0.31		0.42	
CD (0.05)	-		-		-		-	
S x N	S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
N_1	7.88	6.98	70.79	70.99	18.38	18.72	81.62	81.29
N_2	8.21	7.54	71.20	71.54	19.20	18.24	80.80	81.77
N_3	8.16	8.82	71.30	71.50	18.27	18.82	81.74	81.19
SEm	0.154		0.32		0.38		0.52	
CD (0.05)	-		-		-		-	
D x N	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2
N_1	6.80	8.06	70.64	71.14	18.27	18.83	81.74	81.17
N_2	7.38	8.38	71.32	71.42	18.99	18.45	81.02	81.55
N_3	8.75	8.23	71.53	71.27	18.80	18.28	81.20	81.72
SEm	0.154		0.32		0.38		0.52	
CD (0.05)	0.449		-		-		-	
S x D x N								
$s_1d_1n_1$	7.15		70.40		18.13		81.87	
$s_1d_1n_2$	7.65		71.37		19.77		80.23	
$s_1d_1n_3$	8.17		70.73		18.40		81.60	
$s_1d_2n_1$	8.60		71.17		18.63		81.37	
$s_1d_2n_2$	8.77		71.03		18.63		81.37	
$s_1d_2n_3$	8.15		71.87		18.13		81.87	
$s_2d_1n_1$	6.44		70.87		18.40		81.60	
$s_2d_1n_2$	7.10		71.27		18.20		81.80	
$s_2d_1n_3$	9.33		72.33		19.20		80.80	
$s_2d_2n_1$	7.52		71.10		19.03		80.97	
$s_2d_2n_2$	7.98		71.80		18.27		81.73	
$s_2d_2n_3$	8.31		70.67		18.43		81.57	
SEm	0.22		0.65		0.54		0.74	
CD (0.05)	0.635		1.331		1.593		2.163	
Treatment mean	7.26		71.22		18.60		81.51	
Control mean	8.93		70.30		22.66		77.34	
Treatment Vs. Control	S		NS		S		S	
Between treatments (including control)	S		S		S		S	

4.3.3 Organoleptic Test

The quality attributes selected in this study were appearance, colour, flavour, texture and taste. The mean scores obtained are presented in Table 14 and Fig. 9.

The highest mean score for appearance (3.0) was obtained for $s_2d_2n_1$ (20cm x 15cm + 2 seedlings per hill + 90: 45: 45 kg NPK ha^{-1}) in hybrid rice. The control Jaya also ranked equally best in terms of appearance. The appearance of hybrid rice, in general was not that appealing (2.5) as the control Jaya (3.0).

Among the twelve treatment combinations for hybrid rice, $s_1d_2n_3$ and $s_2d_1n_3$ recorded the highest mean score value (3.4) for colour. Hybrid rice (KRH-2) and the control were equally appreciated by the panel with same score (3.0) for colour.

The results of the organoleptic test revealed that hybrid rice, KRH-2 had a desirable flavour as compared to the control, Jaya. This was clearly indicated by the mean score of 3.3 for hybrid rice and 2.8 for Jaya. The treatment combinations, $s_1d_1n_2$, $s_1d_2n_1$, $s_2d_1n_2$ and $s_2d_2n_2$ recorded mean score value of 3.4 for flavour in the case of hybrid rice.

Texturally, hybrid rice (KRH-2) was observed to be inferior to the control (Jaya). While Jaya recorded a mean score of 3.8 for texture, KRH-2 could record only 3.1. In the case of hybrid rice, the treatment combination $s_2d_2n_1$ was scored as the best (3.3).

The perusal of the data on mean scores for taste revealed that KRH-2 and Jaya were equally acceptable. Both the varieties shared the same score (2.9) for taste.

Table 14. Mean score in organoleptic test for appearance, colour, flavour, texture and taste

Treatment	Mean score				
	Appearance	Colour	Flavour	Texture	Taste
$s_1d_1n_1$	2.1	3.1	3.3	2.8	3.0
$s_1d_1n_2$	2.0	3.1	3.4	3.0	3.0
$s_1d_1n_3$	1.8	3.0	3.3	3.2	2.5
$s_1d_2n_1$	2.0	3.3	3.4	3.2	2.4
$s_1d_2n_2$	2.6	3.1	3.2	3.2	2.6
$s_1d_2n_3$	2.6	3.4	3.0	3.0	3.0
$s_2d_1n_1$	2.8	3.2	3.3	2.9	2.8
$s_2d_1n_2$	2.7	3.0	3.4	3.0	2.8
$s_2d_1n_3$	2.7	3.4	3.2	3.2	3.0
$s_2d_2n_1$	3.0	3.3	3.2	3.3	3.0
$s_2d_2n_2$	2.6	3.2	3.4	3.2	3.1
$s_2d_2n_3$	2.7	3.1	3.3	3.2	3.0
Treatment mean	2.5	3.2	3.3	3.1	2.9
Control mean	3.0	3.2	2.8	3.8	2.9

4.4 NUTRIENT CONTENT

4. 4 .1 Nitrogen Content

4. 4.1.1 *Nitrogen Content of Grain*

The data on the nitrogen content of grain are presented in Table 15a and 15b. Seedling density and nutrient levels significantly affected the nitrogen content of the grain. The grains produced by the crop cultivated with higher seedling density (D_2) and at the highest nutrient level (N_3) recorded significantly higher grain nitrogen contents of 1.32 per cent and 1.36 per cent respectively.

All the three first order interactions were significant. The interactions s_1d_2 (1.36 per cent), s_2n_3 (1.41 per cent) and d_1n_3 (1.40 per cent) were significantly higher with respect to the grain nitrogen content. The treatment combinations d_1n_3 and d_2n_2 were at par.

Jaya recorded significantly higher grain nitrogen content (1.43 per cent) than KRH-2 (1.24 per cent). The comparison made between treatments including control proved significant. The treatment combination, $s_2d_1n_3$ recorded the highest grain nitrogen content (1.49 per cent).

4.4.1.2 *Nitrogen Content of Straw*

The data on the nitrogen content of straw are presented in Table 16a and 16b. The perusal of results revealed that spacing and nutrient levels had significant effect on the nitrogen content of straw. Significantly higher straw nitrogen contents were recorded at S_2 (0.79 per cent) and N_2 (0.83 per cent) which was on a par with N_3 (0.80 per cent). The interactions between and among the treatments were not significant.

Hybrid rice (KRH-2) had significantly higher nitrogen content (0.76 per cent) than the control (Jaya) with 0.55 per cent nitrogen in straw. The comparison made between treatments including control showed that $s_2d_1n_2$ resulted in higher nitrogen assimilation (0.92 per cent) in the straw.

4. 4. 2 Phosphorus Content

4.4.2.1 *Phosphorus Content of Grain*

The data on the effect of spacing, seedling density and nutrient levels on the phosphorus content of grain are presented in Table 15a. The interaction effects are presented in Table 15b. Phosphorus content of grains varied significantly with seedling density and nutrient levels. While the higher seedling density, D_2 recorded higher grain phosphorus content (0.18 per cent), the highest nutrient level, N_3 recorded the same (0.20 per cent) in grains.

The interactions between spacing and seedling density, spacing and nutrient levels and among spacing, seedling density and nutrient levels were significant. The treatment combination s_1d_2 (0.19 per cent), s_2n_3 (0.21 per cent) and $s_1d_2n_2$

(0.22 per cent) recorded the highest phosphorus content in grains. The treatment combination, $s_1d_2n_2$ was on a par with $s_1d_2n_3$, $s_2d_1n_3$ and $s_2d_2n_3$.

The phosphorus content in the grains of Jaya (0.23 per cent) was significantly higher than that (0.17 per cent) in KRH-2. The data revealed that between the treatments including control, Jaya was significantly superior in terms of the phosphorus content of the grain.

4.4.2.2 *Phosphorus Content of Straw*

The perusal of data on the phosphorus content of straw presented in Table 16a, showed that nutrient levels alone had significant effect. The highest nutrient level, N_3 resulted in more phosphorus (0.24 per cent) in straw. The interaction effects are presented in Table 16b. The S x N interaction alone exhibited significant effect. The treatment combination s_1n_3 recorded significantly higher phosphorus content in straw (0.25 per cent).

The phosphorus content in the straw of hybrid rice, KRH-2 (0.23 per cent) was significantly higher than that (0.18 per cent) in the control, Jaya. The comparison made between treatments including control showed that the treatment combination, $s_1d_2n_3$ had the highest straw phosphorus content (0.25 per cent) and the least (0.18 per cent) in the control, Jaya.

4.4.3 Potassium Content

4.4.3.1 *Potassium Content in Grain*

The data on the potassium content in grains as affected by spacing, seedling density, nutrient level and their interaction are presented in Table 15a and 15b respectively. All the three factors and their interaction had significant effect on the potassium content of the grains of hybrid rice. Wider spacing (S_2) and lower seedling density (D_1) resulted in significantly higher grain potassium contents of 0.35 per cent each respectively. Among the nutrient levels, grains produced at N_2 and N_3 recorded significantly higher potassium content of 0.35 per cent each.

The first order interactions were non- significant. The S x D x N interaction alone had significance. The treatment combination, $s_2d_1n_3$ recorded the highest potassium content in the grains of hybrid rice.

The potassium content of the grains of hybrid rice, KRH-2 (0.34 per cent) was significantly higher than that (0.30 per cent) of Jaya. The comparison made between treatments including control proved to be significant. The treatment combination, $s_2d_1n_3$ recorded the highest grain potassium content (0.36 per cent).

4.4.3.2 *Potassium Content in Straw*

The perusal of data on the potassium content in straw presented in Table 16a, revealed the treatments S_2 (4.15 per cent) and N_3 (4.26 per cent) to record significantly higher potassium content in the straw of hybrid rice. The data on interaction effects are presented in Table 16b. The interaction between spacing and seedling density was significant with s_2d_1 and d_1n_3 exhibiting the highest straw potassium content of (4.18 per cent and 4.27 percent) respectively

The potassium content was significantly higher in the straw of hybrid rice, KRH-2 (4.12 per cent) compared to control, Jaya (3.4 per cent). Significance was observed when the treatments were compared including the control. The treatment combination, $s_2d_1n_3$ had maximum potassium in the straw (4.35 per cent).

Table 15a. Effect of spacing, seedling density and nutrient level on nutrient content in grain, %

Treatment	Nutrient content in grain		
	Nitrogen	Phosphorus	Potassium
Spacing			
S_1	1.29	0.17	0.34
S_2	1.31	0.18	0.35
Seedling density			
D_1	1.22	0.16	0.35
D_2	1.32	0.18	0.34
Nutrient level			
N_1	1.19	0.15	0.34
N_2	1.26	0.17	0.35
N_3	1.36	0.20	0.35
SEm S	0.01	0.004	0.001
D	0.01	0.004	0.001
N	0.02	0.005	0.001
SDN			
CD (0.05) S	-	-	0.0031
D	0.042	0.0121	0.0031
N	0.051	0.0148	0.0037

Table 15b. Interaction effect of spacing, seedling density and nutrient level on nutrient content in grain, %

Treatment	Nutrient content in grain					
	Nitrogen		Phosphorus		Potassium	
S x D	S_1	S_2	S_1	S_2	S_1	S_2
D_1	1.22	1.22	0.14	0.18	0.34	0.35
D_2	1.36	1.27	0.19	0.18	0.34	0.34
SEm	0.02		0.005		0.008	
CD (0.05)	0.058		0.0171		-	
S x N	S_1	S_2	S_1	S_2	S_1	S_2
N_1	1.26	1.12	0.14	0.16	0.34	0.34
N_2	1.31	1.21	0.18	0.16	0.34	0.35
N_3	1.31	1.41	0.19	0.21	0.34	0.35
SEm	0.02		0.007		0.001	
CD (0.05)	0.072		0.021		-	
D x N	D_1	D_2	D_1	D_2	D_1	D_2
N_1	1.09	1.29	0.14	0.16	0.34	0.33
N_2	1.18	1.34	0.15	0.18	0.35	0.34
N_3	1.40	1.32	0.19	0.21	0.35	0.35
SEm	0.02		0.007		0.001	
CD (0.05)	0.072		-		-	
S x D x N						
$s_1d_1n_1$	1.14		0.13		0.34	
$s_1d_1n_2$	1.22		0.14		0.34	
$s_1d_1n_3$	1.31		0.17		0.34	
$s_1d_2n_1$	1.38		0.14		0.34	
$s_1d_2n_2$	1.40		0.22		0.34	
$s_1d_2n_3$	1.30		0.21		0.35	
$s_2d_1n_1$	1.03		0.15		0.34	
$s_2d_1n_2$	1.14		0.17		0.35	
$s_2d_1n_3$	1.49		0.21		0.36	
$s_2d_2n_1$	1.20		0.18		0.33	
$s_2d_2n_2$	1.28		0.14		0.34	
$s_2d_2n_3$	1.33		0.21		0.35	
SEm	0.04		0.010		0.002	
CD (0.05)	-		0.0296		0.0075	
Treatment mean	1.24		0.17		0.34	
Control mean	1.43		0.23		0.30	
Treatment Vs. Control	S		S		S	
Between treatments (including control)	S		S		S	

Table16a. Effect of spacing, seedling density and nutrient level on nutrient content in straw, %

Treatment	Nutrient content in straw		
	Nitrogen	Phosphorus	Potassium
Spacing			
S_1	0.73	0.24	4.10
S_2	0.79	0.23	4.15
Seedling density			
D_1	0.76	0.24	4.12
D_2	0.76	0.23	4.14
Nutrient level			
N_1	0.65	0.23	3.99
N_2	0.83	0.23	4.13
N_3	0.80	0.24	4.26
SEm S	0.02	0.0007	0.01
D	0.02	0.0007	0.01
N	0.02	0.0009	0.01
CD (0.05) S	0.049	-	0.029
D	-	-	-
N	0.061	0.003	0.036

Table 16b. Interaction effect of spacing, seedling density and nutrient level on nutrient content in straw, %

Treatment	Nutrient content in straw					
	Nitrogen		Phosphorus		Potassium	
S x D	S_1	S_2	S_1	S_2	S_1	S_2
D_1	0.71	0.81	0.24	0.24	4.05	4.18
D_2	0.75	0.77	0.23	0.23	4.16	4.12
SEm	0.020		0.001		0.010	
CD (0.05)	-		-		0.042	
S x N	S_1	S_2	S_1	S_2	S_1	S_2
N_1	0.58	0.71	0.23	0.23	3.97	4.01
N_2	0.79	0.87	0.23	0.23	4.10	4.16
N_3	0.81	0.80	0.25	0.24	4.24	4.28
SEm	0.020		0.001		0.010	
CD (0.05)	-		0.004		-	
D x N	D_1	D_2	D_1	D_2	D_1	D_2
N_1	0.65	0.65	0.23	0.23	3.95	4.03
N_2	0.86	0.81	0.23	0.23	4.12	4.14
N_3	0.78	0.82	0.24	0.24	4.27	4.24
SEm	0.020		0.001		0.001	
CD (0.05)	-		-		0.005	
S x D x N						
$s_1d_1n_1$	0.54		0.23		3.91	
$s_1d_1n_2$	0.80		0.24		4.04	
$s_1d_1n_3$	0.80		0.24		4.19	
$s_1d_2n_1$	0.63		0.23		4.03	
$s_1d_2n_2$	0.79		0.23		4.16	
$s_1d_2n_3$	0.81		0.25		4.28	
$s_2d_1n_1$	0.76		0.23		3.99	
$s_2d_1n_2$	0.92		0.23		4.21	
$s_2d_1n_3$	0.77		0.24		4.35	
$s_2d_2n_1$	0.66		0.23		4.03	
$s_2d_2n_2$	0.82		0.23		4.12	
$s_2d_2n_3$	0.82		0.24		4.21	
SEm	0.04		0.0018		0.02	
CD (0.05)	-		-		-	
Treatment mean	0.76		0.23		4.12	
Control mean	0.55		0.18		3.49	
Treatment Vs. Control	S		S		S	
Between treatments (including control)	S		S		S	

4.5 NUTRIENT UPTAKE

4.5.1 Nitrogen Uptake

The results summarized in Table 17a and graphically presented in Fig. 10a, revealed significant effect for spacing and nutrient levels on nitrogen uptake. Seedling density failed to exhibit significance. Higher nitrogen nuptake (99.51 kg ha^{-1}) was recorded at the wider spacing S_2 (20cm x 15cm). The highest nutrient level, N_3 resulted in the maximum nitrogen uptake (117.10 kg ha^{-1}).

The results on interaction effects are presented in Table 17b and Fig. 10b. The first order interactions, *viz.* S x D and D x N were significant, with the treatment combinations, s_2d_1 and d_1n_3 recording significantly higher nitrogen uptake values of 115.89 kg ha^{-1} and 122.15 kg ha^{-1} respectively. Among the D x N interactions, d_1n_3 was on a par with d_2n_3 (112.55 kg ha^{-1}).

The treatment mean (95.45 kg ha^{-1}) for KRH-2 when compared against the control mean for Jaya (102.18 kg ha^{-1}) did not vary significantly. The between treatments including control comparison was significant. The treatment combination, $s_2d_1n_3$ revealed highest nitrogen uptake (139.63 kg ha^{-1}).

4.5.2 Phosphorus Uptake

The data on phosphorus uptake are presented in Tables 17a and 17b and Figures 10a and 10b. It was observed that the phosphorus uptake of hybrid rice varied significantly between the two spacings and among the three nutrient levels. Seedling density could not generate any significant variation. Wider spacing, S_2 (20cm x 15cm) and nutrient level N_3 (150: 75: 75 kg NPK ha^{-1}) recorded significantly higher phosphorus uptake of 22.99 kgha^{-1}and 25.17 kg ha^{-1} respectively.

The interactions, S x D, S x N and S x D x N were significant. Among the four S x D and S x N interactions each, s_2d_1 and s_2n_3 recorded higher phosphorus uptake of 24.77 kg ha^{-1} and 27.54 kg ha^{-1} respectively. The results on S x D x N interaction data showed $s_2d_1n_3$torecordthemaximumphosphorusuptake (29.15 kg ha^{-1}).

The phosphorus uptake (23.06 kg ha^{-1}) by control (Jaya) was significantly higher than that (20.92 kg ha^{-1}) for the hybrid (KRH-2). The treatment combination $s_2d_1n_3$ resulted in significantly higher phosphorus uptake among all the treatment combinations, including the control.

4.5.3 Potassium Uptake

The perusal of the data in Table 17a and Fig. 10a revealed that spacing and nutrient levels had significant effect on potassium uptake of hybrid rice. The effect of seedling density was non-significant. While the wider spacing, S_2 recorded higher potassium uptake (274.83 kg ha^{-1}), the highest nutrient level, N_3 recorded the same (286.82 kg ha^{-1}) for this parameter.

The data on interaction effects are summarized in Table 17b and graphically presented in Fig. 10b. The interactions, S x D, S x N, D x N and S x D x N were observed to be significant. Significantly higher potassium uptake was observed at s_2d_1 (294.58 kg ha^{-1}), s_2n_3 (308.44 kg ha^{-1}) and d_1n_3 (293.73 kg ha^{-1}). However, d_1n_3 was at par with d_2n_3 (279.90 kg ha^{-1}). The combination of wider spacing (S_2), lower seedling density (D_1) and highest nutrient level (N_3), *i.e.* $s_2d_1n_3$ recorded the maximum potassium uptake (321.46 kg ha^{-1}).

No significant variation could be observed between the potassium uptake of hybrid rice, KRH-2 (251.28 kg ha^{-1}) and the control, Jaya (247.17 kg ha^{-1}). The comparison made between treatments including control was significant and it was observed that the treatment combination, $s_2d_1n_3$ recorded the highest potassium uptake.

Table 17a. Effect of spacing, seedling density and nutrient levels on nutrient uptake, kg ha^{-1}

Treatment	Nitrogen uptake	Phosphorus uptake	Potassium uptake
Spacing			
S_1	96.41	18.85	227.74
S_2	99.51	22.99	274.83
Seedling density			
D_1	85.78	20.73	252.22
D_2	108.05	21.12	250.35
Nutrient level			
N_1	76.16	17.46	219.08
N_2	98.77	20.14	247.96
N_3	117.10	25.17	286.82
SEm S	1.88	0.36	3.77
D	1.88	0.36	3.77
N	2.30	0.44	4.62
CD (0.05) S	3.021	1.064	11.014
D	-	-	-
N	6.736	1.303	13.489

Table 17b. Interaction effect of spacing, seedling density and nutrient levels on nutrient uptake, kg ha^{-1}

Treatment	Nitrogen uptake		Phosphorus uptake		Potassium uptake	
S x D	S_1	S_2	S_1	S_2	S_1	S_2
D_1	78.42	115.89	16.69	24.77	209.85	294.58
D_2	97.16	98.94	21.02	21.22	245.63	255.07
SEm	2.66		0.51		5.33	
CD (0.05)	7.777		1.504		15.576	
S x N	S_1	S_2	S_1	S_2	S_1	S_2
N_1	66.67	86.17	14.67	20.25	190.69	247.48
N_2	91.21	106.86	19.08	21.19	227.34	268.57
N_3	105.48	129.22	22.81	27.54	265.20	308.44
SEm	3.26		0.63		6.53	
CD (0.05)	-		1.842		19.077	
D x N	D_1	D_2	D_1	D_2	D_1	D_2
N_1	72.48	80.37	17.14	17.79	217.25	220.91
N_2	96.84	101.23	19.55	20.72	245.67	250.24
N_3	122.15	112.55	25.51	24.84	293.73	279.90
SEm	3.26		0.63		6.535	
CD (0.05)	9.527		-		19.077	
S x D x N						
$s_1d_1n_1$	52.40		12.77		165.41	
$s_1d_1n_2$	78.20		15.43		198.14	
$s_1d_1n_3$	104.66		21.88		266.00	
$s_1d_2n_1$	80.95		16.57		215.96	
$s_1d_2n_2$	104.22		22.73		256.54	
$s_1d_2n_3$	106.30		23.74		264.40	
$s_2d_1n_1$	92.56		21.50		269.09	
$s_2d_1n_2$	115.48		23.66		293.20	
$s_2d_1n_3$	139.63		29.15		321.46	
$s_2d_2n_1$	79.78		19.00		225.86	
$s_2d_2n_2$	98.25		18.72		243.94	
$s_2d_2n_3$	118.80		25.93		295.41	
SEm	4.61		0.89		9.24	
CD (0.05)	-		2.606		26.979	
Treatment mean	95.45		20.92		251.28	
Control mean	102.18		23.06		247.17	
Treatment Vs. Control	NS		S		NS	
Between treatments (including control)	S		S		S	

4.6 SOIL FERTILITY STATUS AFTER THE EXPERIMENT

The fertility status of soil after the experiment was assessed in terms of organic carbon, available nitrogen, available phosphorus, and available potassium status.

4.6.1 Organic Carbon

The results on the organic carbon status of the soil after the experiment (Table 18a and Table 18b) showed that spacing, seedling density and nutrient levels and their interaction had no significant effect. The comparison made between treatment and control and between treatments including control also proved non-significant.

4.6.2 Available Nitrogen

The results pertaining to the available nitrogen status of the soil after the experiment are presented in Table 18a. The results on interaction effects are presented in Table 18b.

Among the three factors (spacing, seedling density and nutrient levels), nutrient levels significantly influenced the available nitrogen status of the soil. The treatment, N_3 recorded the highest available nitrogen status (297.64 kg ha^{-1}) for the soil.

None of the interactions could affect the available nitrogen status of the soil. The treatment *versus* control comparison and the comparison made between treatments including control did not vary significantly between hybrid rice KRH-2 and the control, Jaya.

4.6.3 Available Phosphorus

The results summarized in Table 18a, revealed a non-significant effect for the treatments (spacing, seedling density and nutrient levels) on the available phosphorus status of the soil. Among the first order interactions, S x D and S x N were significant. The treatment combination s_2d_1 (17.94 kg ha^{-1}) and s_2n_3 (18.47 kg ha^{-1}) recorded the maximum available phosphorus. The effect of the treatments as compared against the control and between treatments including control were insignificant.

4.6.4 Available Potassium

The results on the available potassium status of the soil after the experiment as affected by spacing, seedling density and nutrient levels are presented in Table 18a. The data on interaction effects are presented in Table 18b. The available potassium status of the soil varied significantly with nutrient levels and the maximum (163.09 kg ha^{-1}) was observed at N_3. None of the interactions had significant effect on available potassium. Significant difference was not observed between hybrid rice, KRH-2 and control, Jaya. The comparison made between treatments including control was also not significant.

Table 18a. Effect of spacing, seedling density and nutrient levels on organic carbon and available nutrient status of soil after the experiment

Treatment	Organic carbon (%)	Available nitrogen (kg ha^{-1})	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})
Spacing				
S_1	0.80	262.69	13.55	150.08
S_2	0.80	275.13	13.88	150.62
Seedling density				
D_1	0.79	269.40	14.03	147.48
D_2	0.78	268.43	13.98	149.21
Nutrient level				
N_1	0.81	243.47	13.80	142.21
N_2	0.79	265.62	14.41	153.10
N_3	0.74	297.64	14.20	163.09
SEm S	0.056	5.87	0.21	1.48
D	0.056	5.87	0.21	1.48
N	0.068	7.19	0.26	2.04
CD (0.05) S	-	-	-	-
D	-	-	-	-
N	-	21.008	-	8.892

Table 18b. Interaction effect of spacing, seedling density and nutrient levels on organic carbon and available nutrient status of soil after the experiment

Treatment	Organic carbon (%)		Available nitrogen (kg ha^{-1})		Available phosphorus (kg ha^{-1})		Available potassium (kg ha^{-1})	
S x D	S_1	S_2	S_1	S_2	S_1	S_2	S1	S2
D_1	0.79	0.78	266.21	272.59	13.31	17.94	146.04	148.91
D_2	0.80	0.74	259.17	277.68	13.95	15.93	154.12	162.13
SEm	0.07		8.31		0.30		3.51	
CD (0.05)	-		-		0.901		-	
S x N	S_1	S_2	S_1	S_2	S_1	S_2	S1	S2
N_1	0.82	0.80	238.17	248.78	12.99	15.34	142.28	142.13
N_2	0.80	0.78	258.50	272.75	13.90	17.00	150.14	156.06
N_3	0.77	0.71	291.41	303.87	14.01	18.47	157.82	168.37
SEm	0.09		10.17		0.37		4.30	
CD (0.05)	-		-		1.104		-	
D x N	D_1	D_2	D_1	D_2	D_1	D_2	D1	D2
N_1	0.82	0.79	243.45	243.50	14.36	13.97	139.61	144.81
N_2	0.81	0.77	265.79	265.45	15.78	15.12	149.61	159.51
N_3	0.73	0.75	298.96	296.32	16.74	15.74	156.13	170.06
SEm	0.09		10.17		0.37		4.30	
CD (0.05)	-		-		-		-	
S x D x N								
$s_1d_1n_1$	0.81		244.64		12.88		138.00	
$s_1d_1n_2$	0.80		262.60		13.63		144.94	
$s_1d_1n_3$	0.76		291.40		13.43		155.19	
$s_1d_2n_1$	0.82		231.71		13.11		146.56	
$s_1d_2n_2$	0.80		254.39		14.16		155.34	
$s_1d_2n_3$	0.78		291.42		14.11		160.45	
$s_2d_1n_1$	0.83		242.26		14.85		141.21	
$s_2d_1n_2$	0.81		268.98		14.32		148.44	
$s_2d_1n_3$	0.70		306.52		15.11		157.07	
$s_2d_2n_1$	0.76		255.29		14.26		143.05	
$s_2d_2n_2$	0.74		276.52		14.34		163.68	
$s_2d_2n_3$	0.71		301.22		14.74		179.67	
SEm	0.130		14.39		0.53		5.21	
CD (0.05)	-		-		-		-	
Treatment mean	0.78		268.91		15.01		152.80	
Control mean	0.68		271.01		12.91		141.30	
Treatment Vs. Control	NS		NS		NS		NS	
Between treatments (including control)	NS		NS		NS		NS	

4.7 ECONOMICS OF CULTIVATION

4.7.1 Gross Returns

The data summarized in Table 19a, showed that spacing and nutrient levels had significant effect on the gross returns. Cultivating hybrid rice, KRH-2 at a spacing of 20cm x 15cm (S_2) and at a NPK dose of 150: 75: 75 kg ha^{-1} (N_3) fetched more gross returns than the other treatments.

The results on first order and second order interactions are presented in Table 19b. Among the various interactions, spacing x density proved significant with s_2d_1 recording the highest gross returns (Rs.109531.50 ha^{-1}). The control, Jaya was observed to confer higher mean gross returns (Rs.111590.00 ha^{-1}) than hybrid rice, KRH-2 (Rs.92649.51 ha^{-1}). The comparison made between treatments including control proved to be significant. The treatment combination, $s_2d_1n_3$ recorded the maximum gross returns (Rs. 125171.50 ha^{-1}).

4.7.2 Net Returns

The perusal of data on net returns presented in Table 19a and Fig. 11a, revealed significant effect for spacing, seedling density and nutrient levels. Hybrid rice, KRH-2 raised at a spacing of 20cm x 15cm (S_2), at 1 seedling per hill (D_1) and at a nutrient level of 150: 75: 75 kg ha^{-1} (N_3) resulted in more net returns to the tune of Rs.53813.30 ha^{-1}, Rs.46207.00 ha^{-1} and Rs. 57388.55 ha^{-1} respectively. The results on the first order and second order interactions are summarized in Table 19b and graphically depicted in Fig. 11b. The first order interactions were not significant. The S x D x N interaction exhibited significant effect with the treatment combination $s_2d_1n_3$ recording maximum net returns (Rs.77877.40 kg ha^{-1}).

The comparison made between KRH-2 and Jaya showed that, the control, Jaya performed better with a mean net returns of Rs.66753.27 ha^{-1} compared to hybrid rice, KRH-2 (Rs.43909.12 ha^{-1}). The comparison made between treatments including control was also significant. The treatment combination,

$s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) fetched the maximum net returns (Rs. 77877.40 ha^{-1}).

4.7.3 Benefit Cost Ratio

The data presented in Table 19a and Fig. 12a, showed that the benefit cost ratio varied significantly with spacing, seedling density and nutrient levels. Benefit cost ratio was higher at S_2 (2.13), D_1 (1.98) and N_3 (2.17).

The results on interaction effects are presented in Table 19b and Fig. 12b. Among the first order interactions, the interaction between spacing and seedling density and seedling density and nutrient levels were significant. The interactions, s_2d_1 and d_1n_3 recorded the highest benefit cost ratio of 2.35 and 2.31 respectively for hybrid rice. The S x D x N interaction was also significant with the treatment combination $s_2d_1n_3$ recording the highest benefit cost ratio (2.65).

The comparison made between KRH-2 (treatment) and Jaya (control) showed that the control, Jaya was more advantageous with a mean benefit cost ratio of 2.49 than hybrid rice, KRH-2 with 1.90. The comparison between treatments including control had significance with the treatment combination, $s_2d_1n_3$ recording a benefit cost ratio of 2.65, which was the highest. Thus it could be concluded that cultivating hybrid rice, KRH-2 at a spacing of 20cm x 15cm at one seedling per hill with a NPK dose of 150: 75: 75 kg ha^{-1} resulted in higher benefit cost ratio than the control, Jaya raised as per the KAU package of practices.

Table 19a. Effect of spacing, seedling density and nutrient level on gross returns, net returns and benefit cost ratio

Treatment	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	Benefit cost ratio
Spacing			
S_1	83720.34	34004.93	1.68
S_2	101578.70	53813.30	2.13
Seedling density			
D_1	93322.41	46207.00	1.98
D_2	91976.64	41611.24	1.83
Nutrient level			
N_1	79824.08	31982.38	1.67
N_2	91166.84	42426.42	1.88
N_3	106957.70	57388.55	2.17
SEm S	1211.28	1211.27	0.02
D	1211.28	1211.27	0.02
N	1483.51	1483.50	0.03
CD (0.05) S	3535.653	3535.631	0.076
D	-	3535.631	0.076
N	4330.273	4330.245	0.093

Table 19b. Interaction effect of spacing, seedling density and nutrient level on gross returns, net returns and benefit cost ratio

Treatment	Gross returns (Rs. ha^{-1})		Net returns (Rs. ha^{-1})		Benefit cost ratio	
S x D	S_1	S_2	S_1	S_2	S_1	S_2
D_1	77113.34	109531.50	29347.93	63066.07	1.61	2.35
D_2	90327.34	93625.94	38661.93	44560.53	1.75	1.91
SEm	1713.01		1712.99		0.03	
CD (0.05)	5000.169		-		0.107	
S x N	S_1	S_2	S_1	S_2	S_1	S_2
N_1	69914.25	89733.91	21027.55	42797.20	1.43	1.92
N_2	83536.20	98797.46	33820.80	51032.05	1.68	2.07
N_3	97710.56	116204.80	47166.46	57388.55	1.94	2.40
SEm	2098.001		2097.98		0.044	
CD (0.05)	-		-		-	
D x N	D_1	D_2	D_1	D_2	D_1	D_2
N_1	78483.91	81164.25	32197.20	31627.55	1.70	1.64
N_2	90913.60	91420.06	43798.20	41054.65	1.93	1.82
N_3	110569.70	103345.60	62625.60	52151.50	2.31	2.02
SEm	2098.001		2097.98		0.044	
CD (0.05)	-		-		0.131	
S x D x N						
$s_1d_1n_1$	60613.10		13676.40		1.29	
$s_1d_1n_2$	74759.00		26993.60		1.56	
$s_1d_1n_3$	95967.90		47373.80		1.97	
$s_1d_2n_1$	79215.41		28378.70		1.56	
$s_1d_2n_2$	92313.40		40648.00		1.79	
$s_1d_2n_3$	99453.21		46959.11		1.90	
$s_2d_1n_1$	96354.71		50718.00		2.11	
$s_2d_1n_2$	107068.20		60602.81		2.30	
$s_2d_1n_3$	125171.50		77877.40		2.65	
$s_2d_2n_1$	83113.10		34876.40		1.72	
$s_2d_2n_2$	90526.71		41461.30		1.85	
$s_2d_2n_3$	107238.00		57343.90		2.15	
SEm	2967.02		2967.00		0.06	
CD (0.05)	3033.142		3033.142		0.076	
Treatment mean	92649.51		43909.12		1.90	
Control mean	111590.00		66753.27		2.49	
Treatment Vs. Control	S		S		S	
Between treatments (including control)	S		S		S	

Discussion

5. DISCUSSION

The results of the study conducted to evaluate the performance of hybrid rice with the major objectives of evaluating the production potential of hybrid rice in lowland ecosystem, quantifying its nutritional requirement in relation to plant spacing and seedling density and working out the economics of cultivating hybrid rice as compared against a conventional inbred, are briefly discussed in this chapter.

5.1 EFFECT OF SPACING ON GROWTH AND PRODUCTIVITY

Wider spacing helped in increasing the growth and yield of hybrid rice. The only avenue left to increase the production of rice is through vertical expansion, where use of improved varieties and optimum spacing are two of the most effective means to increase the yield of transplanted rice. Good plant spacing gives the right plant density, which is the number of plants, allowed on a given unit of land for optimum yield.

Spacing had no significant effect on plant height and number of tillers per hill of hybrid rice at maximum tillering, panicle initiation and harvest stages as indicated by almost similar values for 20cm x 10cm and 20cm x 15cm spacings (Tables 2a and 3a).

The number of leaves per hill was significantly more at wider plant spacing of 20cm x 15cm. Leaf production at closer spacing was lower probably due to overcrowding at closer spacing which might have in turn led to competition for space and light as suggested by Verma *et al.* (2002) and Nayak *et al.* (2003).

Leaf area index (Table 5a) was significantly higher at wider spacing (20 cm x 15cm). Around 5 per cent increase in LAI recorded at 20cm x 15cm can be

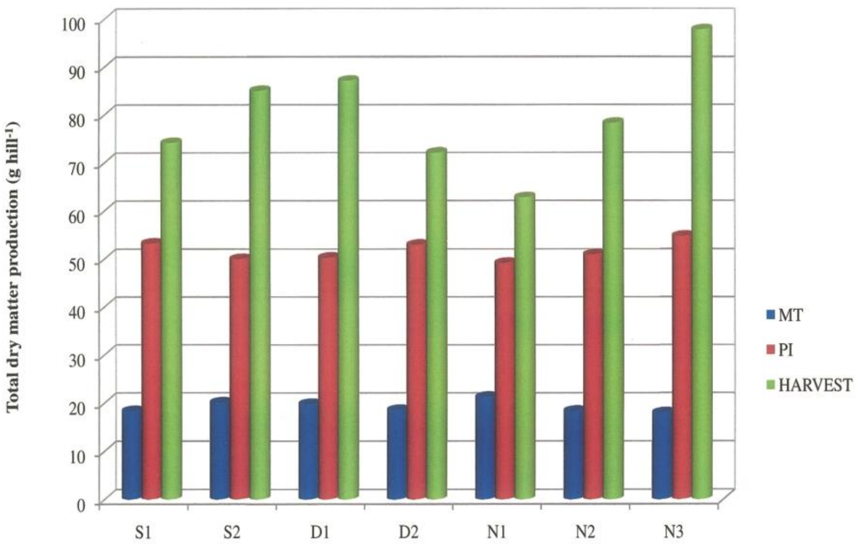

Fig.3a. Effect of spacing (S) , seedling density (D) and nutrient level (N)on total dry matter production of hybrid rice

attributed to the vigorous growth of hybrid rice (Islam, 2009) and production of more number of leaves. Similar results were recorded by Sarath and Thilak (2004).

Rooting depth of hybrid rice did not vary significantly between the two spacings (Table 6a).

While the shoot dry matter production was significantly higher at wider spacing during maximum tillering and at harvest, closer spacing recorded the same at panicle initiation stage. This is probably due to the fact that hybrid rice accumulates more dry matter in early and middle growth stages as reported by Yan (1988).

Root dry matter was about 8 per cent higher at wider spacing during the maximum tillering stage. The total dry matter production varied significantly showing the superiority of wider spacing which was perhaps due to better photosynthesis and reduced competition among plants at wider spacing. The results are in conformation with the findings of Gani *et al.* (2002).

The productive tiller count per hill did not vary significantly between the two spacings. However, the closest spacing (20cm x 10cm) recorded higher productive tiller count per hill. The number of spikelets per panicle was significantly higher at closest spacing. This is possibly due to the efficient and greater sink number of hybrid rice as reported by Peng *et al.* (1998). Panicle weight did not exhibit any significant variation with spacing. The length of panicles produced were significantly more at closer spacing (20cm x 10cm). Salahuddin *et al.* (2010) have also observed longer panicles at closer spacing.

The number of filled grains per panicle was not affected significantly by spacing. Sterility percentage was observed to be significantly higher at closer spacing (20cm x 10cm). The vigorous growth of the plant exhibited in terms of higher leaf area index and dry matter at wider spacing might have helped in better filling of spikelets at wider spacing of 20cm x 15cm. These results are in agreement

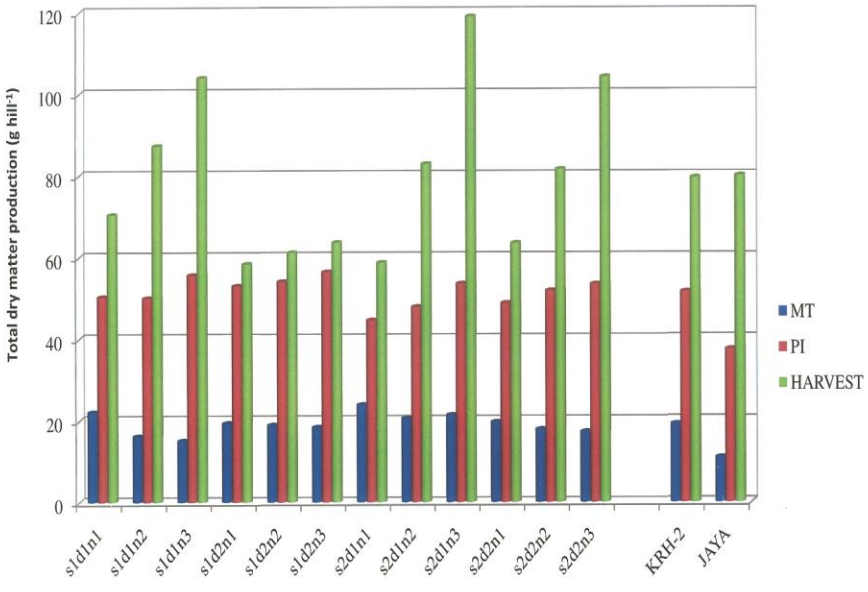

Fig. 3b. Effect of S x D x N on total dry matter production

with the findings of Barison (2002) and Obulamma *et al.* (2004). Thousand grain weight was not affected significantly by spacing. However, a marginal increase in thousand grain weight was observed at wider spacing.

Grain yield was not significantly affected by spacing. However, wider spacing of 20cm x 15 cm produced more grain yield compared to 20cm x 10cm. Tillering, plant height and leaf area index increased with plant spacing. The plants at wider spacing were more vigorous with higher photosynthetic efficiency. Further plants grown at wider spacing had greater opportunity for root growth and increased availability and accessibility of nutrients. Baloch *et al.* (2003) also reported that increased plant spacing resulted in vigorous plant growth and increased grain yield. Straw yield and harvest index also exhibited the same trend, of not varying significantly with spacing.

5.2 EFFECT OF SEEDLING DENSITY ON GROWTH AND PRODUCTIVITY

The success of hybrid rice cultivation depends on exploiting the full heterotic potential of the hybrids with improved package of practices such as number of seedlings per hill and optimum plant population. Planting density exerts a strong influence on grain yield and rice growth because of its competitive effects, both on the vegetative and reproductive development. The number of seedlings per hill helps in boosting the yield of rice crop. It is very essential to reduce the cost on seed which could be achieved by optimizing the seed rate through appropriate adjustment of seedling density which would help a long way in popularizing hybrid rice cultivation in India.

Plant height and number of tillers per hill were not affected significantly by seedling density (one seedling per hill, two seedlings per hill).

The number of leaves produced per hill was significantly higher at two seedlings per hill during the maximum tillering and panicle initiation stages. The

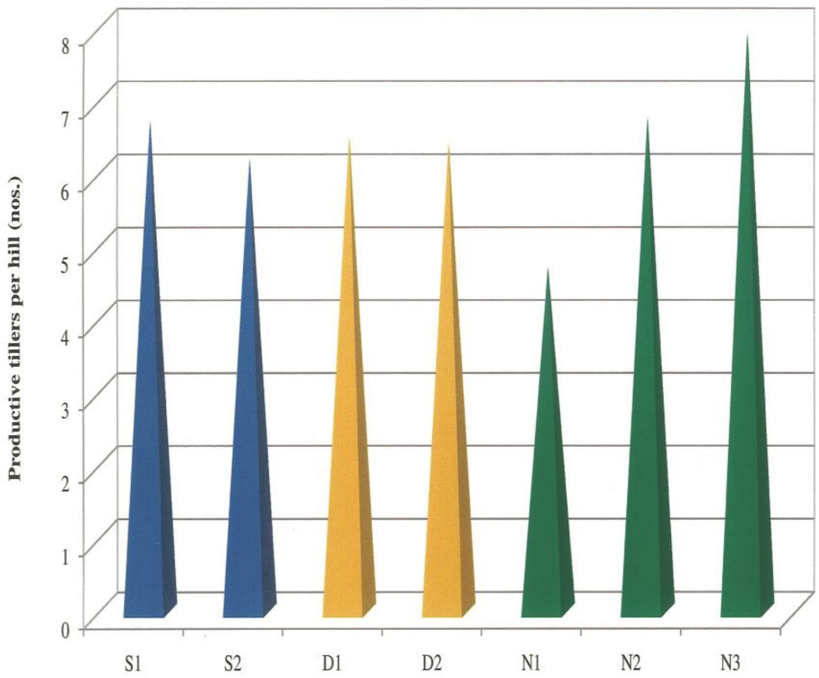

Fig. 4a. Effect spacing (S), seedling density (D) and nutrient level (N) on productive tiilers per hill of hybrid rice

higher number of leaves per hill might be due to the exposure of large number of plants and leaf area to sunlight during the growth period resulting in better photosynthesis. Similar results have been reported by Huang (1990) and

Srinivasulu (1999). Leaf area index (LAI) did not vary significantly with seedling density.

Seedling density had significant effect on the rooting depth, with two seedlings per hill recording significantly deeper roots. San - oh *et al.* (2008) have reported that higher hill density or higher number of plants per hill is generally advantageous during the early stages of growth, where in better development of roots occur supporting rapid development of shoots. Further they had also observed that planting more number of seedlings per hill increased the root length due to higher density of branched roots.

Shoot dry matter production was significantly higher at two seedlings per hill during the panicle initiation stage and at one seedling per hill during the harvest stage. Root dry matter production was significantly higher with one seedling per hill at maximum tillering, panicle initiation and harvest stages. The higher shoot dry matter production with two seedlings per hill at panicle initiation stage might be due to the effect of more number of plants per hill. On the other hand the higher dry matter production (DMP) at harvest stage might be due to better vegetative growth afforded by single seedling, were the competition among plants might have been less compared to two seedlings per hill. Similar results have been reported by Islam *et al.* (2008). The better root dry matter production at lower seedling density can be attributed not only to the better rooting capacity of hybrid rice but also to the availability of inter plant space and nutrients as reported by Inaba and Kitano (2005). While the total dry matter production per hill was significantly higher with one seedling per hill at maximum tillering and harvest stages, it was significantly higher at two seedlings per hill during the panicle initiation stage (Fig. 3a). The higher total

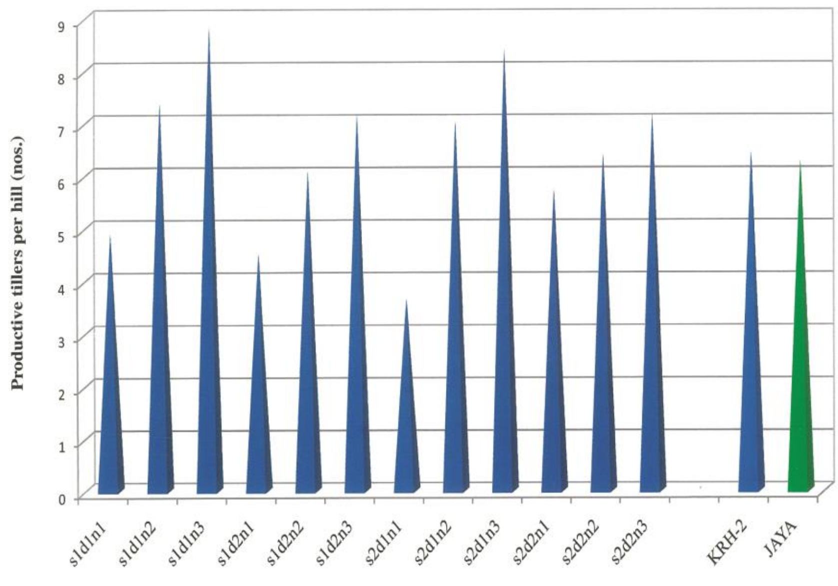

Fig. 4b. Effect of S x D x N on productive tillers per hill

dry matter production at panicle initiation stage with two seedlings per hill can be attributed to the higher shoot dry matter production at this stage. While the root dry matter production contributed to total dry matter production at maximum tillering stage, the contribution of shoot and root was equally important in recording higher total dry matter production per hill at harvest stage.

Optimum seedlings per hill ensure that plants grow better in their aerial and underground parts through efficient utilization of solar radiation, water and nutrients (Miah *et al*., 2004).

Productive tillers per hill were not affected significantly by seedling density. However, the productive tiller count was found to be marginally higher at one seedling per hill (Fig. 4a). The number of spikelets per panicle was significantly higher when planted at two seedlings per hill (Fig. 5a). Similar results have been recorded by Asif *et al.* (1997). Panicle weight and panicle length did not vary significantly between the two seedling densities.

The number of filled grains per panicle was significantly higher with two seedlings per hill than one seedling per hill. This can be attributed to the significantly higher sterility percentage recorded at one seedling per hill (Fig. 6a). Similar results have been reported by (Nayak *et al*., 2003). Thousand grain weight failed to show any significant variation with seedling density as it may be an attribute controlled by the genetic makeup of the variety as reported by Islam *et al.* (2008).

Planting hybrid rice at two seedlings per hill resulted in significantly higher grain yield. The significant increase in number of spikelets and filled grains per panicle at higher seedling density has contributed towards higher grain yield. This finding is in conformity with Sanico *et al.* (2002) and Islam *et al.* (2008). Straw yield was also significantly higher at two seedlings per hill. The crop had exhibited better vegetative growth at two seedlings per hill as indicated by higher tiller and leaf

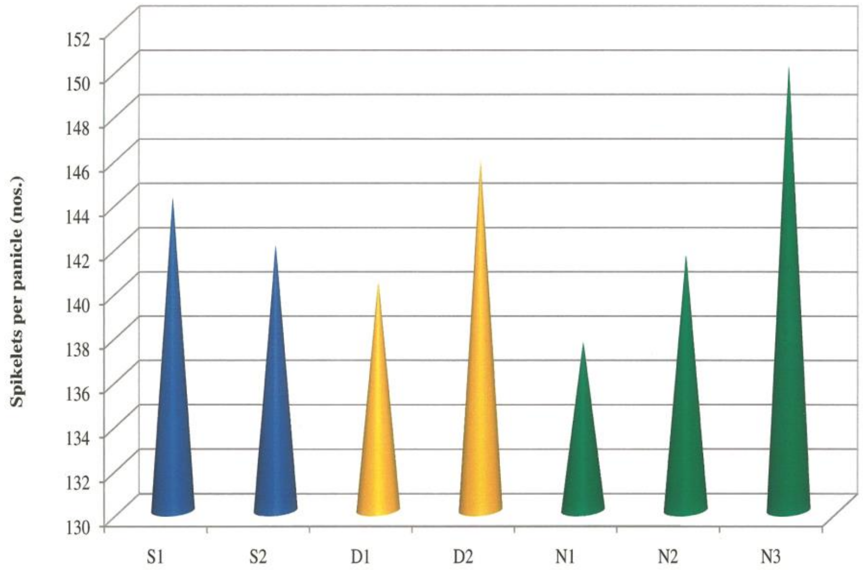

Fig. 5a. Effect of spacing (S), seedling density (D) and nutrient level (N) on number of spikelets per panicle of hybrid rice

count at higher seedling density. Harvest index did not show any significant variation between the two seedling densities.

5.3 EFFECT OF NUTRIENT LEVELS ON GROWTH AND PRODUCTIVITY

Nutrients supplied by way of fertilizers play a key role in supporting crop growth. Crop varieties vary in their response to fertilizers depending on their agronomic traits. Fertilizer being a costly input, it is important to investigate its appropriate dosage, so that it would be both economically and adequately efficient to enhance the production and profitability of crops.

Plant height was found to increase significantly with increasing levels of nutrients. The crop was tallest at the highest nutrient level of 150: 75: 75 kg NPK ha^{-1}, at panicle initiation and harvest stages. The number of tillers per hill increased linearly with nutrient levels. The number of leaves per hill and leaf area index (LAI) also showed a similar trend with respect to nutrient levels. Herbert (2005) observed that application of major nutrients as fertilizers in a balanced manner as per the requirement of the crop or variety is one of the major cultural measures that improve the vegetative growth and ultimately the yield of the plant. Increasing tiller count, leaf count and leaf area index due to increasing fertilizer application was also reported by Sudhakar *et al.* (1986) and Reddy (1986).

Rooting depth exhibited a reverse trend with increasing nutrient levels. The lowest nutrient level recorded the deepest roots. The higher nutrient requirement of hybrid rice might have induced the production of deeper roots, helping the crop to forage better for nutrients at lower doses of NPK.

The shoot dry matter production increased significantly with nutrient levels. The effect of nutrients, especially nitrogen in increasing the vegetative growth has been reported by several workers. Navin *et al.* (1996), Salahuddin *et al.* (2010) and Ogbodo *et al.* (2010) have made similar observations. Root dry matter production

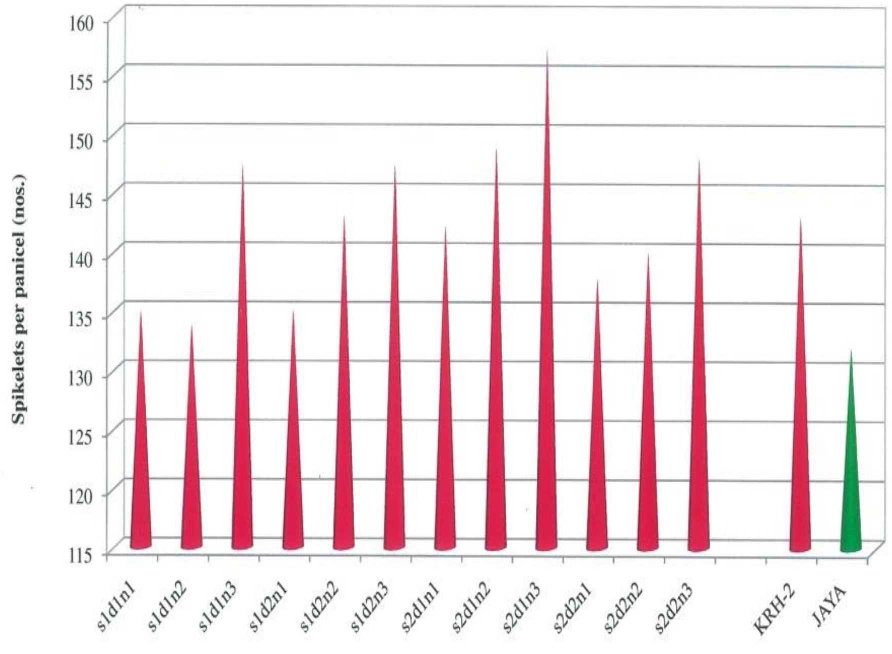

Fig. 5b. Effect of S x D x N on the number of spikelets per panicle

was observed to be the highest at the lowest nutrient level (90: 45: 45 kg NPK ha^{-1}). This can be attributed to deeper root system observed at the lowest level of nutrients. The total dry matter production per hill which was significantly higher at the lowest nutrient level at the maximum tillering stage, turned out to be maximum at the highest nutrient level during panicle initiation and harvest stages. While the high dry matter production at maximum tillering is mainly due to the root dry matter, that at panicle initiation and harvest stages could be attributed to the higher shoot dry matter production.

Nutrient levels significantly affected the yield attributes. Productive tillers per hill, number of spikelets per panicle, panicle weight, panicle length, filled grains per panicle and thousand grain weight were significantly higher at the highest NPK dose of 150: 75: 75 kg ha^{-1}. The possible and direct effect of the number of tillers and indirect effect of plant height on the productive tiller count has been reported by Oad *et al.* (2002). Thus the higher tiller count offered by the highest nutrient level might have contributed towards the increase in the productive tiller count also. The major nutrients, especially nitrogen directly takes part in panicle formation and panicle elongation. Further balanced and adequate nutrition also aids in proper filling of the grains. This might be the reason for longer and heavier panicles with more number of filled grains at the highest nutrient level. Similar results have been reported by Salahuddin *et al.* (2010). The least sterility percentage at the highest nutrient level might have also contributed towards more number of filled grains.

Grain yield and straw yield were maximum at 150: 75: 75 kg NPK ha^{-1} (Fig. 7a). This could be attributed to the positive and moderate direct effect of number of productive tillers and the strong direct effect of number of filled grains per panicle on grain yield as suggested by Hairmansis *et al.* (2010). Further yield is also linearly related to the total dry matter production (Ahmad *et al.*, 2005). The increase in straw yield and harvest index at higher nutrient levels observed in the

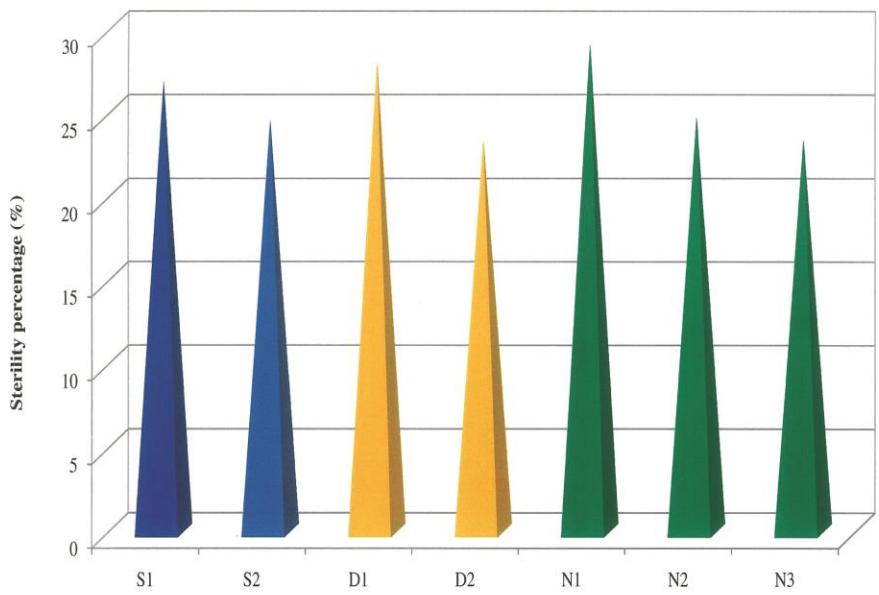

Fig. 6a. Effect of spacing (S), seedling density (D) and nutrient level (N) on sterility percentage of hybrid rice

present study corroborate the findings of Agarwal *et al.* (1985) and Ahmad *et al.* (2005). The better yield attributes and yield with application of highest level of nutrients might be due to its key role in root development, energy translocation and metabolic process through which increased translocation of photosynthates towards sink development might have occurred as suggested by Tripathi *et al.* (2009).

5.4 EFFECT OF SPACING x SEEDLING DENSITY ON GROWTH AND PRODUCTIVITY

The combined effect of spacing and seedling density was not significant with respect to plant height. The number of tillers per hill remained unaffected by spacing x seedling density at maximum tillering and panicle initiation stages. The tiller count at harvest was significantly higher at S_2 (20cm x 15cm) x D_2 (two seedlings per hill). While the number of leaves per hill was not affected by spacing x seedling density, the leaf area index (LAI) at maximum tillering, panicle initiation and harvest stages was significantly higher when planted at wider spacing with two seedlings per hill (s_2d_2). Rooting depth also exhibited the same trend at the harvest stage. These results revealed that at higher seedling density the spacing need to be wider to increase the photosynthetic capacity of the plant. These results corroborated with the findings of Hossain *et al.* (2003).

While planting at S_1 (20cm x 10cm) with D_2 (two seedlings per hill) gave significantly higher shoot dry matter per hill at panicle initiation stage, s_1d_1 helped to maintain higher shoot dry matter production at harvest stage. The root dry matter production at maximum tillering, panicle initiation and harvest stages was significantly higher when planted at one seedling per hill maintaining a wider spacing of 20cm x 15cm. The total dry matter production per hill also showed a similar trend with s_2d_1 recording higher value at maximum tillering stage. However, at harvest stage s_1d_1 and s_2d_1 remained at par. It clearly showed the superiority of planting single seedling at wider spacing for attaining higher dry matter production.

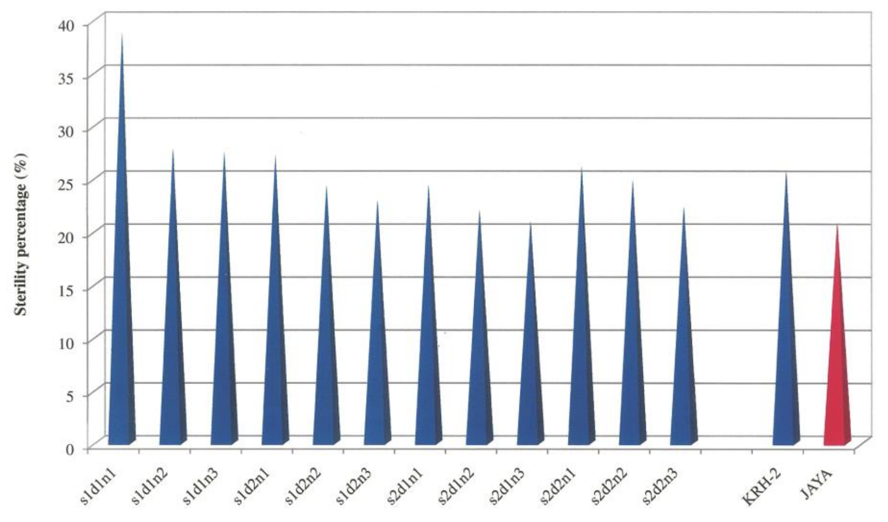

Fig. 6b. Effect of S x D x N on sterility percentage

Among the yield attributes, the combined effect of spacing and seedling density had profound effect on productive tiller and spikelet count, panicle length, filled grains per panicle and sterility percentage. Even though the number of productive tillers per hill was significantly higher at 20cm x 10cm with one seedling per hill (s_1d_1), the sterility percentage was also higher in this combination. The other yield attributes were significantly superior at 20cm x 15cm with single seedling per hill.Similar results have been reported by Venketeswarlu *et al.* (1987), who opined that wider spacing in conjunction with lower seedling density improves the light harvesting and reduces the competition, thereby improving the vegetative and reproductive growth of the crop.

Grain yield, straw yield and harvest index were significantly higher in planting one seedling per hill at a spacing of 20cm x 15cm (s_2d_1). This can be attributed to the yield attributes *viz.*, number of spikelets, filled grains per panicle and panicle length which were superior at the same combination of spacing and seedling density. These results are in conformity with those of Panicker *et al.* (1981)and Hasanuzzaman *et al.* (2009).

5.5 EFFECT OF SPACING x NUTRIENT LEVEL ON GROWTH AND PRODUCTIVITY

While plant height was unaffected by the combination of spacing and nutrient level, the number of tillers per hill was significantly higher at panicle initiation when planted at closer spacing (20cm x 10cm) with 150: 75: 75 kg NPK ha^{-1}. The number of leaves per hill was not affected by this interaction. The treatment combination s_1n_3 (20cm x 15cm + 150: 75: 75 kg NPK ha^{-1}) recorded significantly higher leaf area index at maximum tillering and panicle initiation stages. At the harvest stage s_1n_3 and s_2n_3 were on a par. The higher vegetative growth supported by higher levels of nutrients, especially nitrogen might have contributed to the higher leaf area index (LAI).

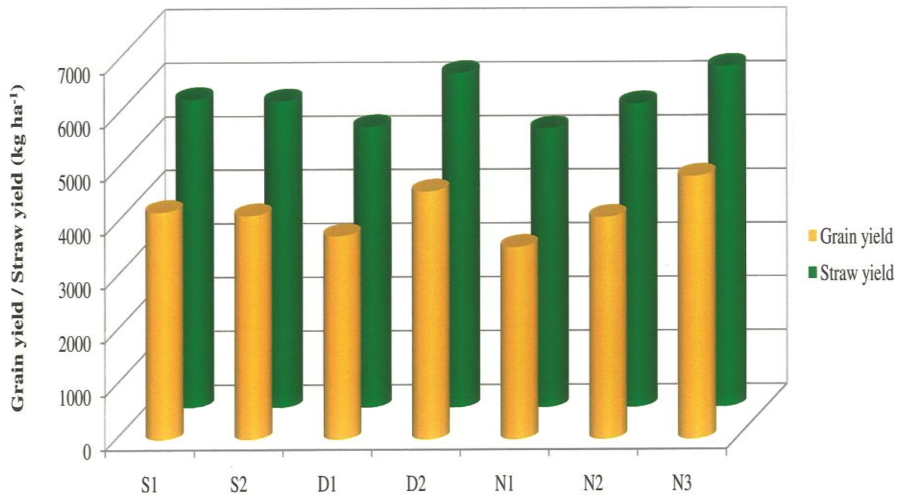

Fig. 7a. Effect of spacing (S), seedling density (D) and nutrient level (N) on grain yield and straw yield of hybrid rice

The combined effect of spacing and nutrient level resulted in significantly deeper roots at closer spacing and lower nutrient level (s_1n_1). The demand for more nutrients and higher competition among plants at closer spacing might have stimulated the plant to produce deeper roots. Shoot dry matter production per hill at harvest was maximum with s_2n_3 (20cm x 15cm + 150: 75: 75 kg NPK ha^{-1}) and root dry matter per hill showed significance at maximum tillering with s_2n_1 and s_1n_1 producing on a par values. The total dry matter per hill showed significance at maximum tillering and harvest stages. The significance of s_2n_1 (20cm x 15cm + 90: 45: 45 kg NPK ha^{-1}) at maximum tillering was probably because of root dry matter and that of s_2n_3 (20cm x 15cm +150: 75: 75 kg NPK ha^{-1}) at harvest stage could be attributed to the higher shoot dry matter.

Among the yield attributes, productive tillers per hill and filled grains per panicle exhibited significantly higher values at closer spacing (20cm x 10cm) with highest nutrient level (150: 75: 75 kg NPK ha^{-1}). Spikelets per panicle, panicle weight, panicle length and thousand grain weight remained unaffected. The effect of spacing x nutrient level is mainly because of the highly positive effect of nutrient levels on the yield attributing characters. Similar results have been reported by Ogbodo *et al.* (2010).

While grain yield and harvest index were significantly influenced by spacing x nutrient level, straw yield remained unaffected. The increase in grain yield at s_1n_3 (20cm x 10cm + 150: 75: 75 kg NPK ha^{-1}) could be attributed to the higher leaf area index and higher number of productive tillers per hill and filled grains per panicle supported by this treatment combination. This is again a manifestation of the effect of the higher nutrient level rather than spacing because among the second order interactions higher yield was observed at wider spacing (20cm x 15cm) in conjunction with single seedling and highest nutrient level (150: 75: 75kg NPK ha^{-1}).

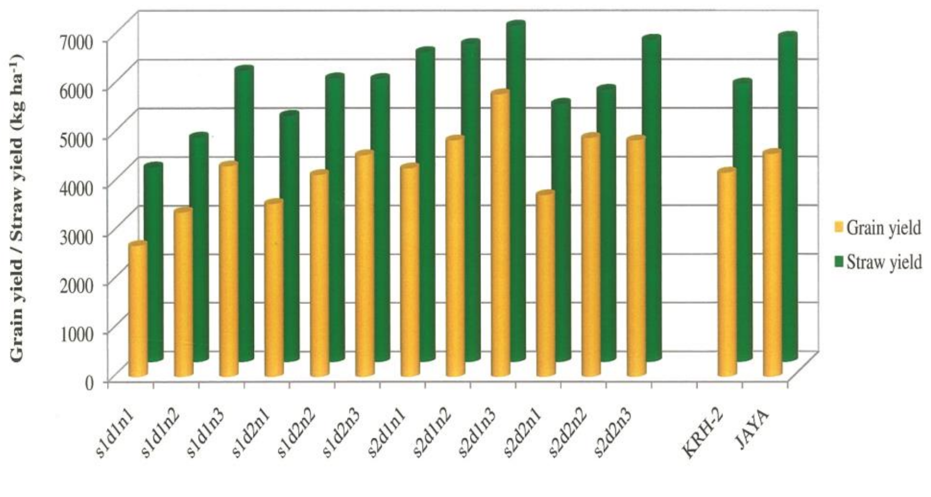

Fig. 7b. Effect of S x D x N on grain yield and straw yield

5.6 EFFECT OF SEEDLING DENSITY x NUTRIENT LEVEL ON GROWTH AND PRODUCTIVITY

Plant height, tiller count and number of leaves per hill were unaffected by the combination of seedling density and nutrient levels. The leaf area index recorded at panicle initiation stage was significantly higher with planting one seedling per hill at 150: 75: 75 kg NPK ha^{-1} (d_1n_3). Rooting depth was significantly influenced by this treatment combination with d_2n_1 (2 seedlings per hill + 90: 45: 45 kg NPK ha^{-1}) recording deeper roots. The higher seedling density and lower nutrient level might have stimulated hybrid rice to produce deeper roots to satisfy its nutrient demand for supporting better vegetative growth.

Planting two seedlings per hill along with 150: 75: 75 kg NPK ha^{-1} (d_2n_3) recorded higher shoot dry matter production at panicle initiation stage and was on a par with single seedling at the same nutrient level (d_1n_3). The treatment combination d_1n_3 resulted in maximum shoot dry matter production at harvest stage. The root dry matter per hill was maximum at single seedling + 90: 45: 45 kg NPK ha^{-1} (d_1n_1). The total dry matter per hill varied significantly at maximum tillering and harvest stages. The superiority of d_1n_1 at maximum tillering was probably supported by higher root dry matter production, and that of d_1n_3 at harvest was possibly due to the better photosynthesis supported by this treatment combination as indicated by the higher leaf area index.

Panicle weight, filled grains per panicle and sterility percentage alone varied significantly with seedling density and nutrient level. Panicle length and thousand grain weight remained unaffected. The panicle weight was maximum at d_1n_3 (1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}). Although, filled grains per panicle were maximum at d_2n_2 (two seedlings per hill + 120: 60: 60 kg NPK ha^{-1}), it remained at par with d_2n_3 and d_1n_3. This clearly showed the superiority of planting single seedling with 150: 75: 75 kg NPK ha^{-1} in hybrid rice. Sterility percentage was maximum at d_1n_1 and least at d_2n_3. The highest sterility percentage at single seedling with lower NPK dose (90: 45: 45 kg NPK ha^{-1}) might be because of the lower source and sink at that level as indicated by lower dry matter production and yield attributes. Similar results were reported by Hossain *et al.* (2003). Grain yield, straw yield and harvest index did not vary significantly due to the combined effect of seedling density and nutrient level.

5.7 EFFECT OF SPACING x SEEDLING DENSITY x NUTRIENT LEVEL ON GROWTH AND PRODUCTIVITY

Plant height and number of tillers per hill failed to show significant variation in response to the combination of spacing, seedling density and nutrient levels. The number of leaves per hill was maximum at $s_2d_2n_3$ which was on a par with $s_2d_1n_3$, $s_1d_2n_3$, $s_2d_2n_2$, $s_1d_2n_2$ and $s_1d_2n_1$. However the leaf area index remained unaffected. The roots of hybrid rice were significantly deeper at $s_2d_2n_1$ (20cm x 15cm + 2 seedlings per hill + 90: 45: 45 kg NPK ha^{-1}) during panicle initiation stage and was at par with $s_2d_2n_2$ and $s_1d_2n_1$. The results pointed out that at wider spacing, higher seedling density and lower nutrient levels, hybrid rice tended to develop deeper roots probably for supporting the better vegetative growth of the plant.

The shoot dry matter production and total dry matter production per hill was maximum at $s_2d_2n_3$ (20cm x 15cm + 2 seedlings per hill +150: 75: 75 kg NPK ha^{-1}) during the harvest stage (Fig. 3b). The root dry matter production was maximum at $s_2d_1n_1$ at all the three stages. The higher total dry matter production at maximum tillering stage recorded with $s_2d_1n_1$ could be attributed to the roots and that at the panicle initiation and harvest stages could be attributed to the shoot dry matter production. This finding is in conformity with that of Yan (1988), who observed that hybrid rice has more root dry matter accumulation in the early and middle growth stages and more shoot dry matter at the later stages.

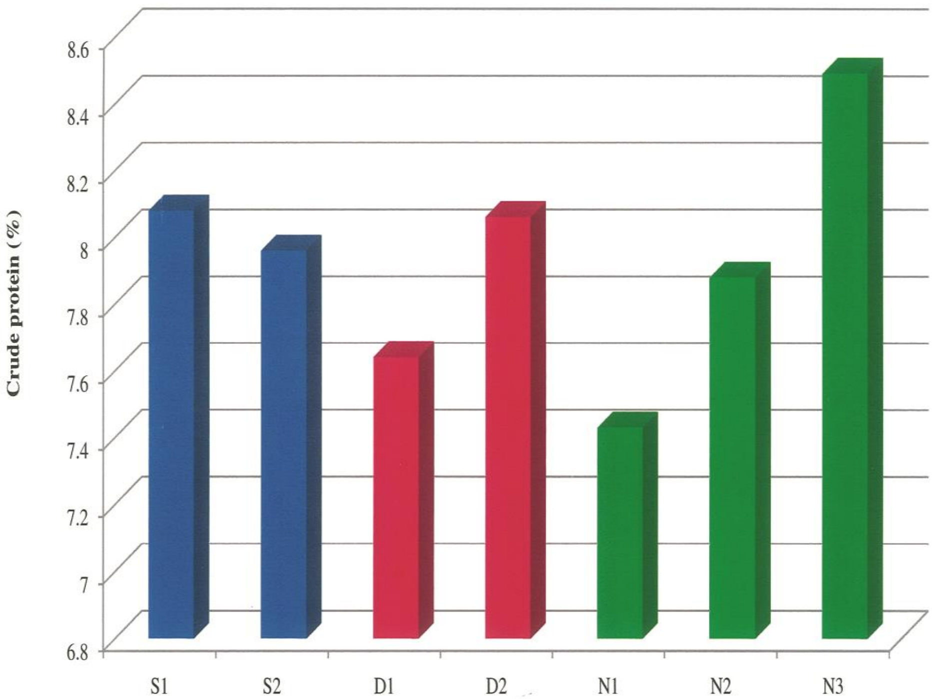

Fig. 8 a. Effect of spacing (S), seedling density (D) and nutrient level (N) on crude protein content of hybrid rice

Among the different yield attributes, the number of spikelets per panicle and sterility percentage varied significantly with S x D x N. The number of spikelets per panicle was significantly higher at $s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) with the least sterility percentage (Fig. 5b and 6b). Grain yield failed to differ significantly among the different treatment combinations. But straw yield and harvest index was significantly higher at $s_2d_1n_3$.

5.8 PERFORMANCE OF KRH-2 AS COMPARED AGAINST JAYA

Hybrid rice, KRH-2 was significantly taller than Jaya at panicle initiation and harvest stages. The tillering capacity and number of leaves per hill did not vary significantly between the two varieties. However, the leaf area index of KRH-2 was significantly higher by about 20-25 per cent than Jaya. The mean rooting depth of KRH-2 and Jaya failed to exhibit any significant variation. The total dry matter production per hill was significantly higher for KRH-2 at maximum tillering and panicle initiation stages. At the harvest stage the dry matter production of the two varieties remained almost the same. The root dry matter at maximum tillering, panicle initiation and harvest stages was higher for KRH-2. BRRI (2000) stated that hybrid rice has higher dry matter content, thicker leaves, longer leaf area and longer root system compared to inbreds. The present study also revealed the same trend.

Hybrid rice, KRH-2 recorded significantly more number of productive tillers per hill, panicle weight, panicle length, spikelets per panicle, filled grains per panicle and harvest index, when compared to the control Jaya. However, the sterility percentage was observed to be higher with KRH-2 than Jaya (Fig. 6b). Thousand grain weight, grain yield and straw yield were significantly higher for Jaya than KRH-2. During the vegetative growth phase hybrid rice accumulated more dry matter which might have resulted in more number of spikelets per panicle. On the other hand the yield attributes of inbreds depend basically on the accumulation of assimilates after heading as reported by Yan (1988).

5.9 EFFECT OF SPACING, SEEDLING DENSITY AND NUTRIENT LEVEL ON QUALITY OF HYBRID RICE

The quality of rice is a complex character which is directly or indirectly related to other characters. Cooking time, volume expansion, grain elongation and amylose content are considered as the main parameters of cooking and eating qualities.

5.9.1 Effect on Cooking Properties

The results revealed that the cooking properties *viz*., optimum cooking time, volume expansion ratio and grain elongation ratio failed to vary significantly among the different treatments and their interactions. Thus it could be concluded that the cooking properties are inherited characters which vary very little with external management practices.

5.9.2 Effect on Chemical Properties.

Nutritional quality of rice primarily depends on the chemical property. The chemical properties of hybrid rice were assessed in terms of crude protein, total starch, amylose and amylopectin contents. Spacing and seedling density had no significant effect on the chemical properties. Crude protein content increased significantly with nutrient levels with a maximum of 8.49 per cent at N_3 (150: 75: 75 kg NPK ha^{-1}). This is possibly because of the higher nitrogen uptake realized at N_3 contributing towards higher crude protein content as reported by Tisdale *et al.* (1995). Among the interactions d_1n_3 and $s_2d_1n_3$ recorded significantly higher crude protein content. This can be attributed to the higher nitrogen content of grain and nitrogen uptake by the crop. Similar results have been reported by Adhikari *et al.* (2005). Total starch, amylose and amylopectin content did not show any significant variation neither among treatments nor their interaction.

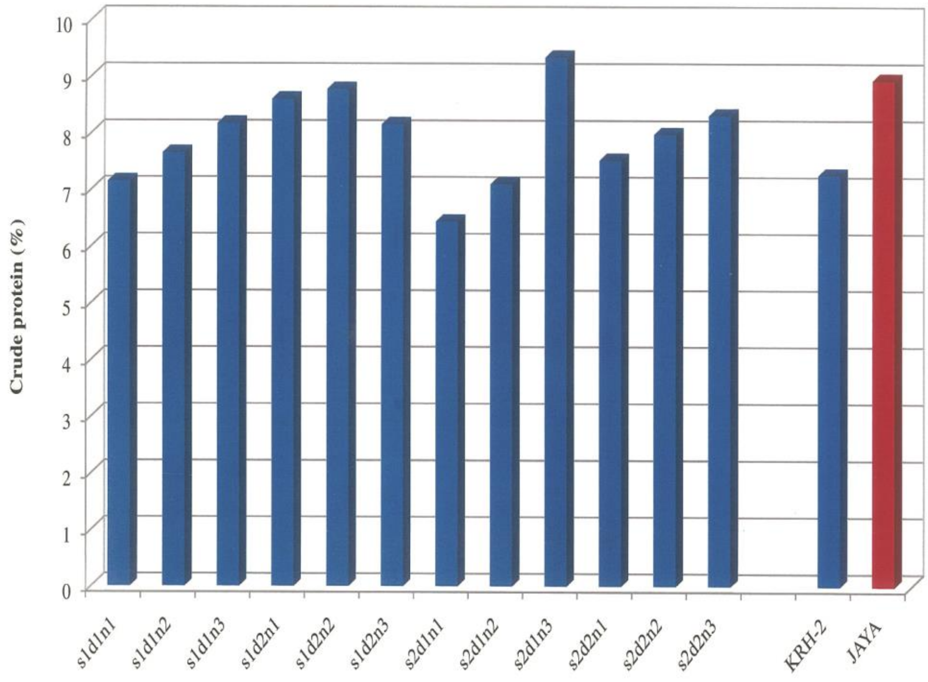

Fig. 8b. Effect of S x D x N on crude protein content

5.9.3 Effect on Organoleptic Qualities.

The sensory estimates of colour, texture and flavour are usually taken as the basis for assessing the quality or relative excellence of food. In the present study scoring was done for appearance, colour, flavour, texture and taste. Appearance and texture are important quality traits because rice is usually consumed in the whole grain form. The treatment combination $s_2d_2n_1$ (20cm x 15cm + 2 seedlings per hill + 90: 45: 45 kg NPK ha^{-1}) gave better appearance for the grains of hybrid rice. Colour was scored as better in $s_1d_2n_3$ and $s_2d_1n_3$. The grains of hybrid rice in general had an appealing flavour upon cooking. Among the different treatment combinations the grains produced at $s_2d_2n_2$ scored better in taste.

5.10 GRAIN QUALITY OF KRH-2 AS COMPARED AGAINST JAYA

With respect to cooking time hybrid rice, KRH-2 got cooked around 5 minutes earlier than inbred Jaya. While the volume expansion ratio of Jaya was significantly higher than KRH-2, the grain elongation ratios of the two varieties did not vary much. Grains of Jaya were richer in crude protein content (8.93 per cent) than KRH-2 (7.26 per cent). The two varieties did not show any significant difference in the total starch content. However, the amylose fraction of the grains was more in Jaya (22.66 per cent of starch) than KRH-2 (18.60 per cent of starch). Amylose content is a major determinant of cooking and eating characteristics. Rice with 20 to 25 percentage of amylose are rated as intermediate (Chikkalingaiah *et al.*, 1997) and reported to possess good grain quality. KRH-2 is a low amylose rice as per the classification put forth by Hizukuri *et al.* (1989) who classified rice with 12 to 20 per cent amylose as low amylose rice, and such rice grains become sticky on cooking. Thus upon cooking KRH-2 turned out to be stickier than Jaya .

The organoleptic test (Fig. 9) revealed that the appearance and texture of KRH-2 was not that appealing as Jaya. However, the colour and taste of the two varieties ere scored as equally good. The peculiarity was that KRH-2 upon cooking, had a desirable flavour compared to Jaya.

5.11 EFFECT OF SPACING, SEEDLING DENSITY AND NUTRIENT LEVEL ON NUTRIENT CONTENT OF HYBRID RICE

5.11.1 Effect of Spacing on Nutrient Content

While spacing had no significant effect on the nitrogen content of grain, it resulted in significant variation in the nitrogen content of straw. The straw nitrogen content was higher at wider spacing (0.79 per cent) compared to closer spacing (0.73 per cent)

Spacing had no significant effect on the phosphorus content of grain and straw. The potassium content of grain and straw was higher at wider spacing. The comparatively higher rooting depth at wider spacing might have helped the plant in accumulating more nutrients.

5.11.2 Effect of Seedling Density on Nutrient Content

Planting two seedlings per hill (D_2) resulted in higher content of nitrogen and phosphorus in grain. On the other hand the potassium content of grain was found to be higher with one seedling per hill. Seedling density had no significant effect on the NPK content of straw. This can also be attributed to the deeper root system and higher dry matter production developed at higher seedling density.

5.11.3 Effect of Nutrient Level on Nutrient Content

In general, the nutrient content of both grains and straw increased with nutrient levels and were significantly higher at the highest nutrient level N_3 (150: 75: 75 kg NPK ha^{-1}). The favourable effect of increasing levels of nutrients on nutrient content has been reported by Bhowmick and Nayak (2000).

5.11.4 Effect of Treatment Interactions on Nutrient Content

The nitrogen and phosphorus content of grain was significantly affected by spacing x seedling density. Planting at closer spacing (S_1) with two seedlings per hill (D_2) resulted in the highest N and P contents in grain. The K content of the grain was not affected. However, spacing x seedling density significantly affected the potassium content of straw with s_2d_1 (20cm x 15cm + 1 seedling per hill) having the highest potassium content (4.18 per cent).

While spacing x nutrient level significantly affected the nitrogen and phosphorus content of grain, significance was observed only with respect to the phosphorus content of the straw. The treatment combination s_2n_3 (20cm x 15cm + 150: 75: 75 kg NPK ha^{-1}) resulted in maximum nitrogen and phosphorus content in grain and phosphorus content in straw, which might be due to the better absorption of nutrients at wider spacing and highest nutrient level. Similar results were reported by Om *et al.* (1998) and Salahuddin *et al.* (2010).

Nitrogen content of grain and potassium content of straw varied significantly with seedling density x nutrient level. The treatment combination d_1n_3 (one seedling per hill + 150: 75: 75 kg NPK ha^{-1}) had the highest nitrogen content in grain and potassium content in straw respectively. The reduced competition between the seedlings supported by the better nutrient availability at wider spacing and higher nutrient level might have resulted in the higher nutrient content, as observed in the present study.

5.12 NUTRIENT CONTENT OF KRH-2 AS COMPARED AGAINST JAYA

The nitrogen (1.43 per cent) and phosphorus (0.23 per cent) content of grains of Jaya was superior to those (1.24 per cent nitrogen, 0.17 per cent phosphorus) of KRH-2. However, the potassium content of grains of KRH-2 (0.34 per cent) was significantly higher than Jaya (0.30 per cent). On the contrary the NPK content of straw of KRH-2 (0.76: 0.23: 4.12 per cent) was significantly higher than Jaya (0.55: 0.18: 3.49 per cent).

5.13 EFFECT OF SPACING, SEEDLING DENSITY AND NUTRIENT LEVEL ON NUTRIENT UPTAKE OF HYBRID RICE

5.13.1 Effect of Spacing on Nutrient Uptake

The NPK uptake of hybrid rice (Fig. 10a) was significantly higher at wider spacing. Nutrient uptake is partly a function of dry matter production and concentration of nutrient in the plant (Chaudhary *et al.*, 2011). Thus the higher total dry matter production and higher nutrient content observed at wider spacing might have contributed towards better nutrient uptake.

5.13.2 Effect of Seedling Density on Nutrient Uptake.

Seedling density had no significant effect on the nutrient uptake of hybrid rice.

5.13.3 Effect of Nutrient Level on Nutrient Uptake

Nutrient uptake increased with increasing levels of nutrients with the maximum at N_3 (150: 75: 75 kg NPK ha^{-1}). These results corroborated with the findings of Ramarao (2004).

5.13.4 Effect of Treatment Interactions on Nutrient Uptake.

The nutrient uptake was significantly higher at s_2d_1 (20cm x 15cm + 1 seedling per hill). Planting at wider spacing with the highest nutrient level (s_2n_3) resulted in maximum uptake of N, P and K. However, significance was observed only in P and K uptake. The least uptake was found at closer spacing with the lowest nutrient level (s_1n_1).

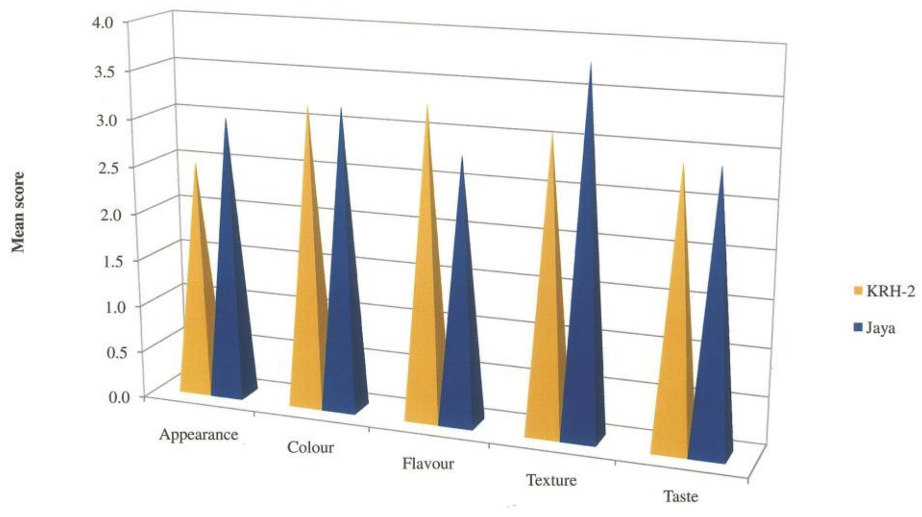

Fig. 9. Organoleptic attributes of KRH-2 and Jaya

The NPK uptake was found to be the highest at d_1n_3 (1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) with nitrogen uptake and potassium uptake exhibiting significance.

The interaction among spacing, seedling density and nutrient level showed significance for phosphorus uptake and potassium uptake (Fig. 10b). The maximum NPK uptake was observed at $s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}). The results showed that nutrient uptake had a direct bearing on the total dry matter production. Thus an increase in nutrient uptake was observed with increase in dry matter production, in terms of grain yield and straw yield as suggested by Yadav *et al*. (2011).

5.14 NUTRIENT UPTAKE OF KRH-2 AS COMPARED AGAINST JAYA

Hybrid rice, KRH-2 and inbred Jaya did not vary significantly in nitrogen uptake and potassium uptake (Fig. 10b). However, Jaya showed significantly higher phosphorus uptake than KRH-2.

5.15 EFFECT OF SPACING, SEEDLING DENSITY AND NUTRIENT LEVEL ON SOIL FERTILITY STATUS

Spacing and seedling density had no significant effect on the organic carbon, available nitrogen, available phosphorus and available potassium status of the soil after the experiment. The available nitrogen and potassium content of the soil increased significantly with increasing nutrient levels. Nottidge *et al*. (2005) observed similar trend of increasing nitrogen and potassium content of soil with the application of NPK fertilizers.

5.15.1 Effect of Treatment Combinations on Soil Fertility Status

Available phosphorus status of the soil alone showed significant variation with spacing x seedling density and spacing x nutrient level. The interaction

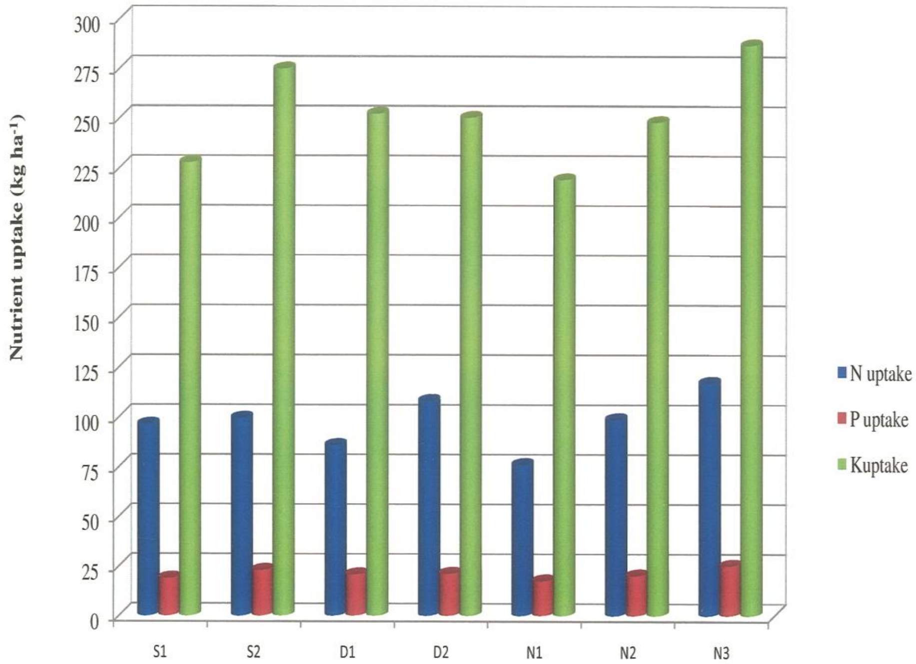

Fig. 10a. Effect of spacing (S), seedling density (D) and nutrient level (N) on nutrient uptake by hybrid rice

between wider spacing (20cm x 15cm) and lower seedling density (1seedling per hill) and that between wider spacing and highest nutrient level (150: 75: 75 kg NPK ha^{-1}) left the soil relatively rich in available phosphorus after the experiment. None of the other interactions had significant impact on the residual nutrient status of the soil.

5.16 COMPARATIVE EFFECT OF KRH-2 AND JAYA ON SOIL FERTILITY STATUS

The two varieties, KRH-2 and Jaya did not vary significantly with respect to their effect on the residual nutrient status of the soil after the experiment.

5.17 EFFECT OF SPACING, SEEDLING DENSITY AND NUTRIENT LEVEL ON ECONOMICS OF HYBRID RICE

Gross returns, net returns and benefit cost ratio were higher for hybrid rice when planted at a wider spacing of 20cm x 15cm. Seed is the costliest input in hybrid rice cultivation. Increasing the spacing is indirectly reducing the seed rate. The higher yield achieved at wider spacing clubbed together with reduction in seed rate might have contributed to the higher gross returns, net returns and benefit cost ratio.

Net returns and benefit cost ratio (Fig. 11a and 12a) were significantly higher at the lowest seedling density (one seedling per hill) probably due to the reduction in cost of cultivation due to the lower seed rate required and also due to the higher economic yield realized.

Gross returns, net returns and benefit cost ratio were maximum at the highest nutrient level N_3 (150: 75: 75 kg NPK ha^{-1}) which could be attributed to the higher grain yield attained at that level.

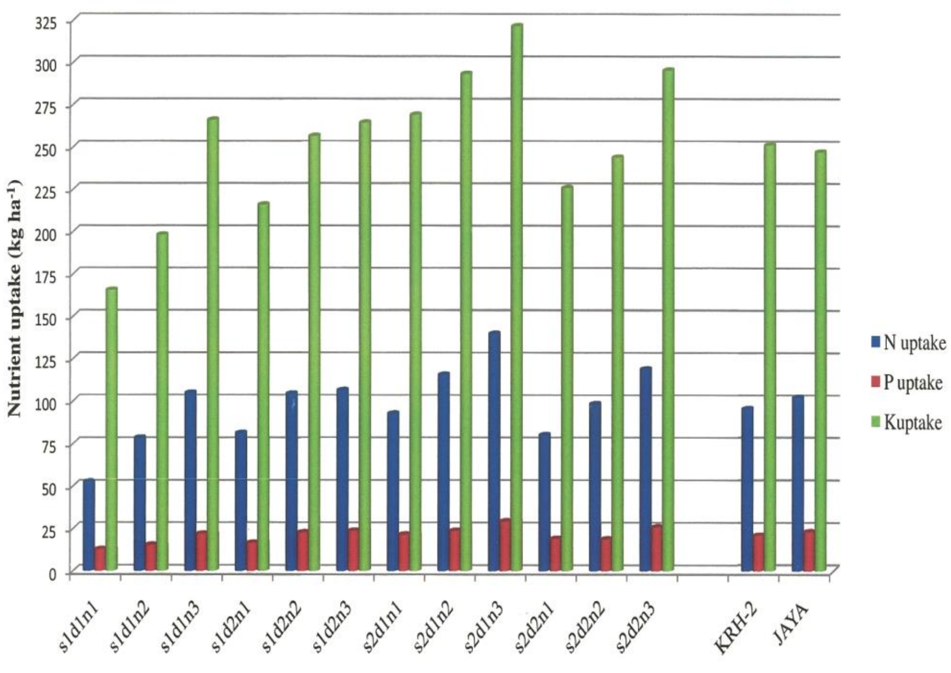

Fig. 10b. Effect of S x D x N on nutrient uptake

5.17.1 Effect of Treatment Interactions on Economics of Hybrid Rice

Spacing x seedling density had significant effect on gross returns and benefit cost ratio with s_2d_1 (20cm x 15cm + 1 seedling per hill) recording the maximum values.

Spacing x nutrient level failed to affect the economics of hybrid rice. The benefit cost ratio was significantly higher (2.31) at d_1n_3 (one seedling per hill + 150: 75: 75 kg NPK ha^{-1}).

The interaction among the three factors was significant. The treatment combination $s_2d_1n_3$ (20cm x15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) proved superior in terms of gross returns, net returns and benefit cost ratio for hybrid rice. This clearly indicates the possibility of reducing the seed rate of hybrid rice without reduction in yield.

5.18 COMPARATIVE ECONOMICS OF KRH-2 AND JAYA

The mean economics of Jaya was better than that of hybrid rice KRH-2 as evidenced by significantly higher gross returns, net returns and benefit cost ratio (Rs.1,11,590 ha^{-1}, Rs.66,753.27 ha^{-1}, 2.49) for Jaya compared to KRH-2 (Rs.92,649.51 ha^{-1}, Rs.43,909.12 ha^{-1}, 1.90). Further the stickiness of hybrid rice reduced the consumer preference and consequently it fetched a lower price (Rs.18 kg^{-1}) than Jaya (Rs.20 kg^{-1}).

5.19 BETWEEN TREATMENT COMBINATIONS INCLUDING CONTROL

5.19.1 Growth and Productivity

The treatment combination of wider spacing (20cm x 15cm) + lower seedling density (one seedling per hill) + highest nutrient level (150: 75: 75 kg NPK ha^{-1}) *i.e.* $s_2d_1n_3$ recorded significantly taller plants, more number of tillers, total dry matter

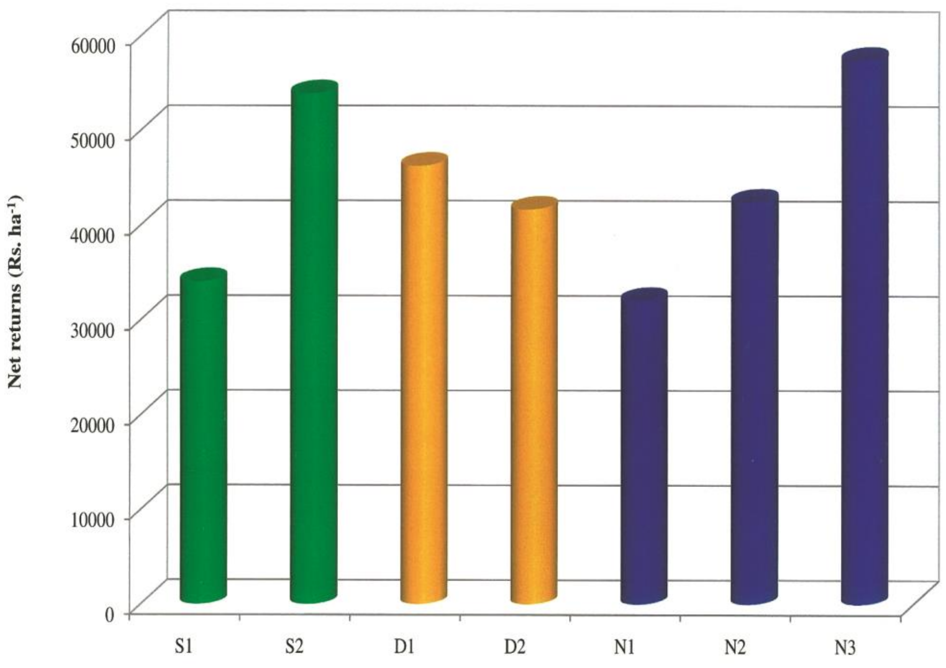

Fig. 11a. Effect of spacing (S), seedling density (D) and nutrient level (N) on net returns of hybrid rice

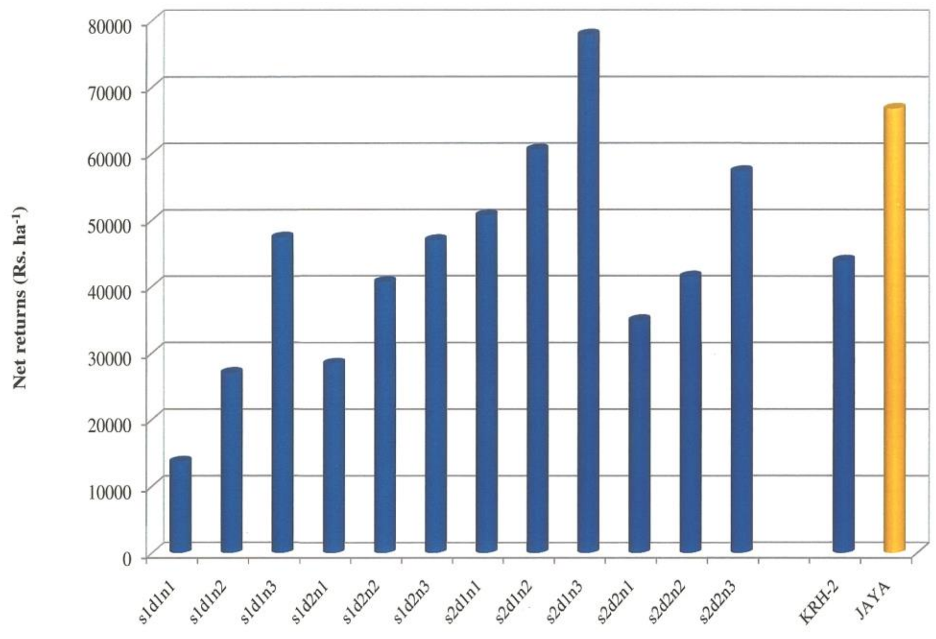

Fig. 11b. Effect of S x D x N on net returns

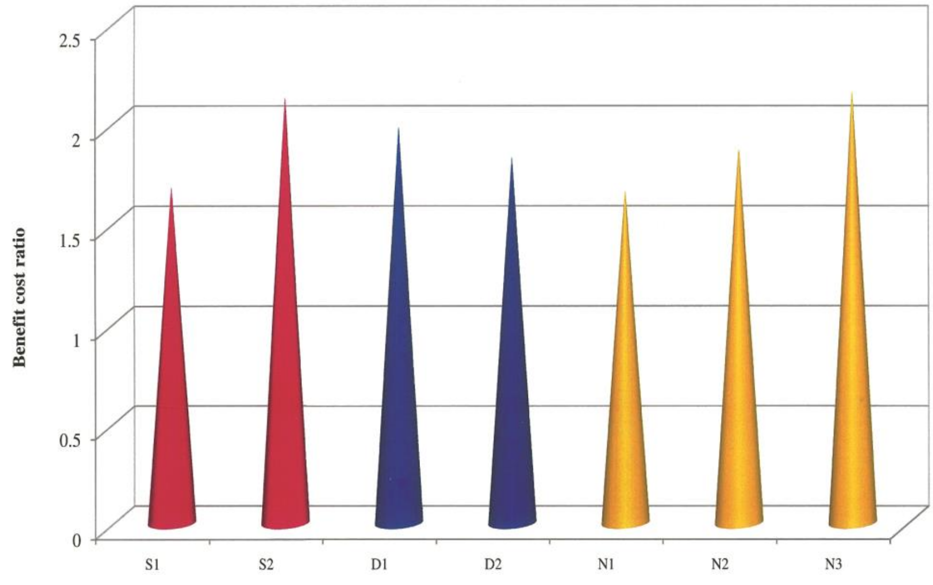

Fig. 12a. Effect of spacing (S), seedling density (D) and nutrient level (N) on benefit cost ratio of hybrid rice

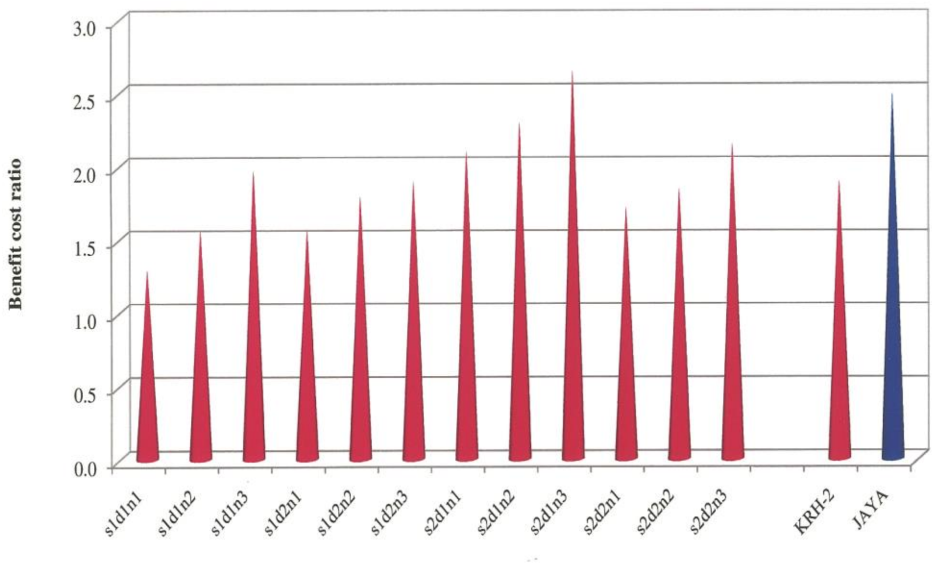

Fig. 12b. Effect of S x D x N on benefit cost ratio

production per hill at harvest, spikelets per panicle, panicle weight, panicle length and filled grains per panicle. The sterility percentage was least with this treatment combination. Grain yield, straw yield and harvest index was maximum with this treatment combination.

5.19.2 Grain Quality

The control, Jaya took longer time to cook as indicated by the optimum cooking time of 29 minutes compared to the treatment combination $s_2d_2n_1$ (20cm x 15cm + 2 seedlings per hill + 90: 45: 45 kg NPK ha^{-1}). While the volume expansion ratio was maximum for Jaya, the grain elongation ratio did not show much variation among the treatments. The total starch content and crude protein content were maximum at $s_2d_1n_3$. Jaya had a favourable amylose content (22.66 per cent) which reduced the stickiness of cooked rice.

5.19.3 Nutrient Uptake

The uptake of major nutrients N, P and K was maximum at $s_2d_1n_3$, keeping in pace with the higher grain yield and straw yield. The available nutrient status of the soil did not vary significantly between the treatments including the control.

5.19.4 Economics

Cultivating hybrid rice at a spacing of 20cm x 15cm with one seedling per hill and a NPK dose of 150: 75: 75 kg ha^{-1} recorded a benefit cost ratio of 2.65 followed by Jaya cultivated as per KAU package of practices (2.49).

Jaya was raised as per the KAU POP (20cm x 10cm + 2 seedlings per hill + 90: 45: 45 kg NPK ha^{-1}). The growth attributes, yield and yield attributes of hybrid rice, KRH-2 at the same treatment combination was poor. The results indicated the fertilizer responsiveness of hybrid rice up to a nutrient level of 150: 75: 75 kg NPK ha^{-1} and the vigour of hybrid rice to yield best when planted at wider spacing of 20cm x15cm with one seedling per hill.

Summary

6. SUMMARY

An experiment entitled "Production potential of hybrid rice (*Oryza sativa* L.) in low land ecosystem" was undertaken at the Cropping Systems Research Centre, Karamana, Thiruvananthapuram, Kerala during the second crop season, 2011 from 28 July to 25 November. The major objectives of the study were to assess the production potential of hybrid rice in lowland ecosystem, to quantify its nutritional requirement in relation to plant spacing and seedling density and to work out the economics of hybrid rice production as against a conventional inbred.

The experiment was laid out in factorial Randomized Block Design, with three replications. The treatments comprised two spacings (S_1 - 20cm x 10 cm, S_2 - 20cm x 15cm), two seedling densities (D_1 - 1 seedling per hill, D_2 - 2 seedlings per hill) and three nutrient levels (N_1 - 90: 45: 45, N_2 - 120: 60: 60, N_3 - 150: 75: 75 kg NPK ha^{-1}) for hybrid rice as compared against a conventional inbred Jaya raised as per the standard KAU package of practices. There were a total of (12+1) treatment combinations. The varieties used for the experiment were KRH-2 (Karnataka Rice Hybrid -2) and Jaya. Observations were recorded at maximum tillering, panicle initiation and harvest stages.

Spacing and seedling density did not influence the plant height. The nutrient level, 150: 75: 75 kg NPK ha^{-1} (N_3) produced taller plants at panicle initiation and harvest stages (128.19cm and 125.64cm) respectively. Hybrid rice, KRH-2 (123.44cm and 120.99cm) was significantly taller than the control, Jaya (114.25cm, 111.48cm) at panicle initiation and harvest stages. The treatment combination $s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) resulted in taller plants at panicle initiation and harvest stages (129.41cm and 127.05cm) respectively.

Among the three nutrient levels, N_3 (150: 75: 75 kg NPK ha^{-1}) resulted in remarkably higher number of tillers per hill (15.47, 13.48, 11.33) at all the three stages. Among the spacing and seedling density interactions, s_2d_2 (20cm x 15cm + 2 seedlings per hill) recorded the highest number of tillers per hill (9.89) at harvest and remained at par with s_1d_1 and s_2d_1. However, the treatment combination s_1n_3 (20cm x 10 cm + 150: 75: 75 kg NPK ha^{-1}) recorded the maximum tiller count per hill (14.65) at panicle initiation stage. Remarkable difference was not observed between KRH-2 and Jaya with respect to the number of tillers per hill.. The treatment combination, $s_2d_1n_3$ (20cm x 15 cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) recorded the maximum tiller count (15.92, 14.75, 12.37) at maximum tillering, panicle initiation and harvest stages respectively.

The number of leaves per hill was appreciably higher in hybrid rice at higher seedling density D_2 (2 seedlings per hill) at maximum tillering (56.87), panicle initiation (51.95) and harvest stages (37.23) and at the highest nutrient level N_3 (66.49, 60.83, 46.00) during all the three stages. The treatment combination $s_2d_2n_3$ (20cm x 15cm + 2 seedlings per hill + 150: 75: 75 kg NPK ha^{-1}) had more number of leaves per hill (49.22) at harvest and was on a par with $s_1d_2n_3$, $s_2d_2n_2$, and $s_1d_2n_1$. KRH-2 and Jaya did not vary conspicuously.

While spacing significantly influenced the leaf area index of hybrid rice at maximum tillering and harvest stages, nutrient level was significant at all the three stages. Significantly higher leaf area index was recorded at S_2 (20cm x 15cm) during maximum tillering (5.24) and harvest (4.39) stages and by N_3 during all the three stages (5.82, 5.31, and 4.87). The treatment combination s_2d_2 resulted in remarkably higher leaf area index at maximum tillering (5.43), panicle initiation (4.94) and harvest (4.48) stages. Similarly s_1n_3 resulted in noticeably higher leaf area index at maximum tillering (6.04) stage and panicle initiation (5.50) stage and s_2n_3 at harvest (4.88) stage. The treatment combination d_1n_3 proved to be significant at panicle initiation (5.36) stage. KRH-2 had significantly more leaf area index than Jaya throughout the growth period.

Rooting depth of hybrid rice was notably higher at D_2 (2 seedlings per hill) and at N_1 (90: 45: 45 kg NPK ha^{-1}) during the maximum tillering, panicle initiation and harvest stages (24.58cm, 26.46cm, 23.01cm and 25.63cm, 27.39cm, 23.63cm) respectively. Deeper roots were observed at wider spacing S_2 (20cm x 15cm) during the panicle initiation stage (26.04 cm). The treatment combinations, s_2d_2 (23.48cm) and s_1n_1 (23.92cm) produced deeper roots at harvest stage and d_2n_1 (26.75cm, 28.52cm, 24.87 cm) at all the three stages. The mean rooting depth of KRH-2 and Jaya did not vary significantly.

Planting at wider spacing (20cm x 15cm) resulted in remarkably higher total dry matter production at maximum tilering (20.08 g $hill^{-1}$), panicle initiation (49.95 g $hill^{-1}$) and harvest (84.98 g $hill^{-1}$) stages. While the total dry matter production was maximum with one seedling per hill at maximum tillering (19.83 g $hill^{-1}$) and harvest (87.06 g $hill^{-1}$), it was maximum with two seedlings per hill at panicle initiation stage (52.88 g $hill^{-1}$). Among the three nutrient levels, while the lowest nutrient level, N_1 (90: 45: 45 kg NPK ha^{-1}) was superior at maximum tillering (21.22 g $hill^{-1}$), the highest level N_3 (150: 75: 75 kg NPK ha^{-1}) proved superior at panicle initiation (54.73 g $hill^{-1}$) and harvest (97.70 g $hill^{-1}$) stages. Hybrid rice KRH-2 (19.19 g $hill^{-1}$, 51.58 g $hill^{-1}$) when compared to Jaya (10.98 g $hill^{-1}$, 37.43 g $hill^{-1}$) showed significantly higher total dry matter production at maximum tillering and panicle initiation stages. The treatment combination $s_2d_1n_1$ recorded significantly higher total dry matter production (23.81 g $hill^{-1}$) at maximum tillering and $s_1d_2n_3$ at panicle initiation (56.37g $hill^{-1}$) stages.

The nutrient level, N_3 (150: 75: 75 kg NPK ha^{-1}) produced the maximum number of productive tillers per hill (7.91) at harvest in hybrid rice. The treatment combinations, s_1d_1 (7.06) which was at par with s_2d_1 and s_2d_2, and the treatment combination s_1n_3 (8.64) recorded conspicuously more number of productive tillers per hill. KRH-2 and Jaya did not exhibit marked variation with respect to the mean productive tiller count per hill. Between treatments including control, $s_1d_1n_3$ (20cm x 10cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) emerged superior with the highest number of productive tillers per hill (8.86) followed by $s_2d_1n_3$ (8.42).

The number of spikelets per panicle of hybrid rice was outstandingly higher at closer spacing S_1 (144.14), higher seedling density D_2 (145.77), highest nutrient level N_3 (150.08).and the treatment combination, s_2d_1 (149.51). Planting hybrid rice at $s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) produced exceptionally higher number of spikelets per panicle (157.30). Hybrid rice, KRH-2 produced markedly more spikelets per panicle (143.05) than the control Jaya (132.03).

Nutrient levels alone had a striking effect with N_3 (150: 75: 75 kg NPK ha^{-1}) recording the maximum panicle weight (3.16g). Hybrid rice, KRH-2 produced heavier panicles (3.08g) than Jaya (2.47g). The comparison made between treatments including control proved significant with the treatment combination $s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) and the least for $s_2d_2n_1$ (2.89)

The panicles of hybrid rice borne at closer spacing (20cm x 10cm) were distinctly longer (30.29cm) than those at wider spacing (29.68cm) of 20cm x 15cm. Among the three nutrient levels, N_3 (150: 75: 75 kg NPK ha^{-1}) produced appreciably longer panicles (30.28 cm) and was on a par (30.08 cm) with N_2 (120:60:60 kg NPK ha^{-1}). The interaction between spacing and seedling density was noteworthy with the treatment combination, s_2d_1 recording more panicle length (30.61cm). The panicles of KRH-2 (29.98cm) were demonstrably longer than those of Jaya (26.46cm). The treatment combination, $s_2d_1n_3$ produced the longest panicle (31.12 cm).

The number of filled grains per panicle was conspicuously higher in D_2 (111.73) and N_3 (115.00). The interaction s_2d_1, s_1n_3 and d_2n_2 recorded notably higher number of filled grains per panicle (116.03, 115.63 and 110.73). The filled grains per panicle was not appreciably different in KRH-2 and Jaya. The comparison made between treatments including control revealed that the treatment combination $s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) had the highest number of filled grains per panicle (124.37).

Sterility percentage was strikingly lower at wider spacing (24.63 per cent), higher seedling density (23.43 per cent) and highest nutrient level (23.41 per cent). Among the significant interactions, sterility percentage was lower at s_2d_1 (22.44 per cent), s_2n_3 (22.62 per cent), d_2n_3 (21.62 per cent) and $s_2d_1n_3$ (20.93 per cent). Hybrid rice KRH-2 had more sterile grains (25.76 per cent) than control, Jaya (20.76 per cent). The treatment combination $s_1d_1n_1$ recorded highest sterility (38.77 per cent) and the least (20.93 per cent) was observed in $s_2d_1n_3$.

Thousand grain weight of hybrid rice was noticeably higher (22.63g) at N_3 (150: 75: 75 kg NPK ha^{-1}). KRH-2 and Jaya showed obvious difference with higher values for Jaya (25.58g) as compared to KRH-2 (21.96g). The comparison made between treatments including control also proved the superiority of Jaya, followed by the treatment combinations $s_2d_2n_3$ (22.74g), $s_2d_1n_3$ (22.64g) and $s_1d_2n_3$ (22.64g).

Grain yield of hybrid rice was distinctly higher (4607.44 kg ha^{-1}) at 2 seedlings per hill, and at 150: 75: 75 kg NPK ha^{-1} (4887.30 kg ha^{-1}). The treatment combinations s_2d_1 (4985.40 kg ha^{-1}) and s_1n_3 (5068.47 kg ha^{-1}) recorded higher grain yield. The mean grain yield of KRH-2 (4194.67 kg ha^{-1}) was profoundly less than that of control Jaya (4578.33 kg ha^{-1}). The treatment combination $s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) recorded the maximum grain yield (5803.30 kg ha^{-1}) among all the treatment combinations including control.

Significantly higher straw yield was recorded at D_2 (6214.90 kg ha^{-1}), N_3 (6328.75 kg ha^{-1}), s_2d_1 (6598.09 kg ha^{-1}) and $s_2d_1n_3$ (6904.03 kg ha^{-1}). Straw yield of Jaya (6674.43 kg ha^{-1}) was appreciably higher than hybrid rice KRH-2 (5715.17 kg ha^{-1}).

Among the three factors, spacing, seedling density and nutrient levels, harvest index of hybrid rice varied markedly with nutrient levels, with N_3 recording the maximum harvest index (0.44). The treatment interactions s_2d_1 and s_1n_3 had higher harvest index of 0.43 and 0.44 respectively. Hybrid rice, KRH-2 recorded higher harvest index (0.42) than the control Jaya (0.40). Between treatments including control, $s_2d_1n_3$ resulted in the highest harvest index (0.46).

The cooking properties, *viz.* optimum cooking time, volume expansion ratio and grain elongation ratio remained unaffected. The control Jaya took appreciably more time to get cooked (29 minutes) than hybrid rice KRH-2 (24.19 minutes). Volume expansion ratio was considerably higher for Jaya (3.35) than KRH-2 (3.25). Profound difference was not observed in the grain elongation ratio between the two varieties.

The crude protein content of hybrid rice was substantially higher at N_3 (8.49 per cent), d_1n_3 (8.75 per cent) and $s_2d_1n_3$ (9.33 per cent). The comparison made between treatment combinations including control had implication with $s_2d_1n_3$ recording the highest crude protein (9.33 per cent) and starch (72.33 per cent) contents. Jaya recorded noticeably higher crude protein (8.93 per cent) and amylose (22.66 per cent of starch) content than KRH-2 with 7.26 per cent crude protein and 18.60 per cent amylose respectively. The total starch content did not vary considerably between the two varieties.

The mean scores obtained in the organoleptic test showed that the control Jaya presented better appearance and texture than hybrid rice KRH-2. Hybrid rice had a desirable flavour as compared to Jaya. KRH-2 and Jaya were scored as equally tasty, with mean score of 2.9 each.

The N, P and K uptake of hybrid rice was higher (99.51 kg ha^{-1}, 22.99 kg ha^{-1}, 274.83 kg ha^{-1}) at 20cm x 15cm and at 150: 75: 75 kg NPK ha^{-1} (117.10 kg ha^{-1}, 25.17 kg ha^{-1}, 286.82 kg ha^{-1}). The treatment interaction s_2d_1 (20cm x 15cm + 1 seedling per hill) recorded distinctly higher values for N, P and K uptake (115.89 kg ha^{-1}, 24.77 kg ha^{-1}, 294.58 kg ha^{-1}). While s_2n_3 was strikingly superior with respect to P uptake (27.54 kg ha^{-1}) and K uptake (308.44 kg ha^{-1}), d_1n_3 recorded markedly higher values for K uptake (293.73 kg ha^{-1}). Planting hybrid rice at 20cm x 15cm with 1 seedling per hill in conjunction with 150: 75: 75 kg NPK ha^{-1} ($s_2d_1n_3$) resulted in significantly higher phosphorus and potassium uptake. KRH-2 and Jaya exhibited distinct variation for P uptake. Between treatments including control, $s_2d_1n_3$ recorded substantially higher values for NPK uptake (139.63 kg ha^{-1}, 29.15 kg ha^{-1}, 321.46 kg ha^{-1}).

The available nutrient status of the soil after the experiment revealed marked difference in the available N and K status with varying nutrient levels. It was obviously higher at N_3 (297.64 kg ha^{-1}, 163.09 kg ha^{-1}). Cultivation of Jaya maintained a higher available N status in the soil compared to KRH-2.

Wider spacing S_2 (20cm x 15cm), seedling density D_1 (1 seedling per hill) and nutrient level N_3 (150: 75: 75 kg NPK ha^{-1}) resulted in higher net returns (Rs.53813.30 ha^{-1}, Rs.46207.00 ha^{-1} and Rs.57388.55 ha^{-1}) and benefit cost ratio (2.13, 1.98, 2.17) for KRH-2. The treatment combinations s_2d_2 (1.91) and d_1n_3 (2.31) recorded appreciably higher benefit cost ratio for hybrid rice. Comparison made between the treatment (KRH-2) and control (Jaya) revealed that Jaya conferred considerably higher net returns (Rs.66753.27 ha^{-1}) and benefit cost ratio (2.49) than KRH-2 (Rs.43909.12 ha^{-1}, 1.90). However, the comparison made between treatments including control showed that cultivating hybrid rice, KRH-2 at a spacing of 20cm x 15cm with a seedling density of one seedling per hill and a NPK dose of 150: 75: 75 kg ha^{-1} ($s_2d_1n_3$) fetched higher net returns (Rs.77877.40 ha^{-1}) and benefit cost ratio (2.65).

Future line of work

- The same study may be repeated for conformity of results.
- The other promising hybrid rice varieties with better consumer preference may be assessed for their productivity.
- In the present study, hybrid rice, KRH-2 responded up to a NPK dose of 150: 75: 75 kg ha-1. Higher levels may be tried since the variety is highly responsive to added nutrients.
- The feasibility of adopting integrated nutrient management with more emphasis on non-chemical sources in hybrid rice need to be investigated.
- Hybrid rice (KRH-2) has a good flavour upon cooking. Thus the possibility of using it for making baked products may be explored.

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PRODUCTION POTENTIAL OF HYBRID RICE (*Oryza sativa* L.) IN LOWLAND ECOSYSTEM

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ABSTRACT

An investigation entitled "Production potential of hybrid rice (*Oryza sativa* L.) in lowland ecosystem" was carried out at the Cropping Systems Research Centre, Karamana, Thiruvananthapuram, during the second crop season, 2011 (28 July to 25 November). The objectives of the study were to assess the production potential of hybrid rice in lowland ecosystem, to quantify its nutritional requirement in relation to plant spacing and seedling density and to work out the economics of hybrid rice cultivation as against a conventional inbred.

The performance of hybrid rice variety, KRH-2 was assessed in comparison with inbred, Jaya. The treatments comprised two spacings (S_1 - 20cm x 10cm, S_2 - 20cm x 15cm), two seedling densities (D_1 - 1 seedling per hill, D_2 - 2 seedlings per hill) and three nutrient levels (N_1 - 90: 45: 45 kg NPK ha^{-1}, N_2 - 120: 60: 60 kg NPK ha^{-1}, N_3 - 150: 75: 75 kg NPK ha^{-1}) and control Jaya raised as per the KAU package of practices. On the whole, there were (12 + 1) treatment combinations. The field experiment was laid out in factorial randomized block design with three replications. Observations on growth attributes, yield and yield attributes and soil parameters were recorded as per the technical programme. Brief outline of the experimental results are presented below.

Hybrid rice, KRH-2 recorded more plant height, tillers per hill and leaves per hill than Jaya. Nutrient levels had significant effect on plant height at panicle initiation and harvest stages. The tiller count per hill was maximum with N_3 at the panicle initiation and harvest stages. Maximum number of leaves per hill was recorded at D_2 and N_3 at panicle initiation stage and by S_2 and N_3 at harvest stage. The interaction, $s_2d_2n_3$ recorded the maximum number of leaves per hill. The nutrient level, N_3 and the interactions s_2d_2 and s_1n_3 recorded the maximum leaf area index at all the growth stages. Rooting depth of hybrid rice was significantly higher

at wider spacing (S_2) during the panicle initiation and at D_2 and N_1 during the harvest stages. Total dry matter production (g $hill^{-1}$) of hybrid rice was maximum at S_2, D_2 and N_3 during the panicle initiation stage. Hybrid rice, KRH-2 recorded significantly more dry matter per hill than Jaya.

The nutrient level, N_3 and the interactions, s_2d_1 and s_1n_3 recorded the maximum number of productive tillers per hill. Panicle length and number of spikelets per panicle recorded at S_1, D_2, N_3 and the interaction s_2d_1 were the highest. Sterility percentage was minimum at S_2, D_2, N_3 and at s_2d_2, s_2n_3, d_2n_3 and $s_2d_1n_3$. Thousand grain weight of hybrid rice was the highest at N_3. Grain yield and straw yield of hybrid rice were significantly higher at D_2 and N_3. Among the different interactions, maximum grain yield was recorded in s_2d_1 and s_1n_3 and straw yield at $s_2d_1n_3$. KRH-2 produced heavier and longer panicles with more number of spikelets than Jaya. However, the higher mean sterility percentage and lower mean test weight of KRH-2 made Jaya a better performer in terms of mean grain yield.

The cooking properties and chemical properties of hybrid rice in comparison with Jaya, determined in terms of optimum cooking time, grain elongation ratio, volume expansion ratio, amylose and amylopectin contents failed to reveal any significant variation with different spacing, seedling density, nutrient level and their interactions. The organoleptic test revealed the best appearance and texture for KRH-2 at $s_2d_1n_1$, colour at $s_2d_1n_3$ and taste at $s_2d_2n_1$ and $s_2d_1n_3$. Hybrid rice, KRH-2 had a better flavour than Jaya, but became stickier upon cooking. The treatment N_3, and the interactions d_1n_3 and $s_2d_1n_3$ recorded significantly higher values for crude protein and total starch. KRH-2 recorded significantly lower amylose content than Jaya.

The uptake of the major nutrients, N, P and K by hybrid rice was significantly higher at wider spacing (S_2) and highest nutrient level (N_3). Among the significant interactions N, P and K uptake were maximum at s_2d_1, P and K uptake at

s_2n_3 and K uptake at d_1n_3. The treatment combination $s_2d_1n_3$ recorded higher values for phosphorus and potassium uptake. Jaya accumulated more phosphorus in its dry matter than KRH-2.

The nutrient status of the soil after the experiment showed significant higher values for available nitrogen and potassium at N_3. Jaya maintained a higher available nitrogen status in the soil than KRH-2.

The economic analysis revealed highest gross returns, net returns and B : C ratio for hybrid rice at wider spacing (20cm x 15cm), lower seedling density (1 seedling per hill) and highest nutrient level, N_3 (150: 75: 75 kg NPK ha^{-1}). The interaction s_2d_1 and d_1n_3 recorded highest B : C ratios of 2.35 and 2.31 repectively. The data on B : C ratio for hybrid rice, revealed significantly higher ratios for S_2 (2.13), D_1 (1.98), N_3 (2.17) and s_2d_1 (2.35). The control Jaya recorded a higher mean B : C ratio (2.49) than hybrid rice, KRH-2 (1.90). The comparison made between the treatments including the control showed that raising hybrid rice, KRH-2 at $s_2d_1n_3$ (20cm x 15cm + 1 seedling per hill + 150: 75: 75 kg NPK ha^{-1}) fetched higher returns than Jaya raised as per the KAU POP. The result also indicated the possibility of reducing the seed rate required for hybrid rice, which could in turn increase the returns considerably, considering the high cost of the seed of hybrid rice.

Appendices

APPENDIX – I

Standard week wise mean weather parameters during the cropping period (July 2011 - November 2011)

Standard week	Temperature (°C)		Relative Humidity (%)		Total rainfall (mm)	Mean evaporation (mm day^{-1})
	Maximum	Minimum	Maximum	Minimum		
30	30.8	24.4	90.3	82.4	5.4	3.2
31	30.4	24.5	90.9	85.6	13.9	2.9
32	30.6	24.5	87.4	82.1	7.6	3.3
33	30.4	23.7	90.3	79.4	7.8	3.6
34	29.7	23.9	81.2	82.0	41.2	3.3
35	29.7	24.2	90.3	82.3	43.6	3.3
36	29.2	23.9	91.3	84.6	67.0	2.9
37	30.3	24.5	90.9	80.6	0.0	3.5
38	29.5	24.0	91.7	86.9	6.0	3.4
39	29.8	24.3	89.7	86.9	10.6	3.3
40	29.6	24.3	90.1	85.0	70.8	3.2
41	29.9	24.4	90.7	86.4	0.0	3.5
42	30.3	24.1	90.9	86.9	22.1	3.5
43	31.2	23.9	89.6	81.9	0.0	3.7
44	25.7	26.6	83.7	86.5	20.1	3.3
45	29.3	23.5	91.7	80.9	285.8	2.7
46	30.8	23.9	90.0	80.9	130.6	2.9
47	29.2	23.5	90.7	84.9	50.9	2.9

Appendix II

Average input cost and market price of produce

Sl. No.	Items	Cost
	INPUTS	
A	Labour	
1.	Man labourer	Rs.250.00 day-1
2.	Women labourer	Rs.250.00 day-1
B	Cost of manures and fertilizers	
1.	FYM	Rs. 500 t-1
6.	Urea	Rs. 6.0 kg-1
7.	Rajphos	Rs. 4.0 kg-1
8.	Muriate of potash	Rs. 5.5 kg-1
	OUTPUT	
	Market price of Hybrid rice	Rs. 18 kg-1
	Market price of Jaya	Rs. 20 kg-1